INTERMEDIATE

Paper 9

OPERATIONS MANAGEMENT AND STRATEGIC MANAGEMENT

Study Notes

SYLLABUS 2022

The Institute of Cost Accountants of India

CMA Bhawan, 12, Sudder Street, Kolkata - 700 016

www.icmai.in

First Edition : August 2022
Revised Edition: July 2024
Reprint : January 2025

Price: ₹ 600.00

Published by :

Directorate of Studies
The Institute of Cost Accountants of India
CMA Bhawan, 12, Sudder Street, Kolkata - 700 016
studies@icmai.in

Printed at:

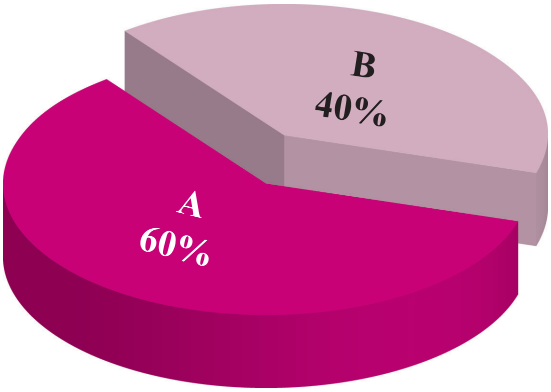
M/S. INFINITY ADVERTISING SERVICES PVT. LTD
Plot No. 171 & 172, Sector-58, Faridabad,
Haryana - 121004

PAPER 9 : OPERATIONS MANAGEMENT AND STRATEGIC MANAGEMENT

Syllabus Structure:

The syllabus in this module comprises the following topics and study weightage:

Module No.	Module Description	Weight
	Section A: Operations Management	**60%**
1	Operation Management – Introduction	5%
2	Operations Planning	5%
3	Designing of Operational System and Control	5%
4	Production Planning and Control	20%
5	Productivity Management and Quality Management	5%
6	Project Management	15%
7	Economics of Maintenance and Spares Management	5%
	Section B: Strategic Management	**40%**
8	Introduction	10%
9	Strategic Analysis and Strategic Planning	10%
10	Formulation and Implementation of Strategy	10%
11	Digital Strategy	10%



Learning Environment – Paper 9

Subject Title	**OPERATIONS MANAGEMENT AND STRATEGIC MANAGEMENT**
Subject Code	**OMSM**
Paper No.	**9**
Course Description	The subject comprises two sections – Operations Management and Strategic Management. The former aims to provide students with a critical understanding of the scope and strategic importance of operations management, various tools and techniques for operations planning and designing as well as production planning. It also offers detail coverage of important techniques for measurement and management of productivity, project management and inventory management which lie at the core of a successful organisation. The section, Strategic Management, tries to address different aspects of strategy formulation and implementation in an organisation. It tries to take into account the problems that strategic managers face while developing and implementing strategies within a dynamic business environment. The subject also deals with the contemporary issues such as digital and social marketing strategies that have immense impact on organisation's competitive advantage.
CMA Course Learning Objectives (CMLOs)	1. Interpret and appreciate emerging national and global concerns affecting organizations and be in a state of readiness for business management. a. Identify emerging national and global forces responsible for enhanced/varied business challenges. b. Assess how far these forces pose threats to the status-quo and creating new opportunities. c. Find out ways and means to convert challenges into opportunities 2. Acquire skill sets for critical thinking, analyses and evaluations, comprehension, syntheses, and applications for optimization of sustainable goals. a. Be equipped with the appropriate tools for analyses of business risks and hurdles. b. Learn to apply tools and systems for evaluation of decision alternatives with a 360-degree approach. c. Develop solutions through critical thinking to optimize sustainable goals. 3. Develop an understanding of strategic, financial, cost and risk-enabled performance management in a dynamic business environment. a. Study the impacts of dynamic business environment on existing business strategies. b. Learn to adopt, adapt and innovate financial, cost and operating strategies to cope up with the dynamic business environment. c. Come up with strategies and tactics that create sustainable competitive advantages. 4. Learn to design the optimal approach for management of legal, institutional, regulatory and ESG frameworks, stakeholders' dynamics; monitoring, control, and reporting with application-oriented knowledge. a. Develop an understanding of the legal, institutional and regulatory and ESG frameworks within which a firm operates. b. Learn to articulate optimal responses to the changes in the above frameworks. c. Appreciate stakeholders' dynamics and expectations, and develop appropriate reporting mechanisms to address their concerns.

	5. Prepare to adopt an integrated cross functional approach for decision management and execution with cost leadership, optimized value creations and deliveries. a. Acquire knowledge of cross functional tools for decision management. b. Take an industry specific approach towards cost optimization, and control to achieve sustainable cost leadership. c. Attain exclusive knowledge of data science and engineering to analyze and create value.
Subject Learning Objectives [SLOB(s)]	**A. Operations Management** 1. To appreciate the recent trends and challenges in production and operations management and understand the relationships between operations and other business functions. (CMLO 1a, b, c) 2. To attain knowledge on techniques and tools to be applied for product and process designing, capacity planning and production line balancing; and job designing; in operations management. (CMLO 3c, 5a, b, c) 3. To develop detailed understanding about frameworks and tools for measuring and managing productivity of resources as well as quality control of outputs. (CMLO 2q 3c, 5c) 4. To gain knowledge on project planning, managing and control to ensure optimum utilization of time and resources. (CMLO 2b, 3c, 5b) 5. To appreciate the importance and gather knowledge about processes for spares management in mitigating related risks and optimising costs. (CMLO 2a, 3c, 5b) **B. Strategic Management** 1. To analyse the dynamics of national and global business environment in order to assess the potential impacts of changes on existing strategies and risks and challenges. (CMLO 1a, 3a) 2. To assess organisational strengths, weaknesses, opportunities, threats, and challenges with introspective analysis of internal realities with applications of various managerial tools and frameworks. (CMLO 1b) 3. To develop the ability to identify, understand, assimilate, and use innovative strategies to create and sustain with competitive advantages. (CMLO 3 b, c) 4. To gain a comprehensive views and abilities towards achieving the overall organisational vision, mission, always remaining in search of excellence for value creation and high ESG score. (CMLO 2, c, 4a 5 c)
Subject Learning Outcome [SLOC(s)] and Application Skill [APS]	**A. Operations Management** **SLOC(s)** 1. Students will be able to attain abilities to identify the elements of operations management and various transformation processes to enhance productivity and competitiveness. 2. They will achieve application-oriented skills for analysing and evaluating various facility alternatives and their capacity decisions, develop a balanced line of production, scheduling and sequencing techniques in different operating environments. 3. They will acquire knowledge and application skills for project planning and control with the objective to ensure optimised utilisation of time and resources. 4. They will be equipped with knowledge and skills to apply materials handling principles and operating practices, measures in quality control, Quality Circles and TQM.

5. Students will accomplish application skills for mathematical tools that are needed to solve optimisation problems.
6. They will attain application-oriented knowledge for using mathematical models and software to solve various problems of operations management for improved performance and optimisation of results.

APS

1. Students will be able to independently apply attained skills to identify relevant frameworks, models and tools for solving optimisation problems and analyse how different factors in various areas of operations can affect success of business.
2. They will be able to apply attained skills for planning and time management in scheduling deadlines, monitoring important production milestones and ensuring teams finish projects within specific deadlines.
3. They will be able to apply the attained skills to examine the associated information for figuring out relevant factors responsible for a problem, and apply frameworks, methods, and tools to analyse the issues and solve problems for optimisation of results from operating actions.

B. Strategic Management

SLOC(s)

1. Students will be able to analyse an organisation's competitive position within a dynamic business environment and devise appropriate strategies to create and sustain with competitive advantage both nationally and globally.
2. Students will be capable of identifying the core competencies of an organisation and the critical success factors which would enable them to continuously nurture and build on those to achieve a state of readiness for future.
3. Students will develop a fair understanding of the requirements to provide strategic leadership in an organisation. They will know the common gaps, biases and heuristics in decision making and how to overcome those.

APS

1. Students will be able to apply various management tools and frameworks for continuous evaluation of both present realities and emerging dimensions of external and internal business environment and impacts thereof prepare a SWOTC analyses report.
2. Students will be able to apply the acquired skill sets to frame an organisation's strategies and tactical plans for execution thereof with a 3600 view and considering the dynamics of ever emerging business ecosystem.

Module wise Mapping of SLOB(s)

Module No.	Topics	Additional Resources (Research articles, books, case studies, blogs)	SLOB Mapped
A. Operations Management			
1	**Operation Management – Introduction**	Sustainable operations management: recent trends and future directions – Walker et al. https://www.emerald.com/insight/content/doi/10.1108/IJOPM-12-2013-0557/full/html	To appreciate the recent trends and challenges in production and operations management and understand the relationships between operations and other

2	**Operations Planning**	Orlicky’sMaterial Requirements Planning – Ptak et al. McGraw Hill Education	To attain knowledge on techniques and tools to be applied for product and process designing, capacity planning andproduction line balancing; and job designing; in operations management.
3	**Designing of Operational System and Control**	Principles of Process Planning – A Logical Approach Halevi & Weill Springer Publication	
4	**Production Planning and Control**	Lean operations management: Identifying and bridging the gap between theory and practice– Tracy & Knight https://scholar.google.com/scholar?hl=en&as_sdt=0%2C5&q=lean+operations&btnG=	
5	**Productivity Management and Quality Management**	ISO 9000 Family Quality Management https://www.iso.org/iso-9001-quality-management.html	To develop detailed understanding about frameworks and tools for measuring and managing productivity of resources as well as quality control of outputs.
6	**Project Management**	Fundamentals of Project Management (Fifth Edition)- Joseph Heagney Amacom Publication	To gain knowledge on project planning, managing and control to ensure optimum utilization of time and resources.
7	**Economics of Maintenance and Spares Management**	Maintenance and Spare Parts Management– Gopalakrishnan & Banerji PHI Learning	To appreciate the importance and gather knowledge about processesfor spares management in mitigatingrelated risks and optimising costs.
B. Strategic Management			
8	**Introduction**	Conceptual Foundations of the Balanced Scorecard – Kaplan https://www.sciencedirect.com/science/article/abs/pii/S1751324307030039	1. To analyse the dynamics of national and global business environment in order to assess the potential impacts of changes on existing strategies and risks and challenges. 2. To gain a comprehensive views and abilities towards achieving the overall organisational vision, mission, always remaining in search of excellence for value creation and high ESG score.
9	**Strategic Analysis and Strategic Planning**	Not dead yet: the rise, fall and persistence of the BCG Matrix – Madsen https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2954610	To assess organisational strengths, weaknesses, opportunities, threats, and challenges with introspective analysis of internal

			realities with applications of various managerial tools and frameworks.
10	**Formulation and Implementation of Strategy**	Measuring the Success of Technology-Based Strategic Business Units – Dvir&Shenhar https://www.tandfonline.com/doi/abs/10.1080/10429247.1992.11414701	To develop the ability to identify, understand, assimilate, and use innovative strategies to create and sustain with competitive advantages.
11	**Digital Strategy**	Digital Transformation - Interplay of Strategies and Technologies for Customers' Delight in Banking Industry – CMA. ParitoshBasu http://52.172.159.94/public/journals/255/images/Volume-27-November-2021.pdf	

Contents as per Syllabus

Contents as per Syllabus

Contents as per Syllabus

SECTION-A

Operations Management

Introduction

1

This Module Includes

Introduction

SLOB Mapped against the Module

To appreciate the recent trends and challenges in production and operations management and understand the relationships between operations and other

Module Learning Objectives:

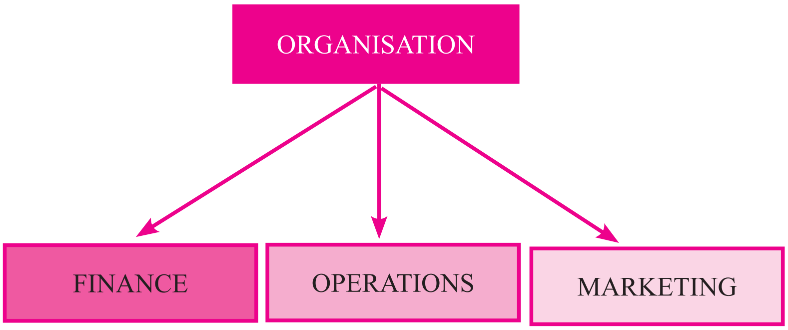
After studying this module, the students will be able to:

- Understand the concept of operation management
- Identify the resource utilisation objectives
- Describe objectives of operation management.

Scope

1.1

Operations is that part of a business organisation that is responsible for producing goods and/or services. The three basic functions of a business organisation are



The ideal situation for a business organisation is to achieve an economic match of supply and demand.

Having excess supply or excess capacity is wasteful and costly; having too little means lost opportunity and possible customer dissatisfaction.

The key function on the supply side are Operations & Supply chains;

The key function on the demand side are Sales & Marketing;

The driving fuel to all these is Finance;

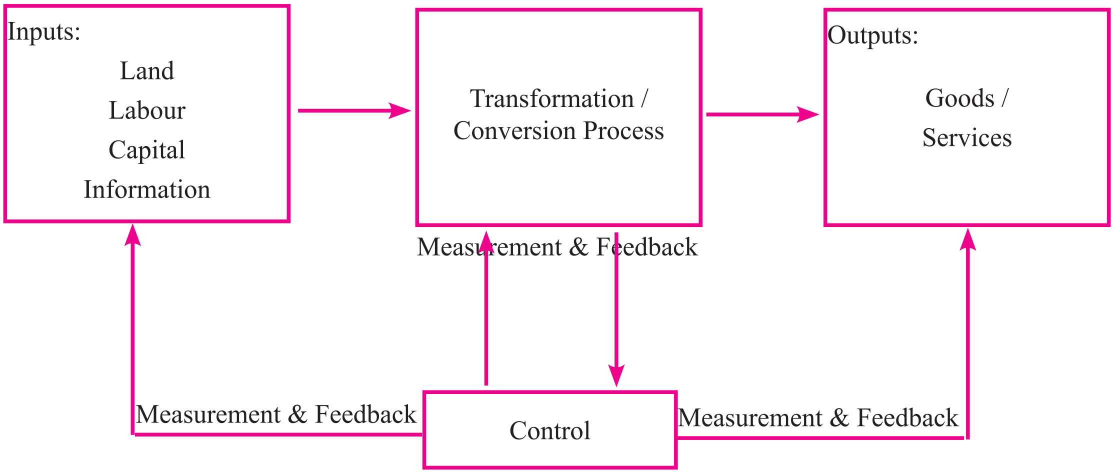
If the business organisation is a Car, Operations would be its engine. And just as the engine is the core of what a car does, in a business organisation operations is the core of what the organisation does.

Operations Management is responsible for managing that core. Operations management is the management of systems or processes that create goods and/or provide services.

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

Sometimes from inputs goods and services often occur jointly. Like painting of a house is a service but paint which is used is a good.

The whole gamut of Operations management is represented in the following figure:



Operations Management

Objectives of Operations Management

Objectives of operations management can be categorised into (i) Customer service and (ii) Resource utilisation.

(i) Customer service

The first objective is the customer service which means the service for the satisfaction of customer wants. Customer service is therefore a key objective of operations management.

The Operations Management must provide something to a specification which can satisfy the customer in terms of cost and timing. Thus, primary objective can be satisfied by providing the 'right thing at the right price at the right time'.

These three aspects of customer service - specification, cost and timing - are described in a little more detail for the four functions in **Table 1**. They are the principal sources of customer satisfaction and must, therefore, be the principal dimension of the customer service objective for operation managers.

Table 1: Aspects of Customer Service

Principal customer wants		
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 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

Generally an organization will aim reliably and consistently to achieve certain standards, or levels, on these dimensions, and operations managers will be influential in attempting to achieve these standards.

Hence, this objective will influence the operations manager's decisions to achieve the required customer service.

(ii) Resource Utilization

Another major 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.

Operations management is concerned essentially with the utilization of resources, i.e., obtaining maximum effect from resources or minimizing their loss, under utilization or waste. The extent of the utilization of the resources' potential might be expressed in terms of the proportion of available time used or occupied, space utilization, levels of activity, etc. Each measure indicates the extent to which the potential or capacity of such resources is utilized. This is referred as the objective of resource utilization.

Operations management is also concerned with the achievement of both satisfactory customer service and resource utilization. An improvement in one will often give rise to deterioration in the other. Often both cannot be maximized, and hence a satisfactory performance must be achieved on both objectives. All the activities of operations management must be tackled with these two objectives in mind, and many of the problems will be faced by operations managers because of this conflict. Hence, operations managers must attempt to balance these basic objectives.

Below **Table 2** summarizes the twin objectives of operations management. The type of balance established both between and within these basic objectives will be influenced by market considerations, competitions, the strengths and weaknesses of the organization, etc. Hence, the operations managers should make a contribution when these objectives are set.

Table 2 : The twin objectives of operations management

The customer service objective.	The resource utilization objective.
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.	To achieve adequate levels of resource utilization (or productivity) e.g., to achieve agreed levels of utilization of materials, machines and labour.

Scope of Operation Management

Operations Management concerns with the conversion of inputs into outputs, using physical resources, so as to provide the desired utilities to the customer while meeting the other organizational objectives of effectiveness, efficiency and adoptability. It distinguishes itself from other functions such as personnel, marketing, finance, etc. by its primary concern for 'conversion by using physical resources'. Following are the activities, which are listed under Production and Operations Management functions:

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.

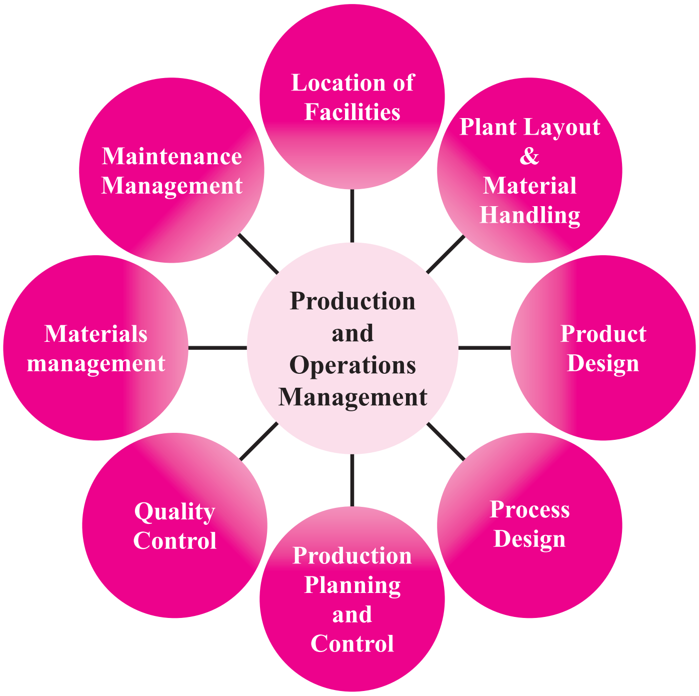


Figure 1.1 : Scope of Production and Operations Management

Let us take an example of a product manufacturing company xyz Ltd.

The xyz Ltd requires to take few important decisions. The first question comes into picture is: "What to produce?"

This question is linked with the basic existence of the company It talks about the product that xyz Ltd. is manufacturing. Here, the organization needs to understand that what is the need of the customers in terms of product attributes/Features & quality. In other words, it talks about the competitive positioning of the company, its products acceptability at the market place this decision is based on the input received from market intelligence team and often is a part of the product design process later on we will study an important concept related to product design, such as QFD. In this regard, one important point to be noted that, many a times the organizations need to forecast about product life cycle & related requirement of the technology. Forecasting we will discuss separately.

One the company is aware that what it needs to produce, the second question comes: "How much to produce?"

This question is an ongoing questions, as the organization is engaged in estimating the quantity ("How much") on a daily, weekly, monthly, quarterly & yearly basis. Again this information is obtained from marketing team. Based on the information received, the planning team (as a part of supply chain's planning section) provides a forecast of demand. Hence, here deal with an important aspect of operational planning known as Demand Forecasting.

The next question is: "Where to produce?".

This question leads to facility location selection problem after this, a series of questions need to be answered that lead to a member of decision areas such as "

Q: "How to produce?" (Process selection & Layout)

Q: "When to produce?" (Aggregate Planning inventory Master Production decision schedule)

Q: "Do we have materials to produce?" (MRP, Inventory Management)

It also deals with Sourcing

Q: "Are we producing right things?" (Quality Management)

Q: "Are our machines able to provide desired results?" (Maintenance Management)

Q: "How to reach the products to the customers?"(Distribution or Delivery planning)

It includes transportation decision, warehousing, materials handling ets. Logistics issues

In case the organization is practicing sustainability then another important decision area is reverse Logistics i.e., taking returns

Therefore, in summary the major decision areas are:

1. Product selection
2. Facility Location Selection
3. Demand Forecasting
4. Process selection & Layout decision
5. Capacity planning
6. Aggregate Planning, Master production schedule
7. Materials Requirement Planning (MRP)/Manufacturing Resource Planning (MRP I)/ Distribution Resource Planning (DRP) / Enterpnse Resource Planning (ERP)
8. Inventory Management
9. Supplier Selection/Sourcing
10. Process Management
11. Quality Management
12. Maintenance
13. Warehousing /Transportation
14. Reverse Logistics

In Addition, an operations manager is also responsible for working capital management, skill-management etc.

Characteristics of Modern Operations Functions

1.2

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 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 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 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 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.

Recent Trends in Production and Operations Management

1.3

Modern Operations Management is characterized by the following :

(a) Technological development

(b) Shorter product life cycle

(c) Changing needs and preferences of the customers

(d) Disruptions (market and product) and pressure for innovation

(e) Globalization

(f) Requirement for supreme service at an affordable price

(g) Pressure for optimization of operational cost

Production Management vs Operations Management

There are two points of distinction between production management and operations management. First, the term production management is more used for a system where tangible goods are produced. Whereas, operations management is more frequently used where various inputs are transformed into intangible services. Viewed from this perspective, operations management will cover such service organisations as banks, airlines, utilities, pollution control agencies, super bazaars, educational institutions, libraries, consultancy firms and police departments, in addition, of course, to manufacturing enterprises. The second distinction relates to the evolution of the subject. Operations management is the term that is used nowadays. Production management precedes operations management in the historical growth of the subject.

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 Market Place :** 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) :** 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 as 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 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 right sizing 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).

Operations Planning

2

This Module Includes

Operations Planning

SLOB Mapped against the Module

To attain knowledge on techniques and tools to be applied for product and process designing, capacity planning and production line balancing; and job designing; in operations management.

Module Learning Objectives:

After studying this module, the students will be able to:

- Comprehend the challenges faced by the operations manager.
- Understand the characteristics of capacity Planning and requirement
- Understand the different forecasting techniques used in planning.
- Understanding the inventory management.

Demand Forecasting

2.1

“Demand” is in a simpler way defined as the requirement and desire of consumers to purchase products and services and willingness and abilities to pay for availing the same.

Example of product: Household durable products like television, daily use products like soap. Example of service: Pathological tests by medical service providing laboratories like Drs. Ray & Trivedi Lab.

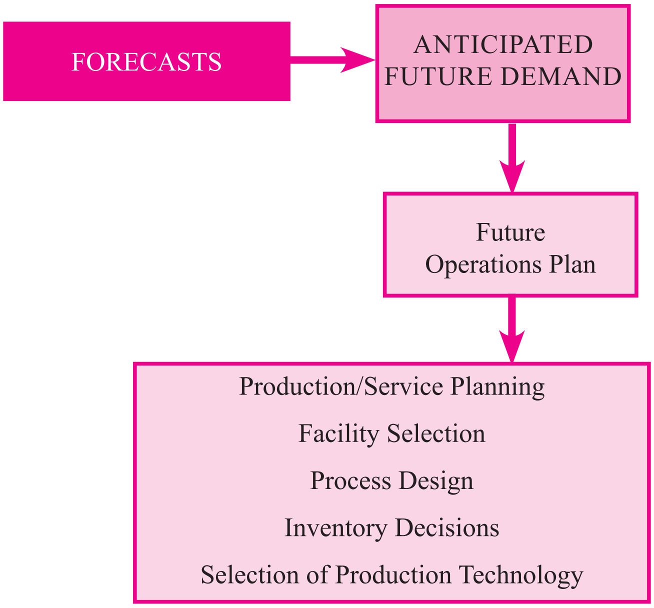
The products/services demanded are of two categories such as industrial purpose products like machines and consumers, specific products like confectionaries

“Forecasting” is the process of making prediction about future happenings and/or requirements based on available information and/evidences. Example, forecasting of product requirements, forecasting of weather, forecasting of fashion trends, forecasting of tourist inflow, forecasting of patient admission, forecasting of technology etc.

A forecast is an estimate about the future value of a variable such as demand.

Forecasts of demand are a basic input in the decision processes of operations management.

The primary goal of operations management is to match supply to demand. Therefore, demand forecasting is essential for determining how much capacity or supply will be needed to meet demand.



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

Source of Information (used for forecasting)

There are a number of sources from where past information and/or evidences are gathered to facilitate forecasting of demand such as

- Market Report
- Sales force opinion
- Experts' views
- Industry report
- Point of Sales data
- Structured customer survey
- Field report etc.

Range of period

Forecasting is done on short, medium and long term basis. The underlying objectives are explained below.

Forecasting can have both near and distant horizons. This period of forecasting, that is the time range selected for forecasting depends on the purpose for which the forecast is made. For example demand for a product can have both near and distant horizons but replacement of plant, other than due to obsolescence, is bound to have a distant horizon. The period may vary from one week to some years. Depending upon the period, the forecast can be termed as

- Short range forecasting
- Medium range forecasting
- Long range forecasting

Short range forecasting period may be one week, two weeks or a couple of months. Medium range forecasting period may vary from 3 to 6 months. Long range forecasting period may vary from one year to any period. The objective of above said forecast is naturally different.

In general, short term forecasting will be more useful in production planning. The manager who does short range forecast must see that they are very nearer to the accuracy.

Short run forecasting (usually for highly innovative products with shorter life cycle like smartphones; usually spanning over 6-8 months)

- In case of short-term forecast, following purposes are generally served:
- To estimate the inventory requirement
- To provide transport facilities for dispatch of finished goods
- To decide workloads for men and machines
- To find the working capital needed
- To set-up of production run for the products
- To fix sales quota
- To find the required overtime to meet the delivery promises.

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

The purpose of this type of forecasting is:

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

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

The purpose of long range forecast is:

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

Forecasting Methods (How to forecast demand?)

There are two types of approaches such as

- Qualitative
  - ► Delphi method
- An iterative group process which employs group of experts, staff, respondents to obtain forecasts
  - ► Sales force composite
- Group comprising members from sales force of company are asked to estimate the likely demand in respective sales zones
  - ► Consumer panel Survey
- Group of consumers are asked about their purchase plans to ascertain future demand forecast
- Quantitative
  - ► Causal/Regression analysis

Forecast of a dependent variable is made with the help of its variability nature with an independent variable Follows Simple regression equation $Y = a + bX$

- a = y axis intercept of the regrssion line
- b = slope of the regrssion line
- X = the independent variable
- Y = the forecast value of dependent variable

$$b = \frac{\Sigma XY - n * \overline{X} * \overline{Y}}{\Sigma X^2 - n\overline{X}^2}$$

$a = \overline{Y} - b\overline{X}$

$\overline{Y}, \overline{X}$ are mean of respective variables

n = no of data items in X and Y series

Example: A manufacturer has held road side exhibition which exhibited on the introduction of a new product of its smart phone product. The number of sales personnel employed at each of a sample of 10 exhibitions and the no of smart phones booked at each one are given below:

No of sales person	15	18	16	18	19	13	15	14	16	16
No of smart phone booked	30	60	50	60	70	52	50	80	72	80

If the manufacturer employs 20 salesmen in an exhibition then forecast no of Smartphones that could be booked in that exhibition.

Answer: Here number of smartphones booked needs to be predicted on the basis of no. of salesmen involved

So No of sales person is independent variable: X and

No of smartphones booked is dependent variable: Y

Therefore we will apply simple regression analysis under following steps:

- Find out the value of a,b
- Form the regression equation i.e. Y= a+bX
- Hence find the value of Y,putting X = 20 in the above regression line

Detail computation are as follows:

Sr. No.	X	Y	XY	X^2
1	15	30	450	225
2	18	60	1080	324
3	16	50	800	256
4	18	60	1080	324
5	19	70	1330	361
6	13	52	676	169
7	15	50	750	225
8	14	80	1120	196
9	16	72	1152	256
10	16	80	1280	256
Total	160	604	9718	2592

$$\overline{X} = \frac{\Sigma X}{n} = \frac{160}{10} = 16, \ \overline{Y} = \frac{\Sigma Y}{n} = \frac{604}{10} = 60.4$$

$$\text{Hence } b = \frac{\Sigma XY - n * \overline{X} * \overline{Y}}{\Sigma X^2 - n\overline{X}^2} = \frac{9718 - 10 * 16 * 60.4}{2592 - 10 * 16 * 16} = 1.6875$$

Hence a = $\overline{Y} - b\overline{X}$ = 60.4 - 1.6875 * 16 33.4

Hence Y = a + bX i.e.Y = 33.4 + 1.6875X

Hence required forecast Y = 33.4 + 1.6875 * 20 = 67.15 = 67 (Approx)

- Quantitative
  - Time Series analysis
    - Under this method to make forecast of future, time series data of actual demand for historical previous periods are taken
    - A time ordered sequence of observations taking at regular intervals (e.g. hourly, daily, weekly, monthly etc.)
    - Period wise actual demand data (Y) fluctuates
    - These fluctuations in any time series demand data are caused by four components—Trend(T), Seasonality (S), Cyclical (C) and Irregular (I) or Random(R)
    - These components are related either Additively or Multiplicatively
    - Under Additive model Y=T+S+C+I
    - Under Multiplicative model Y=T*S*C*I
    - Forecast is made by forming trend equation or by average method

Methods of forecasting by forming Trend equation

- Trend (T)
  - Refers to a long term upward or downward movement in the data mainly due to seasonal variations in the time duration
  - The trend component may be linear or may be non-linear.
  - Linear trend is fairly common and measured by forming the equation F_t=a+bt
  - F_t = Forecast for period t, a = value of F_t at t = 0 i.e. y axis intercept, b = slope of the linear trend equation shown above,t = specified no of time periods from t = 0
  - $b = \dfrac{\Sigma tY - n * \overline{t} * \overline{Y}}{\Sigma t^2 - n\overline{t}^2} = \dfrac{n\Sigma tY - \Sigma t * \Sigma Y}{n\Sigma t^2 - (\Sigma t)^2}$
  - $a = \overline{Y} - b\,\overline{t}$
  - $\overline{t}$, $\overline{Y}$ are mean of respective variables
  - n = no of data items in t and Y series
  - Very similar to causal method discussed earlier

Methods of forecasting by averaging

- Can be found by
  - Simple moving average method
  - Weighted moving average method

Forecast by Simple moving average method is done by

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

  Where F_t = Forecast for period t, MA_n = n period moving average, A_{t-i} = Actual demand in period t - i & n = no of period (data points)in the time series

- ➢ Forecast by weighted moving average method is done by

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

  Where F_t = Forecast for period t, WMA_n = n period weighted moving average, A_{t-i} = Actual demand in period t - i, w_t = weight assigned to period t - i & n = no of period (data points)in the time series

- Seasonality (S)
  - ➢ Refers to short term fairly regular variations in the data
- Cycles (C)
  - ➢ Refer to wave like variations in the data of more than one year's duration due to cyclical variations in the economy during the time period
- Irregular (I)
  - ➢ Random unexplained variations in the time series data

Example: Monthly sales of ABC Company for a seven month period are as follows:

Month	Feb	Mar	April	May	June	July	August
Sales (000 units)	24	23	20	25	23	27	25

a) Plot the data;

b) Forecast September sales volume using each of the following:

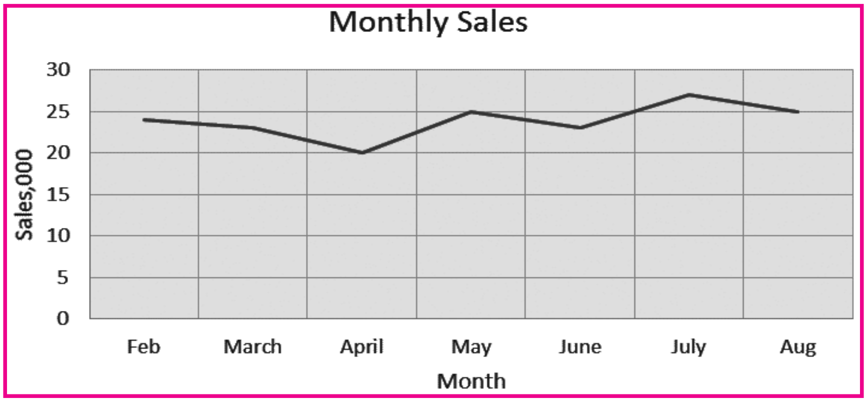
i) A five month moving average;

ii) A weighted average using 0.60 for August, 0.30 for July and 0.10 for June

iii) A linear trend equation

Answer:

(a)



(b) A 5 month moving average : Our formula will be

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

$$\text{Or} = \frac{A_{t-n} \ldots + A_{t-2} + A_{t-1}}{n}$$

Where

F_t = Forecast for time period t. Here time period t = 8 from February month

n = Number of periods (data points) in the moving average = 5 here

MA_n = n period moving average

A_{t-i} = Actual value in period t-i

Since here we are calculating with t = 8, so we require 8 - 1 = 7th, 8 - 2 = 6th, 8 - 3 = 5th, 8 - 4 = 4th & 8 - 5 = 3rd month data respectively from February.

Therefore the concerned months and actual data will be as follows:

A_{t-5} = April	20
A_{t-4} = May	25
A_{t-3} = June	23
A_{t-2} = July	27
A_{t-1} = August	25
Sum	120

So forecast sales for the month of September MA_5 = 120/5 = 24 (in 000)

(c) In case of weighted average the heaviest weights are assigned to the most recent values. And for September our forcast will be

$$F_t = 0.6 * \text{Sales of August} + 0.3 * \text{Sales of July} + 0.1 * \text{Sales of June}$$

$$\text{Or,} = 0.6 * 25 + 0.3 * 27 + 0.1 * 23 = 25.4 \text{ (in 000)}$$

(d) For computation of trend we have to use the following two parameters:

$$b = \frac{n\Sigma tY - \Sigma t * \Sigma Y}{n\Sigma t^2 - (\Sigma t)^2} \ \& \ a = \frac{\Sigma Y - b\Sigma t}{n}$$

Where Y represents sales value and t represents time period & n number of items. Trend equation is $F_t = a + bt$, where F_t = forecast for period t, a = value of F_t at t = 0 & b = slope of the line

Computations are:

t = Month	Y = Sales	t*Y	t^2
1	24	24	1
2	23	46	4
3	20	60	9
4	25	100	16
5	23	115	25
6	27	162	36
7	25	175	49
Sum 28	167	682	140

So b = 0.5 & a = 21.86

For September t = 8

So forecast for September = 21.86 + 0.5 * 8 = 25.857 (in 000)

In time series analysis Seasonality(S) refers to regular annual variation. Well known examples of seasonality is rush hour rate of UBER cab booking, holiday influenced demand like puja shopping etc.

We have learnt that fluctuation in time series due to Seasonality is smoothen out by averaging. Therefore Seasonality in time series is expressed in terms of the amount that actual demand values deviate from the average value of the series. If trend is present, seasonality is expressed in terms of the trend value.

- In additive model, seasonality is expressed as a quantity which is added to or subtracted from the series average in order to incorporate seasonality
- In multiplicative model, seasonality is expressed as a percentage of the average (or trend) which is then used to multiply the value of a series to incorporate seasonality
- In practice, businesses use multiplicative model much more than additive model

  Seasonality expressed as a percentage of the average (or trend) is termed Seasonal relative (Seasonal Index)
- If seasonality relative to Christmas month is 1.60 and a trader has monthly average of 300 units of sales then in December the trader could expect a sales demand around 480 (i.e.300*1.6)
- Seasonal Relatives are used for forecasting in two ways
  - ☐ To deseasonalise the forecast by dividing the forecast data by respective seasonal relative e.g. Christmas month's total demand forecast / Seasonal relative of Christmas month = Actual forecast resulted by following trend pattern of the underlying product/service
  - ☐ To seasonalise a forecast by multiplying the forecast data by respective seasonal relative e.g. Christmas month's demand forecast as per trend pattern of the underlying product * Seasonal relative of Christmas month = Christmas month's total demand resulted from trend and seasonality
  - ☐ Seasonal Relatives can be found by i) Simple average; ii) Centered moving average;

Example: Yearly sales of a company for last 8 years are as follows:

Year	Q1	Q2	Q3	Q4	Total
2016	28	37	33	24	122
2017	27	40	30	23	120
2018	31	36	33	30	130
2019	31	39	36	26	132
2020	29	38	32	24	123
2021	32	40	36	26	134
2022	34	42	34	29	139
2023	31	39	39	23	132

Year	t	Y	t_y	t_2
2016	1	122	122	1
2017	2	120	240	4
2018	3	130	390	9
2019	4	132	528	16
2020	5	123	615	25
2021	6	134	804	36
2022	7	139	973	49
2023	8	132	1056	64
Total	36	1032	4728	204

Form a trend line and find yearly forecast for 2024 and 2025. Hence compute average quarterly forecast for these two years. Hence seasonalise the quarterly forecast of 2024 and 2025. Apply simple average method

Answer: For computation of trend we have to use the following two parameters:

$$b = \frac{n\Sigma tY - \Sigma t * \Sigma Y}{n\Sigma t^2 - (\Sigma t)^2} \ \& \ a = \frac{\Sigma Y - b\Sigma t}{n}$$

Detail computations are as follows from where we get

$$b = 2 \ \& \ a = 120 \text{ and the trend equation is } Y = 120 + 2t$$

So for year 2024, t = 9 and hence yearly forecast = 120 + 2 * 9 = 138

So for year 2025, t =10 and hence yearly forecast = 120 + 2 * 10 = 140

Hence Average quarterly forecast for 2024 = 138/4 = 34.5

Hence Average quarterly forecast for 2025 = 140/4 = 35

To seasonalise these quarterly forecast we have to find Seasonal Relative w.r.t each quarter as follow through simple average

Year	Q1	Q2	Q3	Q4	Total
2016	28	37	33	24	122
2017	27	40	30	23	120
2018	31	36	33	30	130
2019	31	39	36	26	132
2020	29	38	32	24	123
2021	32	40	36	26	134
2022	34	42	34	29	139
2023	31	39	39	23	132
Total	243	311	273	205	
Average	30.375	38.875	34.125	25.625	
Seasonal Relative	(30.375/32.25) *100 = 94.19	(38.875/32.25) *100 = 120.54	(34.125/32.25) *100 = 105.81	(25.625/32.25) *100 = 79.46	

*(30.375+38.875+34.125+25.625)/4 = 32.25

Hence seasonalised quarterly forecast for 2024 & 2025 are

Quarter	2024			2025		
	Quarterly Average	Seasonal Relative (%)	Seasonalised Quarterly forecast	Quarterly Average	Seasonal Relative	Seasonalised Quarterly forecast
Q1	34.5	94.19	32.5	35	94.19	32.97
Q2	34.5	120.54	41.59	35	120.54	42.19
Q3	34.5	105.81	36.50	35	105.81	37.03
Q4	34.5	79.46	27.41	35	79.46	27.81

Seasonalised Quarterly forecast = Quarterly average (available from trend) * Seasonal Relative

Seasonal relative can also be found by Centered Moving average. It gives more accurate result compared to simple average method. Simple average method however could be used for finding Seasonal relative when ratio of intercept to the slope is large.

Example: Quarterly demand data for a manufacturer are as follows. Compute Seasonal relative for each quarter by centered moving average (Apply even numbered moving average say 4)

Year	Q1	Q2	Q3	Q4
1	34	38	55	66
2	48	56	80	91
3	65	74	104	108
4	78			

Answer: First we have to calculate MA_4. Since the computed centered values are not corresponding to actual data point, we have to find MA_2 and the computed centered values correspond to actual data point. With MA_2 we could find Demand/MA_2. Detail computation are as follows:

Year	Quarter	Demand	MA4	MA2	Demand/MA2
1	1	34			
	2	38			
	3	55	48.25		
	4	66	51.75	50	1.10
2	1	48	56.25	54	1.22
	2	56	62.5	59.38	0.81
	3	80	68.75	65.63	0.85
	4	91	73	70.88	1.13
3	1	65	77.5	75.25	1.21
	2	74	83.5	80.50	0.81
	3	104	87.75	85.63	0.86
	4	108	91	89.38	1.16
4	1	78			

	Demand/MA2				Total
	Q1	Q2	Q3	Q4	
			1.10	1.22	
	0.81	0.85	1.13	1.21	
	0.81	0.86	1.18		
Total	1.62	1.71	3.41	2.43	
Average	0.81	0.855	1.137	1.215	4.017
Relative	0.81*4/4.017= 0.807	0.855*4/4.017= 0.851	1.137*4/4.017= 1.132	1.215*4/4.017= 1.210	

For repopulating understanding on time series paper 3 under foundation curriculum could be well referred

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 (₹000 units)	80	90	92	83	94	99	92

Solution:

Computation of Trend Values

Years	Time Deviation from 2020 X	Sales in (₹ 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	$\sum X = 0$	$\sum Y = 630$	$\sum X^2 = 28$	$\sum XY = +56$

Regression equation of Y on X

$Y = a + bX$

To find the values of a and b

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

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

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.

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

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

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

Illustration 2

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

Years	2018	2019	2020	2021	2022	2023
Sales (in lakhs)	100	110	115	120	135	140

Solution:

Computation of trend values of sales

Year	Time deviations from the middle of 2020 and 2021 assuming 6 months = 1 unit	Sales (in lakh ₹)	Squares of time deviation	Product of time deviation and sales
	X	**Y**	**X^2**	**XY**
2018	-5	100	25	-500
2019	-3	110	9	-330
2020	-1	115	1	-115
2021	+1	120	1	+120
2022	+3	135	9	+405
2023	+ 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

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

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

Hence regression equation comes to Y = 120 + 4X

Sales forecast for the next years, i.e., 2024-28

$Y_{2024} = 120 + 4\ (+7) = 120 + 28 =$ ₹ 148 lakhs

$Y_{2025} = 120 + 4\ (+9) = 120 + 36 =$ ₹ 156 lakhs

Y_{2026} = 120 + 4 (+11) = 120 + 44 = ₹ 164 lakhs.

Y_{2027} = 120 + 4 (+13) = 120 + 52 = ₹ 172 lakhs.

Y_{2028} = 120 + 4 (+15) = 120 + 60 = ₹ 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.

Solution:

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

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

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

By putting the values we get

$67 = 5a + 45b$ ... (iii)

$655 = 45a + 455b$ ... (iv)

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

$603 = 45a + 405b$ ... (v)

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

$$b = \frac{52}{60} = 1.04$$

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

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

or, $67 = 5a + 46.80$

or, $67-46.80 = 5a$

or, $5a = 20.20$

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

or $a = 4.04$

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

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

When X = 10 lakhs than

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

or, $Y = 4.04 + 10.40$ or 14.44 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.

Solution:

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

$$\Sigma Y = na + b\Sigma X \quad \text{... (i)}$$

$$\Sigma XY = a\Sigma X + b\Sigma X^2 \quad \text{....(ii)}$$

By putting the values, we get

$$35{,}000 = 5a + 40b \quad \text{... (iii)}$$

$$3{,}11{,}000 = 40a + 370b \quad \text{... (iv)}$$

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

$$2{,}80{,}000 = 40a + 320b \quad \text{... (v)}$$

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

$$31{,}000 = 50b$$

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

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

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

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

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

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

or $10{,}200 = 5a$

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

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

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

When X = 16 lakhs then $Y = 2040 + 620\,(16)$

or $Y = 2040 + 9920$

or $Y = 11{,}960$

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

Capacity Planning

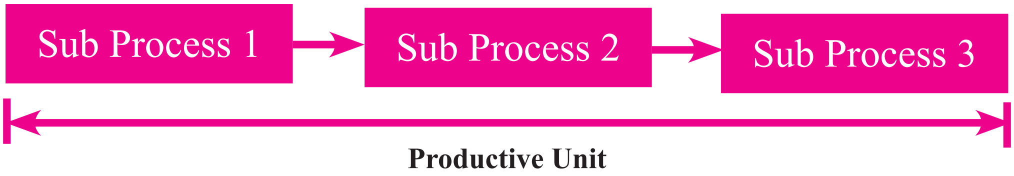
2.2

Capacity is the maximum amount of output a productive unit could produce within a stated time. So capacity is the rate of productive capability of a facility and it is usually expressed as volume of output per period of time.

Capacity refers to the maximum load an operating unit can handle. The operating unit might be a plant, a department, a machine, a store or a worker. Capacity of a plant is the maximum rate of output (goods or services) the plant can produce.

The production capacity of a facility or a firm is the maximum rate of production the facility or the firm is capable of producing. It is usually expressed in terms of units produced per period of time (i.e., hour, shift, day, week, month etc.). But when firms are producing different types of products, it is difficult to use volume of output of each product to express the capacity of the firm. In such cases, capacity of the firm is expressed in terms of monetary value (production value) of the various products produced put together

While producing output if the production process consists of many sub processes, then the capacity of the productive unit is governed by the capacity of the weakest link.



If sub process 2 is the weakest link then capacity of the productive unit is governed by the capacity of weakest link.

But no single capacity measure is best for all situations.

- A retailer measures capacity as annual sales rupees generated per square ft;
- An airline measures capacity as available seat miles per month;
- A theater measures capacity as number of seats;
- A car manufacturer measures capacity as number of cars produced per day;

In general capacity can be expressed in one of two ways:

Output measures of capacity –

Are best utilized when applied to individual processes within the firm or when the firm provides a relatively small number of standardized services and products;

- High volume processes such as car manufacturers are a good example;
- Capacity is expressed as number of cars produced per day;

- This method is less applicable when the amount of customization and variety in the product mix increases;

Input measures of capacity –

- Are generally used for low volume, flexible processes such as furniture maker;
- Capacity is usually expressed as number of workstations or number of workers;

Capacity can be:

- Installed Capacity--It represents capacity in terms of machines actually installed. Productive machines procured for installation have some defined capacity, as provided in their printed literatures. Summation of such capacity gives a total installed capacity.
- Rated Capacity--This denotes the highest output established by the actual trial runs of the productive machines installed. (However, deciding the capacity rate based on the single one-time highest achievement may not be always correct. It is necessary to assume the average of performance rate of machines over a time period for more effective rating decision)
- Licensed Capacity--This denotes the actual capacity licensed by the concerned government authorities**.**
- Design capacity -The maximum output rate or service capacity an operation, process or facility is designed for achieving under ideal condition
- Effective capacity -Design capacity minus allowances such as personal time, maintenance etc.

Effective Capacity can be determined by giving due consideration to the following factors

- **Facilities -** design, location, layout and environment
- **Product -** Product design and product-mix.
- **Process -** Quantity and quality capabilities of the process or to be followed.
- **Human factors -** Job content, Job design, motivation, compensation, training and experience of labour, learning rates and absenteeism and labour turn over.
- **Operational factors -** Scheduling, materials management, quality assurance, maintenance policies, and equipment break-downs.
- **External factors -** Product standards, safety regulations, union attitudes, pollution control standards.

Effective capacity is always less than design capacity owing to changing product mix, the need for periodic maintenance of facilities, tiffin breaks, lunch breaks etc.

Actual output can never exceed effective capacity and is usually less because of machine breakdown, absenteeism, shortages of materials etc.

These different measures are useful in defining two measures of effectiveness of a system:

- Capacity Utilisation
- Efficiency

Capacity Utilisation –

Is the degree to which a resource such as equipment, space or the workforce is currently being used and is measured as the ratio of average output rate to maximum capacity (expressed as a percent).

The average output rate and the maximum capacity needs to be measured in the same terms – that is time, customers, units or rupees.

$$\text{Utilisation} = \frac{\text{Actual output}}{\text{Design Capacity}} \times 100\%$$

The utilization rate indicates the need for adding extra capacity or eliminating unneeded capacity. Utilisation can be increased by increasing actual output and hence effective capacity since actual output is born out of effective capacity

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

Capacity planning is concerned with finding answers to the basic questions regarding capacity such as:

- What kind of capacity is needed?
- How much capacity is needed?
- When this capacity is needed?

Capacity planning is a Long term strategic decision that establishes a firm's overall level of resources.

The goal of capacity planning of an organisation is to achieve a match between its long term supply capabilities and the predicted level of long term demand.

Capacity decisions often involve long term irrevocable commitment of resources

Capacity decisions affect—

- Product lead times (Duration between receipt of order for the product and readiness of the product);
- Customer Responsiveness;
- Operating Costs;
- Firm's ability to compete;

Capacity decisions are strategic because this decisions can affect competitiveness.

The objective of capacity planning and control of capacity, is to match the level of operations to level of demand. Out of Balance Capacity occurs when there is a gap between current and desired capacity. This depletes the competitiveness.

Capacity decisions are made in light of several long term issues such as the firm's economies and diseconomies of scale, capacity cushions, timing, trade offs between customer service and capacity utilisation etc.

Because of the aforesaid long term factors there are risks involved and Capacity strategies should consider all these.

Therefore while taking capacity decisions concerns are on factors

Flexibililty:

- *Flexibility* is introduced into the system
    - ☐ *Provisions for future requirments* must be there in the system

      If future expansion of an education institute is most likely, then during initial construction of the the institute's building water lines, power lines etc must be provided with adequate capacity commesurate with future need
    - ☐ Besides provisions for future requirements, flexibility also incorporated
        - While designing Location & Layout of equipments

  - While making Productin planning, Scheduling & Inventory policies

Life Cycle:

Capacity requirements are often closely linked to the stage of the *Life Cycle* that a product or service is in.

The product life cycle is the process a product goes through from when it is first introduced into the market until it declines or is removed from the market. The life cycle has four stages - introduction, growth, maturity and decline.

- At introduction phase of a product---size of the overall market and organisation's share of the market is uncertain----large and inflexible capacity planning needs to be avoided
- At growth phase of a product---size of the overall market grows—
  - Rate of growth of individual organisation's market share influences its capacity planning
  - Influences individual organisation's level of production, level of investment
  - Opens opportunities to all organisations to bring competitive advantage through introduction of distinguished features into product (product differentiation) by investing in technology and process improvements
  - Brings risks of overcapacity in the market and result in higher unit costs of the output
- At maturity phase of a product---size of the market levels off
  - Organisations tend to have stable market share
  - Organisations could increase profitability through cost reduction and full capacity utilisation
  - Organisations with lower capacity in earlier phases of life cycle could go for capacity addition if maturity stage is thought to be prolonged
- At decline phase of a product---overall market demand declines
  - Organisations face underutilisation of capacity
  - Excess capacity could be sold off
  - Excess capacity could be used for producing other products or services

Interrelation:

- Parts of any system are always interrelated
- Capacity of one part has impacts on other parts and so capacity planning must consider these interrelations
  - Increasing the number of routes from an airport must have influence on security check-in capacity of the station.
- Capacity decisions related to a process has a role on the supply chain of the organisation as a whole
  - Increasing production capapcity may require more raw material supllies and supplliers require time to adjust this change requirement
- So capapcity planning decsions must be made with collaboration among all the interelated players including supplliers, distributos, transporters etc

Bottleneck:

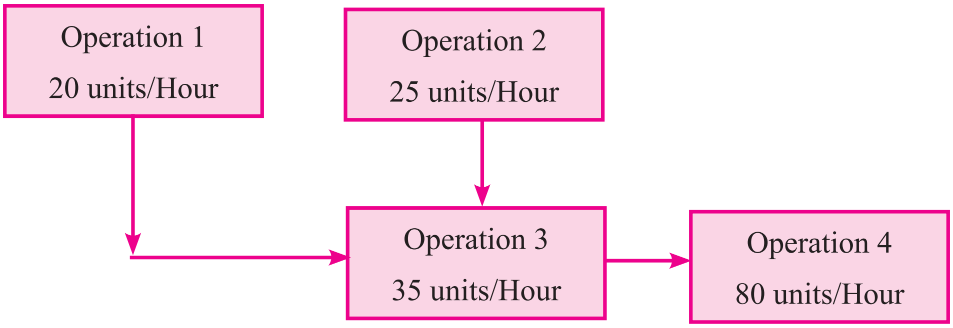
- Capacity planning decision must not encouarge *Bottleneck Operation*

Bottleneck operation is an operation in a sequence of operations whose capacity is lower than the capacities of other operation in the sequence.

- Bottleneak operation limits the capacity utilisation of the previous and successive operation in the whole sequence of opertion
- Capacity utilisation of the whole system is thereby reduced

Supoose there are four operations named Operations 1, Operation 2, Opeartion 3 & Operation 4

Production capacities and and their interrealtion is shown in the following figure:



Operation 3 can handle only 35 units/hour. But Operation 1 and Operation 2 at its full capacity could produce a total of 45 units /hour which Operation 3 cannot handle. So although operation 4 has enough capacity overall capacity of the system is restricted to 35 units per hour

Chunk:

- Capacities are available in Chunks
- Creates mismatch between desired capacity and available capacity
- Creates either shortfall or surplus in production

Variability:

- Demand is variable
- Variability can be seasonal, chance random, cyclical etc.
- Variable demand brings unevenness in capacity requirements
- Capacity strategies should provide allowances for these
- Capacity should be for complementary products & services to cater seasonality

Optimal Operating level:

- Production units always have an ideal or optimal level of operation in terms of unit cost of output
- This brings Economies of scale and Diseconomies of scale

Economies of scale

- States that the average unit cost of a good or service can be reduced by increasing its output rate

Diseconomies of scale

- A level of operation at which average cost per unit increases as the facility's size increases

Miscellaneous:

- Incremental Expansion or single step expansion of capacity considering
  - ☐ Competitive pressure
  - ☐ Market Opportunities
  - ☐ Costs and availability of funds
  - ☐ Disruption of operation
  - ☐ Training requirements

Capacity planning is required for the following:

- Sufficient capacity is required to meet the customers demand in time,
- Capacity affects the cost efficiency of operations,
- Capacity affects the scheduling system,
- Capacity creation requires an investment
- Post selection of required capacity, decisions regarding the facility location and process technology selection etc. starts

Capacity planning is mainly of two types:

- **Long-term capacity plans** which takes into account investments in new facilities and equipment. These plans cover a time horizon of more than two years.
- **Short-term capacity plans** which takes into account work-force size, overtime budgets, inventories etc.

Capacity planning involves activities such as:

- Assessing the capacity of existing facilities.
- Forecasting the long-range future capacity needs.
- Identifying and analysing sources of capacity for future needs.
- Evaluating the alternative sources of capacity based on financial, technological and economic considerations
- Selecting a capacity alternative most suited to achieve strategic mission of the firm.

An operating unit in its life may face any of the following two situations:

- An excess or surplus capacity situation where the present capacity exceeds the expected future demand
- A capacity shortage situation where present capacity is not enough to meet the forecast demand for the product

Capacity planning takes concern on these two cases.

The over capacity is preferred when:

- Fixed cost of the capacity is not very high.
- Subcontracting is not possible because of secrecy of design and/or quality requirement.
- The time required to add capacity is long.
- The company cannot afford to miss the stipulated delivery date and cannot afford to lose the customer.
- There is an economic capacity size below which it is not economical to operate the plant.

Excess capacity –

- Drain company's resources;
- Prevent investments in other more lucrative ventures;

The under capacity is preferred when:

- Fixed cost of the capacity is very high.
- Shortage of products does not affect the company (i.e., lost sales can be compensated).
- The technology changes fast, i.e., the rate of obsolescence of plant and equipment are high.
- The cost of creating the capacity is prohibitively high.

Inadequate capacity –

- Loss of customers;
- Restricts growth;

Two kinds of factors affecting capacity planning are:

- **Controllable Factors:** amount of labour employed, facilities installed, machines, tooling, shifts of work per day, days worked per week, overtime work, subcontracting, preventive maintenance and number of production set ups.
- **Less Controllable Factors:** absenteeism, labour performance, machine break-downs, material shortages, scrap and rework, strike, lock-out, fire accidents, natural calamities (flood, earthquake etc.) etc.

Forms of capacity planning:

- Based on time-horizon
  - ☐ Long-term capacity planning - which takes into account investments in new facilities and equipment. These plans cover a time horizon of more than two years.
  - ☐ Short-term capacity planning - which takes into account work-force size, overtime budgets, inventories etc.
- Based on amount of resources employed
  - ☐ Finite capacity planning and
  - ☐ Infinite capacity planning

Operations managers must examine three dimensions of capacity strategy before making capacity decisions:

- Sizing capacity cushions;
- Timing and sizing expansion;
- Linking Capacity decisions with other operating decisions;

(1) Sizing capacity cushions

Capacity Cushion is the amount of reverse capacity a process uses to handle sudden increases in demand or temporary losses of production capacity.

Capacity Cushion = 100% - Average utilisation rate (%)

The appropriate size of the cushion varies by industry—capital intensive industries prefer under 10% cushion where less capital intensive can run with 40 to 30% cushion

☐ Unused capacity costs money and brings low return on investment

- Business keeps large cushion when demand varies or when future demand is uncertain or with a changing product mix
- In the long run it buffers the organisation against uncertainty as do resource flexibility, inventory and longer customer lead times
- Any change in any decision area needs change in capacity cushion

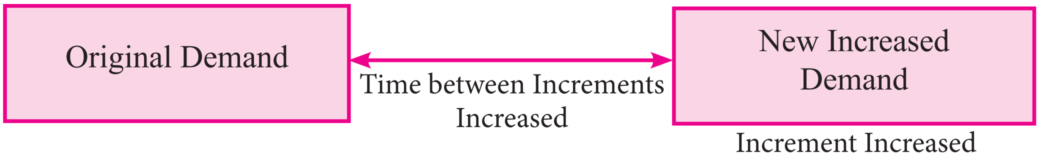
☐ Capacity cushions for a process can be lowered if competitive priorities are given

☐ Capacity cushions can be lowered if the company is willing to smooth the output rate by raising prices when inventory is low (since inventory is low, raising price could restrict demand becomes greater than production) and decreasing prices when it is high

Highly variable demand – In certain service industries (e.g. Grocery) demand on some days of the week is predictably higher than on other days. Long customer waiting times are not acceptable because customer goes impatient if they have to wait in a supermarket checkout line for more than a few minutes. Prompt customer service requires supermarkets to maintain a capacity cushion large enough to handle peak demand.

(2) Timing and sizing expansions

- Has concern when to adjust capacity levels and by how much
- Two extreme strategies for expanding capacity---
  ☐ Expansionist strategy----involves large, infrequent jumps in capacity
- Stays ahead of demand, minimises the chance of sales lost to insufficient capacity
  ☐ Wait and see strategy ---involves smaller more frequent jumps
- Lags behind demand and therefore to meet any shortfalls it relies on short term options such as use of overtime, temporary workers, subcontractors, stock-outs and postponement of preventive maintenance of equipment
- Timing and sizing of expansion are related
  ☐ If demand is increasing and the time between increments increases, the size of the increments must also increase



Factors favouring expansionist strategy:

- It results economies of scale;
- It results reducing cost of operation;
- It facilitates a firm to compete on price;
- It might increase the firm's market share;

Factors favouring wait and see strategy:

- It reduces the risks of overexpansion;
- It facilitates firms to avoid obsolete technology;
- It guards against inaccurate assumptions regarding competition;

Advantages/disadvantage of Expansionist strategy---

- It can result in economies of scale and faster rate of learning
- This helps a firm to reduce its costs and compete on price
- This might increase firm's market share
- It may bring risk of overexpansion

Advantages/disadvantage of Wait & see strategy---

- It reduces the risks of overexpansion
- It is unable to respond if demand is unexpectedly high
- It fits the short term outlook but can erode market share over the long run

Managers may choose one of these two strategies or one of the many between these extremes

Three basic strategies for the timing of capacity expansion in relation to a steady growth in demand are

Capacity Lead Strategy: Capacity is expanded in anticipation of demand growth. This aggressive strategy is used to lure customers from competitors who are capacity constrained ot to gain a foothold in a rapidly expanding market

Capacity Lag strategy: Capacity is increased after an increase in demand has been documented. This conservative strategy produces a higher return on investment but may lose customers in the process. It is used in industries with standard products and cost based or weak competition. The strategy assumes that lost customers will return from competitors after capacity has expanded

Average Capacity strategy: Capacity is expanded to coincide with average expected demand. This is a moderate strategy in which mangers are certain they will be able to sell at least some portion of the additional output

(3) Linking process capacity and other operating decisions

- Capacity decisions should be closely linked to processes and supply chains throughout the organisation
- Capacity decisions must link backward as well as forward channels in the whole operation chain

Level capacity plan

- Based in "produce-to-stock and sell" approaches wherein the production systems are operated at uniform production levels and finished goods inventories rise and fall depending upon whether production level exceeds demand or vice versa from time period to time period (say every quarter).

Matching capacity with demand plan.

- In this plan, production capacity is matched with the demand in each period (weekly, monthly or quarterly demand). Usually, material flows and machine capacity are changed from quarter to quarter to match the demand. The main advantages are low levels of finished goods inventory resulting in lesser inventory carrying costs. Also, the back-ordering cost is reduced. The disadvantages are high labour and material costs because of frequent changes in workforce (hiring, training and lay-off costs, overtime or idle time cost or subcontracting costs).

A higher capacity plant offers some economies of scale:

- Automation is possible in a high capacity plant;
- Labour economies – lower variable cost/unit – increase of skill of worker;
- Managerial economies, technical competence;
- Marketing economies – Purchase in bulk;
- Financial economies – better security, attract investment at lower cost;

Economies of scale – occur when it costs less per unit to produce or operate at high levels of output. This is true when:

- Fixed costs can be spread over a larger number of units;
- Production or operating costs do not increase linearly with output levels;
- Quantity discounts are available for material purchases;
- Operating efficiency increases as workers gain experience;

Economies of scale do not continue indefinitely. Above a certain level of output diseconomies of scale can occur like:

- Overtaxed machines and material handling equipment break down;
- Slowing of service time;
- Quality suffers requiring more rework
- Labour costs increase with more overtime;
- Increase in difficulties in coordination and management activities;

Once long term forecast is found out additions of increments to existing capacity can be done:

- Add capacity increments but more often (less new capacity at a time);
- Add capacity increments but less often (high new capacity at a time);
- Add capacity before the requirements exceed the capacity available;
- Add capacity after the requirements has overtaken the available capacity;

A systematic approach to Long term decisions for capacity would typically include:

(a) Whether to add a new plant

(b) Whether to add a new workstations

(c) Whether to reduce the number of existing workstations/warehouses etc.

Some of these can take years to become operational and so a systematic approach is required to plan for long term capacity decisions. The four step systematic approach involves:

(1) Estimate future capacity requirements

(2) Identify gaps by comparing requirements with available capacity

(3) Develop alternative plans for reducing the gaps

(4) Evaluate each alternative, both qualitatively and quantitatively, and making a final choice

Out of Balance Capacity occurs when there is a gap between current and desired capacity

When just one service or product is processed, then capacity requirement of a single capacity per year is:

$$\text{Capacity Requirement (M)} = \frac{\text{Processing hours required to meet year's demand}}{\text{Hours available from a single capacity unit per year after deducting desired cushion}}$$

[Single capacity means an employee, a machine, a computer etc.]

$$= \frac{D_p}{N[1 - (\frac{C}{100})]} \text{ .... (1)}$$

Where

D = demand forecast for the year (number of customers serviced or units of product)

p = processing time (in hours per customer served or unit product)

N = total number of hours per year during which the process operates

C = desired capacity cushion (expressed as a percent)

After accounting for both processing and setup times equation (1) above for multiple products/services can be modified as

Capacity Requirement (M)

$$= \frac{\text{Processing \& Set up hours required to meet year's demand summed over all services / products}}{\text{Hours available from a single capacity unit per year after deducting desired cushion}}$$

$$= \frac{[Dp + (\frac{D}{Q})s]_{product1} + [Dp + (\frac{D}{Q})s]_{product2} + \text{...............} + [Dp + (\frac{D}{Q})s]_{productn}}{N[1 - (\frac{C}{100})]} \text{ .... (2)}$$

Where

Q = number of units in each lot.

s = set up time (in hours) per lot

Example1: For your company capacity measures is in number of machines. The company produces three product A, B and C. Processing and Set up times (Time standard), lot sizes and demand forecasts are given in the following table. The firm operates 3-8hour shifts, 5 days week, 50 weeks per year. A capacity cushion of 5% is sufficient.

Product	Time standard		Lot Size (units/lot)	Demand Forecast (units/year)
	Processing(hr/unit)	Setup(hr/unit)		
A	2	0.5	300	18000
B	5	1	500	50000
C	3	1	1000	9000

(i) How many machines are needed?

(ii) If the operation currently has fifty machines, what is the capacity gap?

Answer:

(i) The number of hours of operation per year, N = $\frac{\text{3 shifts}}{\text{Day}} = \frac{\text{8 hours}}{\text{shift}} = \frac{\text{5 day}}{\text{week}}$ * 50 week = 6000 hours

The number of machines required M is the sum of machine hour requirements for all three products divided by the number of productive hours available for one machine

Capacity Requirements (M)

$$= \frac{\text{Processing \& Set up hours required to meet year's demand summed over all services / products}}{\text{Hours available from a single capacity unit per year after deducting desired cushion}}$$

$$= \frac{[Dp + (\frac{D}{Q})s]_A + [Dp + (\frac{D}{Q})s]_B + [Dp + (\frac{D}{Q})s]_C}{N[1 - (\frac{C}{100})]}$$

$$= \frac{[18000 * 2 + (\frac{18000}{300})0.5] + [50000 * 5 + (\frac{50000}{500})1] + [9000 * 3 + (\frac{9000}{1000})1]}{6000[1 - \frac{5}{100}]}$$

$$= \frac{313139}{5700} = 54.9 \cong 55 \text{ machines}$$

(ii) The capacity gap is 55 - 50 = 5 machines. 20 more machines should be purchased unless management decides to use short term options, if any available, to fill the gap

Example 2: The base case for a cloud kitchen company whose details are given below is to do nothing. The capacity of the kitchen in the base case is 100,000 meals per year. A capacity alternative is a two stage expansion. This alternative expands the kitchen at the end of the year 0, raising its capacity from 80,000 meals per day to that of the dining area (105,000 meals per year).

If sales in year 1 and 2 live up to expansions, the capacities of both the kitchen and dining room will be expanded at the end of the year 3 to 150,000 meals per year. This upgraded capacity level should suffice up through year 5. The initial investments would be ₹1,20,000 at the end of year 0 and an additional investment of ₹ 2,00,000 at the end of year 3. The pretax profit is ₹15/meal. The owner expects to sale 80,000 meals in the current year. Forecasted Demand for the next 5 years is 90,000 meals for the next year, followed by a 10,000 units increase in each of the succeeding years. What are the pretax cash flows for the alternative through year 5, compared with the base case? Find NPV at 10%

Answer:

Year	0 (Current year)	1	2	3	4	5
Forecasted sale (meals)	80000	90000	1,00,000	1,10,000	1,20,000	1,30,000
Increamental sale Compared to base i.e., current year (units)		10000	20000	30000	40000	50000
Average profit per unit		15	15	15	15	15
Increamental profit flow (Rs.)		150000	300000	450000	600000	750000

	Year	0 (Current year)	1	2	3	4	5
1	Initial Investment	-120000					
2	Incremental profit flow on investment		150000	300000	450000	600000	750000
3	Additional Investment				-200000		
4	Net cash flows (Inflows/Outflows)	-120000	150000	300000	250000	600000	750000
5	PV Factor $(1/1.10)^n$ (Since cost of fund 10%, n = no of years)	1	0.909	0.826	0.751	0.683	0.621
6	PV (4 * 5)	-120000	136363.6	247933.9	187828.7	409808.1	465691
7	NPV (Sum of Row 4)	1327625.286					

Example 3: Up, Up and Away is a producer of kites and wind socks. Relevant data on a bottleneck operation in the shop for the upcoming fiscal year are given in the following table:

Item	Kites	Wind Socks
Demand forecast	30000 units/year	12000 units/year
Lot size	20 units	70 units
Standard processing time	0.3hours/unit	1.0 hour/unit
Standard setup time	3hours/lot	4hours/lot

The shop works for two shifts per day, 8 hours per shift, and 200 days per year. Currently, the company operates four machines and desires a 25% capacity cushion. How many machines should be purchased to meet the upcoming year's demand without resorting to any short term capacity solution?

Answer:

The number of hours of operation per year, $N = \frac{2 \text{ shifts}}{\text{Day}} = \frac{8 \text{ hours}}{\text{shift}} * 200 \text{ days} = 3200 \text{ hours}$

The number of machines required is the sum of machine hour requirements for all two products divided by the number of productive hours available for one machine

Capacity Requirements (M)

$$= \frac{\text{Processing \& Set up hours required to meet year's demand summed over all services / products}}{\text{Hours available from a single capacity unit per year after deducting desired cushion}}$$

$$= \frac{[Dp + (\frac{D}{Q})s]_K + [Dp + (\frac{D}{Q})s]_W}{N[1 - (\frac{C}{100})]}$$

$$= \frac{[30000 * 0.3 + (\frac{30000}{20})3] + [12000 * 1 + (\frac{12000}{70})4]}{3200[1 - \frac{25}{100}]}$$

$$= \frac{26185.71}{2400} = 10.91 \cong 11 \text{ machines}$$

So another 11 - 4 = 7 machines are to be purchased

Example 4: Turf-Rider Inc. manufactures touring bikes and mountain bikes in a variety of frame sizes, colors and component combinations. Identical bicycles are produced in lots of 100. The projected demand, lot size and time standards are shown in the following table:

Item	Touring	Mountain
Demand forecast	5000 units/year	10000 units/year
Lot size	100 units	100 units
Standard processing time	25hours/unit	5 hour/unit
Standard setup time	2hours/lot	3hours/lot

The shop currently works 3shift 8 hours a day, 5 days a week, 50 weeks a year. It operates hundred workstations, each producing one bicycle in the time shown in the table. The shop maintains a 15% capacity cushion. How many workstations will be required next year to meet expected demand without using overtime and without decreasing the firm's current capacity cushion?

Answer:

The number of hours of operation per year, $N = \frac{3 \text{ shifts}}{\text{Day}} = \frac{8 \text{ hours}}{\text{shift}} = \frac{5 \text{ day}}{\text{week}} * 50 \text{ week} = 6000 \text{ hours}$

The number of machines required M is the sum of machine hour requirements for all two products divided by the number of productive hours available for one machine

Capacity Requirements (M)

$$= \frac{\text{Processing \& Set up hours required to meet year's demand summed over all services / products}}{\text{Hours available from a single capacity unit per year after deducting desired cushion}}$$

$$= \frac{[Dp + (\frac{D}{Q})s]_r + [Dp + (\frac{D}{Q})s]_m}{N[1 - (\frac{C}{100})]}$$

$$= \frac{[5000 * 25 + (\frac{5000}{100})2] + [10000 * 50 + (\frac{10000}{100})3]}{6000[1 - \frac{15}{100}]} \qquad = \frac{625400}{5100} = 122.63 \cong 123 \text{ workstations}$$

Example 5: Amrita is considering expanding the floor area of her high-fashion import clothing store, The Frantic, by increasing her leased space in the upscale Acropolis mall from 2000 square feet to 3000 square feet. The Acropolis mall boasts one of the country's highest ratios of sales value per square ft. Rents (including utilities, security and similar costs) are Rs 110 per Sq.ft per year. Salary increases related to Frantic's expansion are shown in the following table, along with projection of sales per square ft. The purchase cost of goods sold average 70% of the sales price. Sales are seasonal, with an important peak during the year-end holiday season.

Year	Quarter	Sales (per Sq.ft)	Salaries
1	1	Rs 90	Rs 120,000
	2	60	80,000
	3	110	130,000
	4	240	240,000
2\	1	99	120,000
	2	66	80,000
	3	121	140,,000
	4	264	240,000

(i) If Amrita expands Frantic at the end of year 0, what will her quarterly pretax cash flows be through year 2?

(ii) Will the expansion be accepted?

Answer:

			POST EXPANSION RESULT						
		1st year				2nd year			
	0	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
	EXPANSION								
1. Sq feet		3000	3000	3000	3000	3000	3000	3000	3000
2. Sales per Sq ft (Rs/Sq ft)		90	60	110	240	99	66	121	264
3. Sales (Rs)		270000	180000	330000	720000	297000	198000	363000	792000
4. Cost of goods sold at 70% of sales		189000	126000	231000	504000	207900	138600	254100	554400
5. Rent of the space @ Rs.110/sq ft		330000	330000	330000	330000	330000	330000	330000	330000
6. Salaries		120000	80000	130000	240000	120000	80000	140000	240000
7. Pretax cash flows (3-4-5-6)		-369000	-356000	-361000	-354000	-360900	-350600	-361100	-332400

The project will not be accepted as negative pretax cash flows in all periods will generate a negative NPV

When demand is uncertain and sequential decisions are involved then a decision tree can be particularly valuable for evaluating different capacity expansion alternatives.

Suppose on the basis of forecast demand position at time t = 0 a business unit decided to expand. During further studies during course of operation with expanded establishment if it is found that future demand will be more compared to demand forecast available at t = 0, then additional expansion will be required to cater the changed demand.

Expanding twice is likely to be much more expensive than building a larger facility from the outset. However, making a large expansion now, when demand growth is low, means poor facility utilisation. Under this type of situation decision tree model will be used.

Optimum Plant Capacity:

Plant capacity has a great influence on cost of production with increasing volume of production, economies of scale arises which results in reduction in average cost per unit produced.

As the volume of output increases outward from zero in a particular production facility, average unit costs fall. These declining costs are because of the following reasons: (i) Fixed costs are spread over more units produced, (ii) Plant construction costs are less, (iii) Reduced costs of purchased material due to quantity discounts for higher volume of materials purchased and (iv) Cost advantages in mass production processes

So for a given production facility, there is an optimum volume of output per year that results in the least average unit cost. This level of output is called the "best operating level" of the plant.

Balancing the Capacity:

In firms manufacturing many products (a product line or a product-mix) the load on different machines and equipment vary due to changes in product-mix. When the output rates of different machines do not match with the required output rate for the products to be produced, there will be an imbalance between the work loads of different machines. This will result in some machine or equipment becoming a "bottleneck work centre" thereby limiting the plant capacity which will in-turn increase the production costs per unit.

To overcome problem of imbalance between different machines, additional machines or equipment are added to the bottleneck work-centre to increase the capacity of the bottle-neck work centre to match with the capacity of other work centre. Adding new machines or equipment to bottleneck work centres to remove the imbalance in capacity between various work centres is found to be economical than giving excessive overtime to workers working in bottle-neck centres which increases production costs. Another method to remove imbalance is to subcontract excess work load of bottleneck centres to outside vendors or subcontractors. Another way to balance capacities is to try to change the product mix by manipulating the sales for different products to arrive at a suitable product-mix which loads all work centres almost uniformly.

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.

Solution:

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 x 4 = 1200 Hrs.
Y	400	6.0	400 x 6 = 2400 Hrs.
Z	500	3.0	500 × 3 = 1500 Hrs.
			Total = 5100 Hrs

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

Step 3 : Number of machines required

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

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.

Solution:

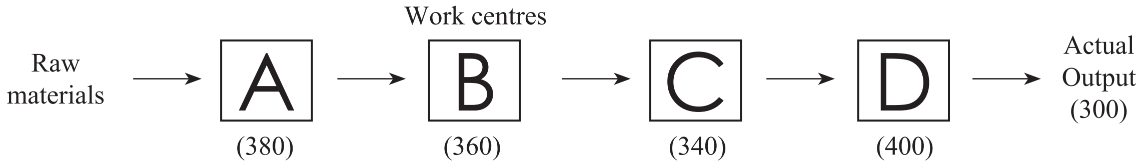
Actual output

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

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

Illustration 7

A firm has four work centres, A, B, 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?

Solution:

(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) $$\text{System efficiency} = \frac{\text{Actual output}}{\text{System capacity}} = \frac{300}{340} \times 100 \text{ (i.e., maximum possible output)} = 88.23\%$$

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	₹ 12,000	0 to 300
Two	₹ 15,000	301 to 600
Three	₹ 21,000	601 to 900

Variable cost is ` 20 per unit and revenue is ` 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?

Solution:

(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 × Q = FC + VCp.u. × 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.

Facility Location and Layout

2.3

For any manufacturing unit operations management starts with “What to produce?” followed by “How much to produce” and then followed by Where to produce”

Where to produce--- results in this topic “Facility location and layout”

Definition of a Facility and Facility Location

- In a simpler term, facility means any type of set-up that an organisation requires to run its operations and produce required products and/or delivers intended services to the customers. Location, on the other hand is the place or region where the above-mentioned facility may be established.

Facility location involves following decision:

- Where to establish the set-up?

Need for an appropriate facility location

The need for selecting an appropriate facility location stems from the following concerns of an organisation such as

- When an organisation wants to start a new business and/or expand the existing business by entering into a new market and/or increases the scale of operations
- When the business faces some complexities and/or difficulties in terms of resource shortage, expiry of lease agreement, socio-cultural problems, legal and political issues and other economic and social issues that force the organisations to change the location.

Benefits from a Good Facility Location

- Cost benefit in terms reduced fixed and variable cost, transportation cost.
- Proximity to market and source
- Easy and hassle free transport facility

In short, a good facility location is one that enables the organisations to strike a balance between cost (cost of production and service) and service and intends to maximize the service quality while minimizing the cost to the extent possible and remain competitive at the market place (in terms of visibility, proximity to source and market). It is a strategic decision that organisation takes.

Factors affecting location selection decision

- Sourcing
    - ☐ Availability of raw materials
    - ☐ Availability of natural resources, energy and waters

  - ☐ Availability of internet connectivity
  - ☐ Proximity to the key suppliers
  - ☐ Connectivity to alternate vendors
  - ☐ Opportunity to cross-docking and utilizing milk vans
- Markets
  - ☐ Proximity to market
  - ☐ Coverage of wide geographical area (with close proximity to target customers) keeping the facility at focal point
  - ☐ Connectivity with a large customer base
  - ☐ Lesser time to market
  - ☐ Connectivity
- Cost
  - ☐ Lesser transportation cost and well availability of various transportation modes
  - ☐ Lesser lease and/or rental cost
  - ☐ Tax, and other duties
  - ☐ Other hidden cost
- Socio-cultural, community and Political issues
  - ☐ Supportive community
  - ☐ Familiarity with language, rituals and culture
  - ☐ Level of crime and other disturbances
  - ☐ Availability of prospective employees
  - ☐ Quality of living
  - ☐ Statutory and regulatory rules and regulations
  - ☐ Availability of medical facilities, fire and police
- Environmental concerns
- Availability of skilled labours
- Competitive pressure

Some approaches for facility location selection

An organisation follows certain steps to make a correct location choice. These Steps are:

- Decide on the criteria for evaluating location alternatives
- Identify important factors
- Develop location alternatives
- Evaluate the alternatives

- Make a decision and select the location

Some of the popular approaches are:

- Factor Rating Method
- Centre of Gravity Technique
- Transportation Model
- Optimization and Heuristic Models

Let us consider some situations of facility location selection problems

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.

Solution:

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**						
	E-1	E-2	E-3	E-4	E-5	**Row**	**Weight**
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 L1 : $0.3 \times 10 + 0.2 \times 7 + 0.4 \times 6 = 3 + 1.4 + 0.7 + 2.4 = 7.5$

As per the weighted score Location L1 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 L1, L2, L3 and L4. 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

		Coordinates	
Location	Volume	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.

Solution:

Loc	V_1	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)

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

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

Facility Layout

Plant Layout, also known as layout of facility refers to the configuration of departments, work-centres and equipment and machinery with focus on the flow of materials or work through the production system.

Plant layout or facility layout means planning for location of all machines, equipments, utilities, work stations, customer service areas, material storage areas, tool servicing areas, tool cribs, aisles, rest rooms, lunch rooms, coffee/tea bays, offices, and computer rooms and also planning for the patterns of flow of materials and people around, into and within the buildings. Layout planning involves decisions about the physical arrangement of economic activity centres within a facility. An economic activity centre can be anything that consumes space, a person or group of people, a machine, a work station, a department, a store room and so on. The goal of layout planning is to allow workers and equipments to operate more effectively.

The questions to be addressed in layout planning are:

- How much space and capacity does each centre need?
- How should each center's space be configured?
- What centres should the layout include?
- Where should each centre be located?

The location of a centre has two dimensions:

- Absolute location or the particular space that the centre occupies within the facility.
- Relative location i.e., the placement of a centre relative to other centers.

The importance of layout decisions:

The need for layout planning arises both in the process of designing new plants and the redesigning existing plants or facilities.

Most common reasons for design of new layouts are:

(i) Layout is one of the key decisions that determine the long-run efficiency in operations.

(ii) Layout has many strategic implications because it establishes an organisation's competitive priorities in regard to capacity, processes, flexibility and cost as well as quality of work life, customer contact and image (in case of service organisations).

(iii) An effective layout can help an organisation to achieve a strategic advantage that supports differentiation, low cost, fast response or flexibility.

(iv) A well designed layout provides an economic layout that will meet the firm's competitive requirements.

Need for redesign of layout arises because of the following reasons:

- Accidents, health hazards and low safety,
- Changes in environmental or legal requirements,
- Changes in processes, methods or equipments,
- Changes in product design/service design,
- Changes in volume of output or product-mix changes,
- Inefficient operations (high cost, bottleneck operations),
- Introduction of new products/services,
- Low employee morale.

Good Plant layout- Objectives:

- Efficient utilisation of labour reduced idle time of labour and equipments,
- Higher flexibility (to change the layout easily),
- Higher utilisation of space, equipment and people (employees),
- Improved employee morale and safe working conditions,
- Improved flow of materials, information and people (employees),
- Improved production capacity,
- Reduced congestion or reduced bottleneck centers,
- Reduced health hazards and accidents,
- To allow ease of maintenance,
- To facilitate better coordination and face-to-face communication where needed,
- To improve productivity,
- To provide ease of supervision,
- To provide product flexibility and volume flexibility,
- To utilise available space efficiently and effectively.

Choices of Layout:

Layout choices can help greatly in communicating an organisation's product plans and competitive priorities. Layout has many practical and strategic implications. Altering a layout can affect an organisation and how well it meets its competitive priorities by:

- Facilitating the flow of materials and information,
- Improving communication,
- Improving employee morale,
- Increasing customer convenience and sales (in service organisations such as retail stores),
- Increasing the efficient utilisation of labour and equipment,
- Reducing hazards to employees.

The type of operations carried out in a firm determines the layout requirements.

Some of the fundamental layout choices available to managers are:

- Whether to plan the layout for the current or future needs?
- Whether to select a single-story or multistory building design?
- What type of layout to choose?
- What performance criteria to emphasise?

Factors influencing layout choices:

Primarily the layout of a plant is influenced by the relationship among materials, machinery and men. Other factors influencing layout are type of product, type of workers, the type of industry, management policies etc.

Some of these factors are discussed in detailed below:

- **Location:** The size and type of the site selected for the plant, influences the type of buildings (single story or multi story) which in turn influences the layout design. Also, the location of the plant determines the mode of transportation from and into the plant (such as by goods trains, truck, or ships) and the layout should provide facilities for mode of transport used. Also, the layout should provide for storage of fuel, raw materials, future expansion needs, power generation requirements etc.
- **Machinery and Equipments:** The type of product, the volume of production, type of processes and management policy on technology, determines the type of machines and equipments to be installed
- **Managerial Policies:** regarding volume of production, provision for future expansion, extent of automation, make-or-buy decisions, speed of delivery of goods to customers, purchasing and inventory policies and personnel policies influence the plant layout design.
- **Materials:** Plant layout includes provision for storage and handling of raw materials, supplies and components used in production. The type of storage areas, racks, handling equipments such as cranes, trolleys, conveyors or pipelines etc., used - all depend on the type of materials used - such as solid, liquid, light, heavy, bulky, big, small etc.
- **Product:** The type of product i.e., whether the product is light or heavy, big or small, liquid or solid etc., it influences the type of layout. For example, Ship building, Aircraft assembly, Locomotive assembly etc., requires a layout type different from that needed to produce refrigerators, cars, scooters, television sets, soaps, detergents, soft drinks etc. The manufacturing process equipments and machines used and the processing steps largely depend on the nature of the product and hence the layout design depends, very much on the product.

Type of Industry:

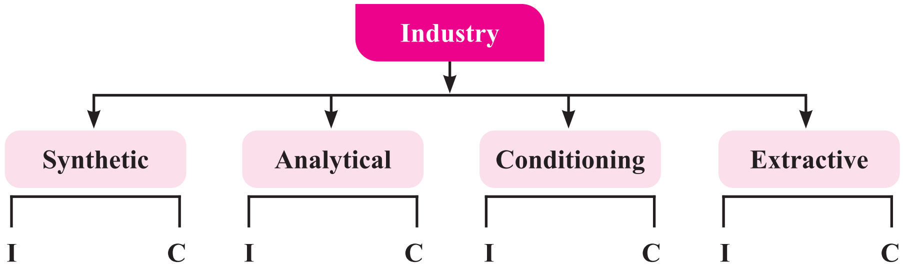


Figure 2.1: Type of Industry Process

I is intermittent type of industry

C is continuous type of industry

Whether the industry is classified under (a) Synthetic, (b) Analytical, (c) Conditioning and (d) Extraction industries and again whether the industry has intermittent production or continuous production has a relevance to the type of layout employed.

- **Workers :** The gender of employees (men or women), the position of employees while working (i.e., standing or sitting), employee facilities needed such as locker rooms, rest rooms, toilets, canteens, coffee/tea bays etc., are to be considered while designing the plant layouts.

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.

Types of Layout:

A layout essentially refers to the arranging and grouping of machines which are meant to produce goods. Grouping is done on different lines. The choice of a particular line depends on several factors. The methods of grouping or the types of layout are:

(i) Process layout or functional layout or job shop layout;

(ii) Product layout or line processing layout or flow-line layout;

(iii) Fixed position layout or static layout;

(iv) Cellular manufacturing (CM) layout or Group Technology layout and

(v) Combination layout or Hybrid layout.

Process Layout:

Also called the functional layout, layout for job lot manufacture or batch production layout, the process layout involves a grouping together of similar machines in one department. For example, machines performing drilling operations are installed in the drilling department; machines performing turning operations are grouped in the turning department; and so on. In this way, there would be an electroplating department, a painting department, a machining departments and the like, where similar machines or equipments are installed in the plants which follow the process layout. The process arrangement is signified by the grouping together of like machines based upon their operational characteristics. For example, centre lathes will be arranged in one department, turret lathes in a second department, and milling machines in a third departments.

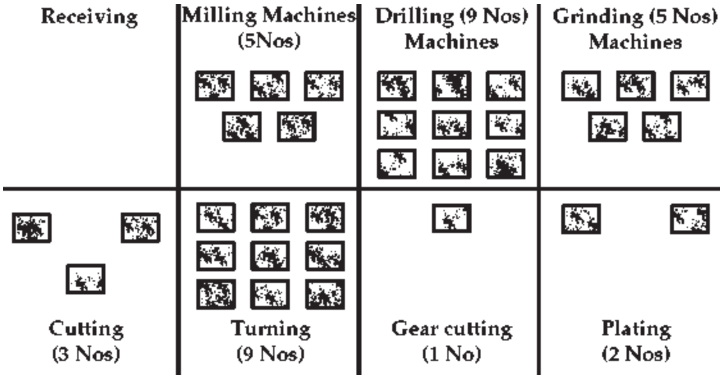


Figure 2.2: Process Layout

A quantity of raw material is issued to a machine which performs the first operation. This machine may be situated anywhere in the factory. For the next operation, a different machine may be required, which may be situated in another part of the factory. The material should be transported to the other machine for the operation. Thus, material would move long distances and along crisscrossing paths. At one stage, the material may be taken to a separate building, say, for heat treatment, and then brought back for grinding. If machines in one department are engaged, the partly finished product awaiting operations may be taken to the store and later reissued for production. Partly finished goods would be waiting for processing in every department, like commuters waiting for buses in a city.

Machines in each department attend to any product that is taken to them. These machines are, therefore, called general purpose machines. Work has to be allotted to each department in such a way that no machine in any department is idle. In a batch production layout, machines are chosen to do as many different jobs as possible, i.e., the emphasis is on general purpose machines. The work which needs to be done is allocated to the machines according to loading schedules, with the objective of ensuring that each machine is fully loaded. The process layout carries out the functional idea of Taylor and from the historical point of view, process layout precedes product layout. This type of layout is best suited for intermittent type of production.

While grouping machines according to the process type, certain principles must be kept in mind. These are:

- Convenience for inspection.

- Convenience for supervision. Process layout may be advantageously used in light and heavy engineering industries, made-to-order furniture industries and the like.
- The distance between departments needs to be as short as possible with a view to avoiding longdistance movement of materials.
- Though similar machines are grouped in one department, the departments themselves should be located in accordance with the principle of sequence of operations. For example, in a steel plant, the operations are smelting, casting; rolling etc. These different departments may be arranged in that order to avoid crossovers and backtracking of materials.

Product Layout:

Also called the straight-line layout or layout for serialised manufacture. The product layout involves the arrangement of machines in one line depending upon the sequence of operations. Material is fed into the first machine and finished products come out of the last machine. In between, partly finished goods move from machine to machine. The output of one machine becoming the input for the next. In a sugar mill, sugar cane, fed at one end of the mill comes out as sugar at the other end. Similarly, in paper mill, bamboos are fed into the machine at one end and paper comes out at the other end.

In product layout, if there are more than one, line of production, there are as many, lines of machines. The emphasis here, therefore, is on special purpose machines in contrast to general purpose machines, which are installed in the process layout. Consequently, the investment on machines in a straight line layout is higher than the investment on machines in a functional layout.

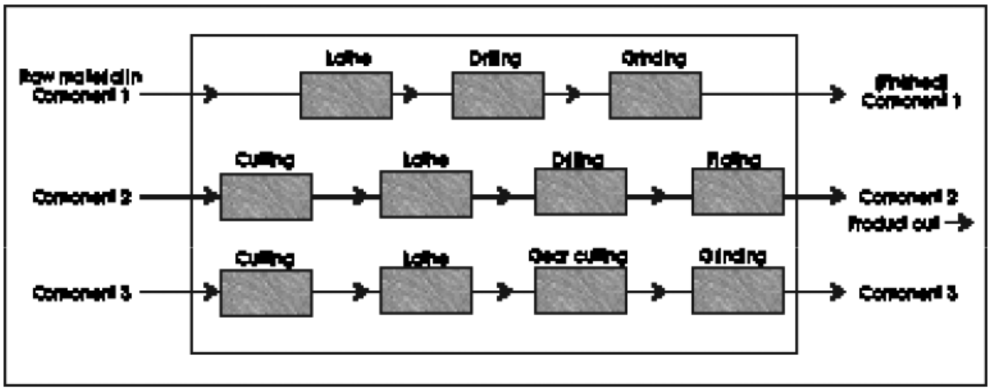


Figure 2.3: Product Layout

The grouping of machines should be done, on product line, keeping in mind the following principles:

- All the machine tools or other types of equipment must be placed at the point demanded by the sequence of operations.
- All the operations, including assembly, testing and packing should be, included in the line.
- Materials may be fed where they are required for assembly but not necessarily all at one point; and
- There should be no points where one line crosses another line;

The product layout may be advantageously followed in plants manufacturing standardised products on a mass scale such as chemical, paper, sugar, rubber, refineries and cement industries.

Layout in the form of Fixed Position:

As the term itself implies, the fixed position layout involves the movement of men and machines to the product which remains stationary. In this type of layout, the material or major component remains in a fixed location, and tools, machinery and men as well as other pieces of material are brought to this location. The movement of men and machines to the product is advisable because the cost of moving them would be less than the cost of moving the product which is very bulky.

Also called static layout, this type is followed in the manufacture, if bulky and heavy products, such as locomotives, ships, boilers, air crafts and generators.

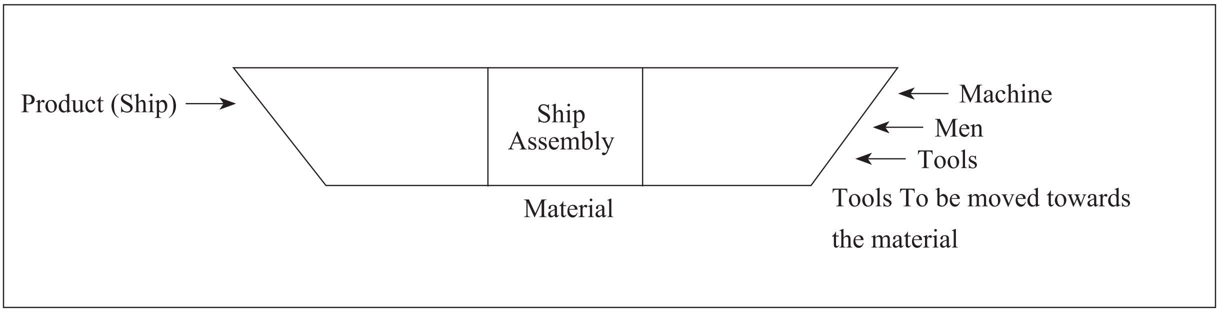


Figure 2.4: Fixed Position Layout

Mixed Layout or Combined Layout

The application of the principles of product layout or process layout in their strict meanings is difficult to come across. A combination of the product and process layouts, with an emphasis on either, is noticed in most industrial establishments. Plants are never laid out in either pure form. It is possible to have both types of layout in an efficiently combined form if the products manufactured are somewhat similar and not complex.

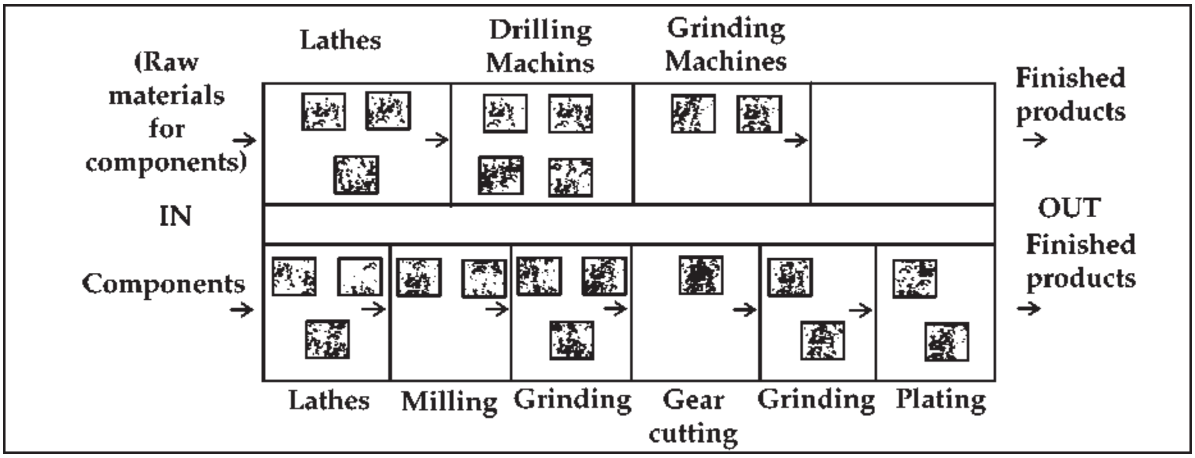


Figure 2.5: Component flow in combined layout

Layout of Service Facility:

The fundamental difference between service facility and manufacturing facility layouts is that many service facilities exist to bring together customers and services. Service facility layouts should provide for easy entrance to these facilities from freeways and busy thoroughfares. Large, well organized and amply lighted parking areas and well designed walkways to and from parking areas are some of the requirements of service facility layouts.

Because of different degree of customer contact, two types of service facility layouts emerge, viz., those that are almost totally designed around the customer receiving and servicing function (such as banks) and those that are designed around the technologies, processing of physical materials and production efficiency (such as hospitals).

Other facilities with reference to Plant Layout:

A plant layout involves, besides the grouping of machinery, an arrangement for other facilities as well. Such facilities include receiving and shipping points, inspection facilities, employee facilities and storage. Not all the facilities are required in every plant. The requirements depend on the nature of the product which is manufactured in a particular plant.

Importance of layout:

The importance of a layout can be described as under:

- **Avoidance of Bottlenecks:** Bottlenecks refer to any, place in a production process where materials tend to pile up or produced at rates of speed less rapid than the previous or subsequent operations. Bottlenecks are caused by inadequate machine capacity, inadequate storage space or low speed on the part of the operators. The results of bottlenecks are delays in production schedules, congestion, accidents and wastage of floor area. All these may be overcome with an efficient layout.
- **Avoidance of Unnecessary and Costly Changes:** *A* planned layout avoids frequent changes which are difficult and costly. The incorporation of flexibility elements in the layout would help in the avoidance of revisions.
- **Better Production Control:** Production control is concerned with the production of a product of the right type at the right time and at reasonable cost. A good plant layout is a requisite of good production control and provides the plant control officers with a systematic basis upon which to build organisation and procedures.
- **Better Supervision:** A good plant layout ensures better supervision in two ways: (a) Determining the number of workers to be handled by a supervisor and (b) Enabling the supervisor to get a full view of the entire plant at one glance. A good plant layout is, therefore, the first step in good supervision.
- **Economies in Handling:** Nearly 30 per cent to 40 per cent of the manufacturing costs are accounted for by materials handling. Every effort should, therefore, be made to cut down this cost. Long distance movements should be avoided and specific handling operations must he eliminated.
- **Effective Use of Available Area:** Every unit of the plant area is valuable, especially in urban areas. Efforts should therefore, be made to make use of the available area by planning the layout properly.
- **Improved Employee Morale:** Employee morale is achieved when workers are cheerful and confident. This state of mental condition is vital to the success of any organisation. Morale depends on better working conditions; better employee facilities; reduced number of accidents; and increased earnings.
- **Improved Quality Control:** Timely execution of orders will be meaningful when the quality of the output is not below expectations. To ensure quality, inspection should be conducted at different stages of manufacture. An ideal layout provides ample space to carryout inspection to ensure better quality control.
- **Improved Utilisation of Labour:** A good plant layout is one of the factors in effective utilisation of labour. It makes possible individual operations, the process and flow of materials handling in such a way that the time of each worker is effectively spent on productive operations.
- **Minimisation of Production Delays:** Repeat order and new customers will be the result of prompt execution of orders. Every management should try to keep to the delivery schedules by minimising delays in production.
- **Minimum Equipment Investment:** Investment on equipment can be minimised by planned machine balance and location, minimum handling distances, by the installation of general purpose machines and by planned machine loading. A good plant layout provides all these advantages.

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	–	–	–	–	–	–

Solution:

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.

Solution:

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

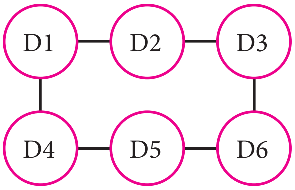
As 'ld' score of the proposed layout is lower than the existing one, there is an improvement in the new layout.

Facility Layout Decision

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 fro 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.

Soluton:

We notice quite obviously that from Di to Di (i = 1, 2….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

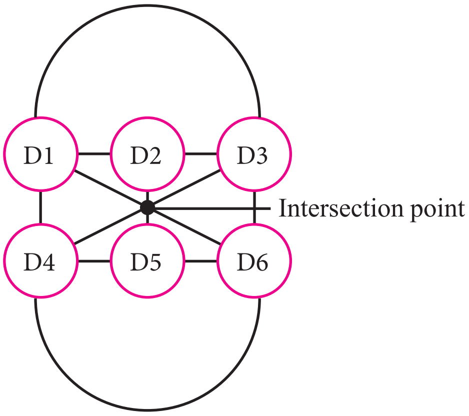
Let us now take another pair, e.g., D4 and D2

Movement	Avg traffic
D4 →D2	10 (red circle)
D2 →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.



Looking at the diagram we can find the adjacent and non-adjacent pairs.

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

Let us now concentrate on the non-adjacent pairs

Non-adjacent Pair	Distance
D1 & D3	(D1 → D2; D2 → D3) D1 → D3 : 2 nodal points Hence, distance is 2
D1 & D6	D1 → D6 = D1 → P & P → D6 Distance = 2
D3 & D4	D3 → D4 = D3 → P & P → D4 Distance = 2
D4 & D6	D4 → D6 = D4 → D5 & D5 → 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.

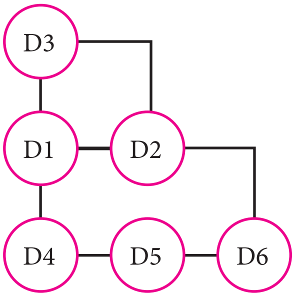
Non-adjacent Pair	Load distance
D1 & D3	30 × 2 = 60
D3 & D4	25 × 2 = 50
D1 & D6	6 × 2 = 12
D4 & D6	7 × 2 = 14
	Total = 136

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

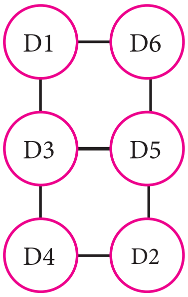


The revised non-adjacent pairs and load distance calculation is given below

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_1D_4	2	0	0
D_6D_2	2	8	16
D_1D_2	2	18	36
D_6D_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.

Resource Aggregate Planning

2.4

Production planning in the intermediate range of time is termed Aggregate Planning. It is the process of planning the quantity and timing of output over the intermediate time horizon (3 months to one year).

It is thus called because the demand on facilities and available capacities are specified in aggregate quantities e.g aggregate quantitates of thousands of litres of paint or no of automobiles etc. That is in aggregate planning the total expected demand is measured without regard to the product mix (Maruti Dzire, Maruti Alto, Maruti Swift etc) that makes up this figure.

For this planning horizon the physical plant and equipment and its capacity are fixed. So the sales orders have to be met by different strategies.

Steps in aggregate planning:

- Development of some logical overall unit for measuring output----gallons of paint in paint industry, rooms occupied in hotel etc.;
- Forecast of demand for the planning period;
- Identification and measurement of Relevant costs;

Aggregate planning increases the range of alternative use for capacity for management for getting answers to following type questions:

- To what extent should inventory be used to absorb the fluctuations in demand that will occur over the next 6 to 12 months?
- Why not maintain a fairly stable work force size and absorb the fluctuations by changing activity rates by varying work hours?
- Why not maintain a fairly stable work force and let subcontracts be engaged for demand fluctuations?

If demand for a company's products or services are stable over time or its resources are unlimited, the aggregate planning is trivial. Under this case---

- Demand forecasts are converted to resource requirements;
- Resources necessary to meet demand over the time horizon are acquired;
- Minor variations in demand are handled with overtime or under time;

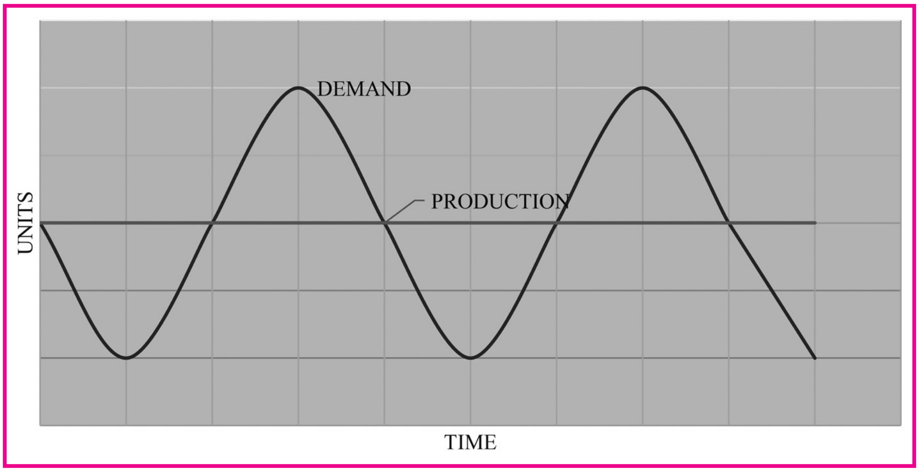
But Aggregate Resource Planning becomes a challenge when demand fluctuates over the planning horizon. Under this case alternatives are---

- Producing at a constant rate and using inventory to absorb fluctuations in demand (level production);
- Hiring and firing workers to match demand (chase demand);
- Maintaining resources for high demand levels;

- Increasing or decreasing working hours (overtime and under time);
- Subcontracting work to other firms;
- Using part time workers;
- Providing the service or product at a later time period (backordering);

When one of these is selected, a company is said to have a Pure Strategy for meeting demand. When two or more are selected, a company has a Mixed Strategy.

Level Production: Refer following figure.

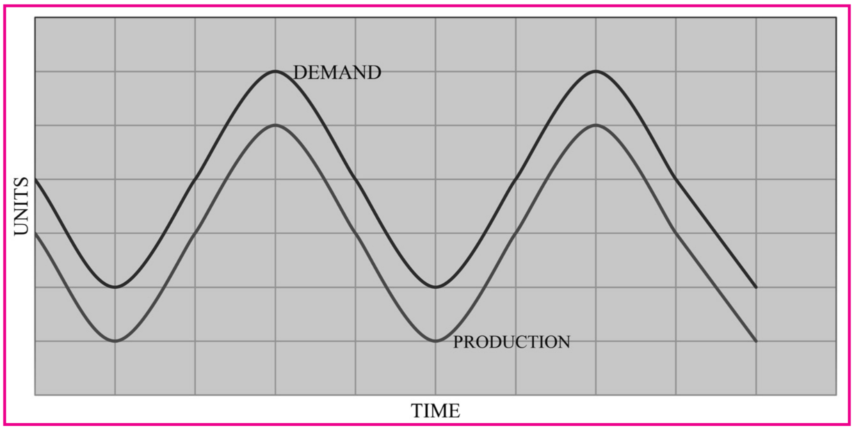


Level production sets production at a fixed rate (usually to meet average demand) and uses inventory to absorb variations in demand. During periods of low demand, overproduction is stored as inventory, to be depleted in periods of high demand. The cost of this strategy is the cost of holding inventory, including the cost of obsolete or perishable items that may have to be discarded.

Chase Demand: Refer the following figure

It matches the production plan to the demand pattern and absorbs variations in demand by hiring and firing workers.

During periods of low demand production is cut back and workers are laid off. During periods of high demand production is increased and additional workers are hired. The cost of this strategy is the cost of hiring and firing workers.



When skilled labour is scarce or when competition for labor is intense, this strategy is not applicable. During period of high unemployment and for industries requiring low skilled labours, this strategy is very much applicable.

Maintaining resources for high demand levels ensures high levels of customer service but very costly in terms of the investment in extra workers and machines that remain idle during low demand period. This strategy is most suitable when superior customer services are required and to get this customers are ready to pay extra for the availability of critical staff or equipment.

When demand fluctuations are not extreme Overtime/Under-time are common strategies. Under this strategy a competent staff is maintained, hiring and firing costs are avoided and demand is met temporarily without investing in permanent resources. Disadvantages include the premium paid for the overtime. But overtime alone may not be sufficient to meet the peak demand and overtime premium may be enjoyed by less efficient and tired workforce.

Subcontracting or outsourcing is a feasible alternative if a reliable supplier is available both in terms of quality and time for supply. This is a very common strategy when demand of final products exceeds expectations and required components are to be made ready through outsourcing to meet the demand. This strategy needs a strong tie with possible subcontractors and first-hand knowledge of their work. Disadvantages of subcontracting include reduced profits, loss of control over production, long lead times and the potential that the subcontractor may become a future competitor.

Using part time workers is feasible for unskilled jobs or in areas with large temporary labour pools (such as students, home makers etc.). Part time workers are less costly than full time workers and they have more flexibility so far as working hours and time are concerned.

Backordering is a viable alternative only if the customer is willing to wait for the product or service.

One aggregate planning strategy is not always preferable to another. The most effective strategy depends on the demand distribution, competitive position and cost structure of the firm or product line. Mixed strategy, the combination of strategies, rather than a single strategy, usually results in the most economical plan.

Each of these strategies has a cost factor associated with it. Some of the cost items that may be relevant are:

- Payroll costs;
- Costs of overtime, second shifts and subcontracting;
- Costs of hiring and laying off workers;
- Costs of excess inventory and backlog;
- Costs of production rate changes;

The cost items that are to be included in the strategy should vary with changes in the decision variables. If a cost item such as the salary of a manufacturing manager is incurred no matter which aggregate plan is chosen, then this cost is excluded from consideration.

Aggregate planning guidelines:

- Determine corporate policy regarding controllable variables.
- Use a good forecast as a basis for planning.
- Plan in proper units of capacity.

- Maintain the stable workforce.
- Maintain needed control over inventories.
- Maintain flexibility to change.
- Respond to demand in a controlled manner.
- Evaluate planning on a regular basis.

Properties of Aggregate Planning:

- 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 litres 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.
- Facilities that are considered fixed to carry out the objective.

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 ₹ 150 per unit to increase production rate ₹ 200 per unit to decrease the production rate, ₹ 50 per unit per quarter to carry the items in inventory and ₹100 per unit if subcontracted. Compare the costs of the pure strategies.

Solution:

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 (₹)	Cost of decreasing Production level (₹)	Total cost of plan (₹)
1	270	—	—	—
2	220	—	50 × 200 = 10,000	10,000
3	470	250 × 150 = 37,500	—	37,500
4	670	200 × 150 = 30,000	—	30,000
5	450	—	220 × 200 = 44,000	44,000
6	270	—	180 × 200 = 36,000	36,000
7	200	—	70 × 200 = 14,000	14,000
8	370	170 × 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 ₹ 96,500.

Quar-ter	Demand forecast	Cumu lative demand	Production level =Av. demand =2920÷8	Cumu. prod. level	Inventory = (Cum. Production – Cum. Demand)	Adjusted inventory with 255 at beginning of period 1	Cost of holding inven-tory (₹)
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 ₹ 1,32,000 as shown in table below.

Quarter	Demand forecast	Production units	Subcontract units	Incremental cost @ ₹ 100/units
1	270	200	70	70 × 100 = 7,000
2	220	200	20	20 × 100 = 2,000
3	470	200	270	270 × 100 = 27,000
4	670	200	470	470 × 100 = 47,000
5	450	200	250	250 × 100 = 25,000
6	270	200	70	70 × 100 = 7,000
7	200	200	0	0
8	370	200	170	170 × 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 (₹)
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 cast estimated at ₹12000. If the unit cost is ₹100 each to produce, carrying cost per year are 20% of the average inventory value and storage cost (based upon maximum inventory) are ₹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 ₹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 ₹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.

Solution:

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 = 140 units/day

(b) Inventory Balance = ∑Production – ∑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 × 460×100 = 9200

Storage Cost = 900 × 0.90 = 810

Inventory Cost = ₹10010

Solution to Plan 2 (Varying Employment):

₹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%) (₹100) /12 Months = ₹**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 1.

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 = ₹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 = ₹107 – ₹100 = ₹7 per unit

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

The total Cost of Plan 3 = Inventory Cost + Sub-contracting cost = 1952 + 7000 = ₹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., ₹1952 and Marginal cost of Overtime = 1000 units × rate of ₹10 per unit = ₹10,000

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

Table: Comparison of Plans

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

Material Requirements Planning

2.5

In this issue we will discuss on Material Requirement Planning (MRP).

Material Requirement Planning is a methodology used for planning the production of assembled products.

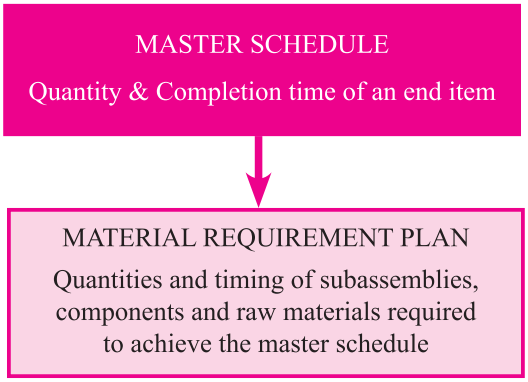
It is a computerised inventory control system that would facilitate determination of demand for component items, keep track of when they are needed and generate work orders and purchase orders that take into account the lead time required to make the item in-house or buy them from a supplier.

MRP begins with a Master Schedule.

Master Schedule designates the quantity and completion time of an assembled product, often referred to as end item.

This Master schedule for end items is translated into time-phased requirements for subassemblies, components and raw material.

The main objective of any inventory system is to ensure that material is available when needed. MRP does this by determining when component items are needed and scheduling them to be ready at that time, no earlier and no later.



MRP answers three questions—

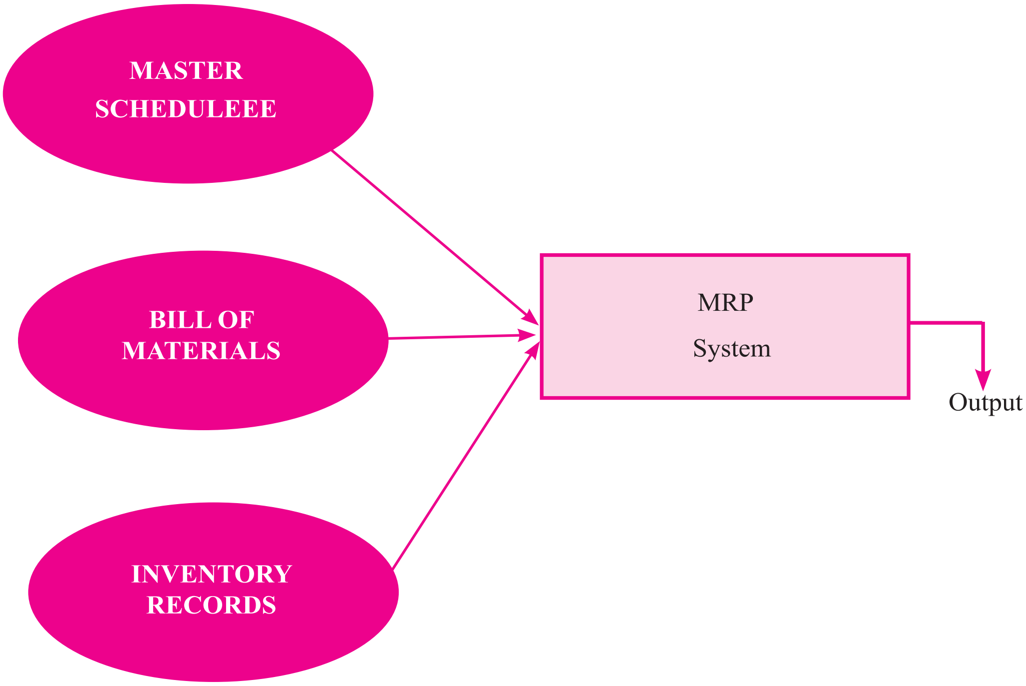
- What is needed
- How much is needed
- When is it needed

An MRP system has three major sources of information---

☐ A master schedule

☐ A bill of materials

☐ An inventory record



Master Schedule also called master production schedule states—

☐ which end items are to be produced

☐ when they are needed

☐ in what quantities

A Bill of Materials contains---

☐ a listing of all the assemblies, subassemblies, parts & raw materials that are needed to produce one unit of an end items

EACH TYPE of FINISHED PRODUCT has its own Bill of materials

Inventory Records refer to---

☐ stored information on the status of each item by time periods i.e.

- Information on quantities on hand
- Information on quantities ordered
- Information on supplier, lead time and lot size policy etc.

MRP Objectives:

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

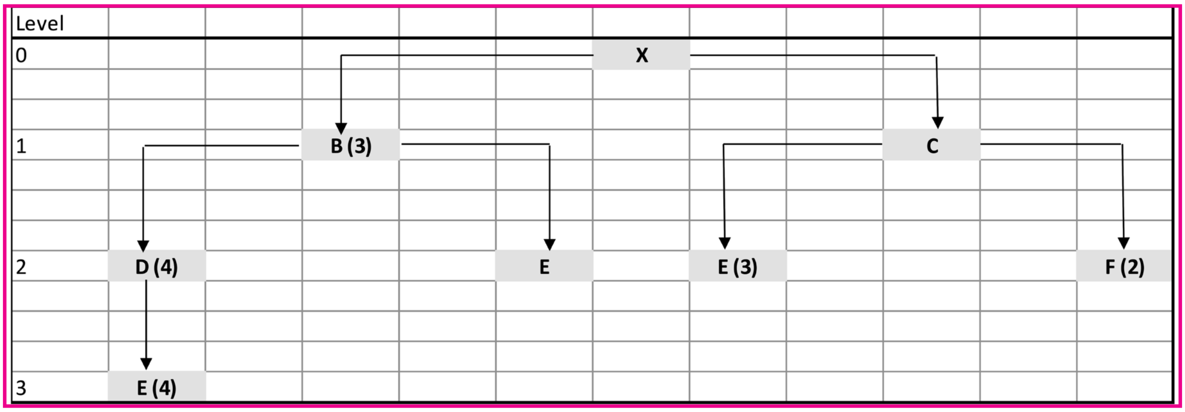
Advantages:

- Reduced inventory,
- Reduced idle time,
- Reduced set up time,
- Ability to change the master production schedule,
- Ability to price more competitively,
- Better customer service,
- Better response to market demands,
- Reduced sales price.

Disadvantages:

- Lack of top management commitment. MRP must be accepted by top management as a planning tool with specific reference to profit results.
- MRP was presented and perceived as a complete and stand-alone system to run a firm, rather than as part of the total system.
- The issue of how MRP can be made to function with just-in-time production system.
- MRP also needs a high degree of accuracy for operation

Example 1: Refer the following figure:



(a) Determine the quantities of B, C, D, E and F needed to assemble one unit of X

(b) Determine the quantities of these components that will be required to assemble 10 units of X taking into account the quantities on hand (i.e. in inventory) of various components as

Component	On Hand
B	4
C	10
D	8
E	60
F	30

Answer: The figure given above is called Product Structure Tree.

To initiate an MRP we know that input information comes from Master Schedule followed by Bills of Materials and Inventory record.

Now the listing in the bill of materials is hierarchical—it shows the quantity of each item needed to complete one unit of its parent item. This aspect of bill of materials is clear when we construct a Product Structure Tree as above which provides a visual depiction of the subassemblies and components needed to assemble a product.

From Master Schedule we gathered the information that we require one unit of end item X. From Bill of materials we collected following information:

☐ End item X is composed of three Bs and one C

☐ Each B requires four Ds and one E

☐ Each D requires four Es

☐ Each C requires three Es and two Fs

These requirements are listed by level beginning with 0 (available from Master Schedule) for the end item, then 1 for the next level and so on. The items at each level are components of the next level up. The quantities of each item in the product structure tree refer only to the amounts needed to complete the assembly at the next higher level---4 units of E required to complete one unit of D or 4 units of D required for one unit of B etc. So following this knowledge through product structure tree of our problem the total requirement of components for producing one unit of end item X are given below:

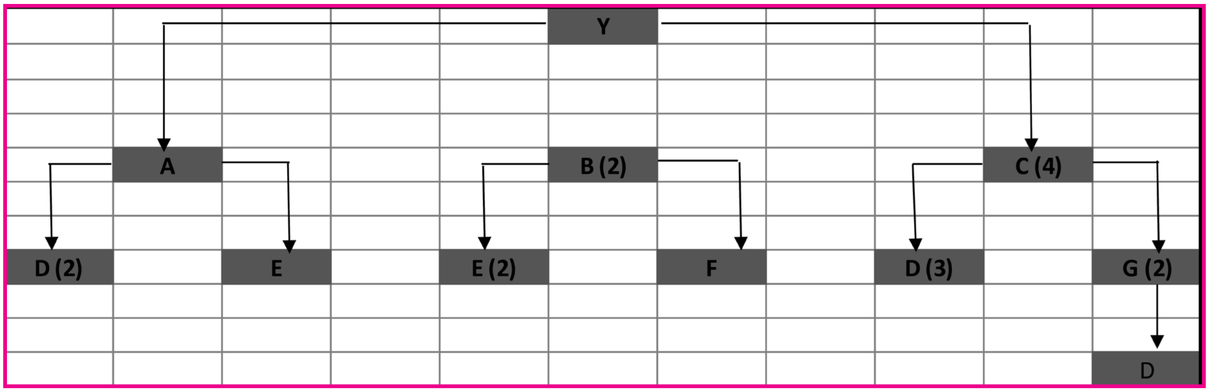
	B	C	D	E	F
1 unit of X requires	3	1			
3 units of B requires			3*4=12	3*1=3	
12 units of D requires				12*4=48	
1 unit of C requires				1*3=3	1*2=2
Total Requirement	3	1	12	54	2

These are the requirement for producing one unit of X. Now inventory records as given in 2nd table of the question is considered and actual requirement for producing 10 units of X will be as follows:

	B	C	D	E	F
Total requirement for 1 unit of X	3	1	12	54	2
Total requirement for 10 units of X	30	10	120	540	20
Less inventory on hand	4	10	8	60	30
Actual requirement now	26	0	112	480	0

At present No F is required as in hand stock (30) is more than the requirement for producing 10 units of X (20)

Example 2: The following product structure tree indicates the components needed to assemble one unit of Product Y. Determine the quantities of each component needed to assemble 100 units of W considering the inventory records.



Inventory records are

Component	On Hand
A	5
B	15
C	7
D	75
E	40
F	20
G	12

Answer: Assuming the items at each level of product structure tree are components of the next level up & the quantities of each item in the product structure tree refer only to the amounts needed to complete the assembly at the next higher level, the basic requirement of components for producing 1 unit of Y are as follows:

	A	B	C	D	E	F	G
1 unit of Y requires	1	2	4				
3 units of A requires				1*2=2	1		
2 units of B requires					2*2=4	2*1=2	
4 unit of C requires				4*3=12			4*2=8
8 unit of G requires				8*1=8			
Total Requirement	1	2	4	22	5	2	8

After considering the inventory records the actual requirement for producing 100 units of Y are:

	A	B	C	D	E	F	G
Total requirement for 1 unit of Y	1	2	4	22	5	2	8
Total requirement for 10 units of Y	100	200	400	2200	500	200	800
Less inventory on hand	5	15	7	75	40	20	12
Actual requirement now	95	185	393	2125	460	180	788

Determining total requirements is usually more complicated than illustrated above. Because---

- Many products have considerably more components and have a complicated Bills of Material
- Issue of timing i.e. when must the components be ordered or made is essential and must be included in analysis

Before application of MRP it is to be fully ensured that the bill of materials accurately reflect the composition of a product as errors at one level become magnified by the multiplication process used to determine quantity requirements.

Like the bill of materials inventory records must also be accurate as erroneous information on requirements can have detrimental impact.

MRP is useful for dependent demand items. The demand for component parts does not have to be forecasted. It can be derived from the demand for the finished product. e.g. suppose demand for a car, consisting of four doors and one engine, is 500/week. Then demand for door-component will be 4*500 =2000/week and demand for engine-component will be 1*500 =500. The demand for door and engine are called derived demand for determining of which we use MRP as discussed in our simple illustrations.

Advantages:

- Reduced inventory,
- Reduced idle time,
- Reduced set up time,
- Ability to change the master production schedule,
- Ability to price more competitively,
- Better customer service,
- Better response to market demands,
- Reduced sales price.

Disadvantages:

- Lack of top management commitment. MRP must be accepted by top management as a planning tool with specific reference to profit results.
- MRP was presented and perceived as a complete and stand-alone system to run a firm, rather than as part of the total system.
- The issue of how MRP can be made to function with just-in-time production system.
- MRP also needs a high degree of accuracy for operation

Manufacturing Resource Planning

2.6

Manufacturing Resource Planning (MRP II) has been developed to facilitate manufacturing managers address the planning and controlling of a manufacturing process and all of its related support functions. It encompasses logically correct planning and control activities related to materials, capacity, finance, engineering, sales and marketing. MRP II is universally applicable to any manufacturing organisation regardless of its size, location, product or process.

MRP II is a management process for taking the business plan and breaking it down into specific, detailed tasks that people evaluate, agree upon and are held accountable for. It involves all departments viz., materials department, engineering department that must maintain bill of materials, sales/marketing department that must keep sales plan upto date, purchasing and manufacturing departments that must meet due dates for bought out items and in-house manufactured items respectively.

From MRP I to MRP II : Manufacturing resource planning (MRP II) is a natural outgrowth of Materials Requirement Planning (MRP I) Whereas MRP I focuses upon priorities of materials, CRP is concerned with time. Both material and time requirement are integrated within the MRP system *[i.e.,* MRP I). Beyond this, MRP II has been coined to 'close the loop' by integrating financial, accounting, personnel, engineering and marketing information along with the production planning and control activities of basic MRP systems. MRP II is the heart of corporate management information system for many manufacturing firms.

Evolution of MRP II

The earlier resource requirement planning systems were quite simple and unsophisticated. The MRP technique was used for its most limited capability to determine what materials and components are needed, how many are needed and when they are needed and when they should be ordered so that they are likely to be available when needed. In other words, MRP simply exploded the MPS into the required materials and was conceived as an inventory control tool or a requirements calculator. Later the logic of MRP technique was extended to serve as the key component in an information system for planning and controlling production operation and purchasing. It was helpful to production and operations managers to determine the relative priorities of shop orders and purchase orders. As a manufacturing planning and controlsystem, MRP laid the basic foundation for production activity control or shop-floor control.

Economic Batch Quantity

2.7

Production managers often have to decide what quantity of output must be produced in a batch (known as lot size or batch size). The products are manufactured in lot sizes against the anticipated demand for the products. Often the quantity produced may exceed the quantity which can be sold. (i.e., production rates exceed demand rates). The optimum lot size which is known as economic lot size or Economic Order Quantity or economic batch quantity or economic manufacturing quantity is that quantity of output produced in one batch, which is most economical to produce, i.e., which results in lowest average cost of production.

Determination of Economic Lot Size for Manufacturing:

The factors to be considered in arriving at the economic lot size are:

(i) **Usage rate:** The rate of production of parts should match with the rate of usage of these parts in the assembly line.

(ii) **Manufacturing cost:** Higher the lot size, lower will be the cost per unit produced because of distribution of set up costs for setting up production or machines and preparing paper work (production orders). But the carrying cost (handling and storing costs) will increase with increase in lot size.

(iii) **Cost of deterioration and obsolescence:** Higher the lot size, higher will be the possibility of loss due to deterioration (items deteriorating after shelf life) or obsolescence (due to change in technology or change in product design).

Before deciding on production using economic lot sizes, the availability of production capacity to produce the product in economic lot size must be verified. The economic lot size balances the two opposing costs related to batch size i.e., setup cost for production and the inventory carrying costs resulting from inventory of products produced when production rate exceeds usage rate or when the items produced are not immediately consumed in the next stage of production. The set up cost per unit decreases with increase in lot size whereas the inventory carrying cost increases with increase in lot size. Diagram below illustrates the concept of economic batch quantity or economic lot size or Economic Order Quantity.

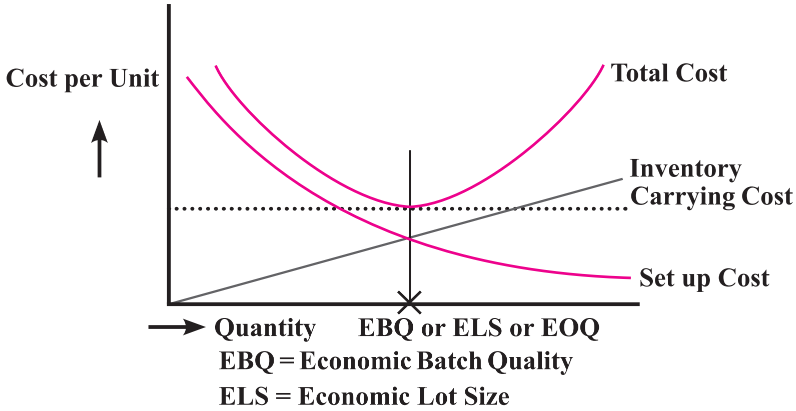


Figure 2.6: Economic Lot Size

If S is the set up cost per set up also known as Ordering Cost, 'C' is the production cost per unit produced and I is the inventory carrying or holding changes (%) and A is the annual demand for the item in units, then,

Economic Batch Quantity (EBQ) or Economic Order Quantity (EOQ)

or Economic Lot Size (ELS)

or Economic Manufacturing Quantity (EMQ)

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

Economic Run Length: When a firm is producing an item and keeping it in inventory for later use, instead of buying it, the formula used to calculate economic order quantity (EOQ) can be used to calculate the economic production quantity referred to as Economic Run Length (ERL).

If 'p' is the production rate and 'd' is the demand rate (or consumption rate), A is the annual demand for the item in units, I is the inventory carrying charges (percentage), C is the production cost per unit, then,

$$\text{Economic Run Length (ERL)} = \sqrt{\frac{2AS}{C1\left(1 - \frac{d}{p}\right)}}$$

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

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 ₹ 2 per unit. The purchase price of raw material is ₹ 20 per unit. The ordering cost is ₹ 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?

Solution:

We are given that,

A = Annual demand = 3,000 × 12 = 36,000 units per annum ; S = Ordering Cost = ₹ 25;

C = Inventory carrying cost = 2 + 20% of ₹ 20 = 2 + 4 = ₹ 6

(i) EOQ = $\sqrt{\frac{2AS}{C}} = \sqrt{\frac{2 \times 36000 \times 25}{6}} = \sqrt{3,00,000}$ = 548 units (approx.)

Total cost = Ordering Cost + Cost of purchasing the material + Storage cost

= (36,000 / 548) × 25 + (36,000 × 20) + (548/2) × 6 [∵ Storage cost = Average Inventory × Inventory carrying cost

= ₹ 1642.33 + 7,20,000+ 1,644 = ₹ 7,23,286. = $\frac{EOQ}{2}$ × 6]

(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 ₹ 20 = ₹ 19.

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

EOQ = $\sqrt{\frac{2 \times 36000 \times 25}{5.80}} = \sqrt{\frac{18,00,000}{5.80}}$ = 557 units app.

Total cost = (36,000/557) × 25 + (36,000 × 19) + (557/2) × 5.80

= ₹ (1,615.79 + 6,84,000 + 1,615.30) = ₹ 6,87,231.09

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

EOQ = 557 units

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

No. of orders per month = $\frac{N}{2} = \frac{36000 / 557}{12}$ = 5.385 = 6 (say) = N*

Quantity to be orderd per month = N* × EOQ = 6 ×557 = 3342 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 ₹ 20 (because 10% concession)

= ₹ 18; A = 36,000 units per annum; S = ₹ 25; C = 2 + 20% of ₹ 18

= 2 + 3.60 = 5.60

EOQ = $\sqrt{\frac{2AS}{C}} = \sqrt{\frac{2 \times 36000 \times 25}{5.60}}$ = 567 units app.

For monthly order quantity more than or equal to 6000 units

EOQ = 567 units

No of orders per month = $\frac{36000 / 567}{12}$ = 5.29 = 6 (say) = N*

Qty. to be ordered per month = N* ×EOQ = 6×567 = 3402 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 = ₹ 6,64,950

Hence the total cost will be minimum (₹ 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	₹ 100 per order
Inventory carrying cost	2% per annum
Cost of tubes	₹ 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	2 – 6 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.

Solution:

(1) Economic Order Quantity:

Annual usage of tubes (A) = Normal usage per week × 52 weeks

= 100 tubes × 52 weeks

= 5,200 tubes.

Ordering cost per order (S) = ₹ 100.

Inventory carrying cost per unit per annum (C) = 2% of ₹ 500 = ₹ 10.

$\text{EOQ} = \sqrt{\frac{2AS}{C}} = \sqrt{\frac{2 \times 5{,}200 \text{ units} \times 100}{10}} = 322 \text{ units (approx.)}.$

(A) Evaluation of order size of 1,500 units at 5% discount

No. of orders $= \frac{5{,}200 \text{ units}}{1{,}500 \text{ units}} = 3.46$ or 4 (in case of a fraction, the next whole number is considered).

	₹
Ordering cost (No. of order per year at ₹ 100 per order)	400
Carrying cost of average inventory:	
$\frac{1{,}500 \text{ units}}{2} \times ₹ \ (500 \text{ less } 5\%) \times \frac{20}{100}$	71,250
Total annual cost (excluding item cost)	71,650

(B) Annual cost if EOQ (102 units) is adopted :	₹
Ordering cost: 5,200 ÷ 102 or 51 orders per year at ₹100 per order	5,100
Carrying cost of average inventory $\frac{102 \text{ units}}{2} \times ₹ \ 500 \times \frac{20}{100}$	5,100
Total annual cost (excluding item cost)	10,200

Increase in annual cost by adopting (A) above : ₹ (71,650 – 10,200) = ₹ 61,450.

Amount of quantity discount: 5% × ₹ 500 × 5,200, units = ₹ 1,30,000.

Since the amount of quantity discount (₹ 1,30,000) is more than the increase in total annual cost (₹ 61,450), it is advisable to accept the offer. This will result in a saving of ₹ (1,30,000 - 61,450) or ₹ 68,550 p.a. in inventory cost.

(2) Maximum Level of Stock:

= Re-order level + Re-order quantity – (Minimum usage × Minimum delivery period) = 1,200 units + 322 units – (50 units × 2 weeks) = 1,422 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 × Normal delivery period) [see Note] = 1,200 units – (100 units × 4 weeks) = 800 units. Note: Normal delivery period is taken to be the average delivery period.

(4) Re-order Level of Stock:

= Maximum usage × Maximum delivery period = 200 units × 6 weeks = 1,200 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 ₹ 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.

Solution:

(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 $= \frac{\text{FBQ}}{\text{Monthly output}} \times 30$

$$= \frac{3600}{24{,}000 \div 12} \times 30 = 54 \text{ Calendar days}$$

(c) Minimum inventory holding cost = Average inventory × Annual carry-ing cost of one unit of inventory

= (3600 ÷ 2) × 0.10×12 = ₹ 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 ₹30 lakh, ₹50 lakh, and ₹25 lakh per annum respectively. The variable costs are ₹300, ₹200 and ₹350 per unit respectively.

The expected sales price of the cooking range is ₹700 per unit Find out:

(i) The range of annual production/sales volume for which each location is most suitable and

(ii) Which one of the three locations is the best location at a production/sales volume of 18,000 units?

Solution:

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 (₹)	30,00,000	30,00,000	30,00,000	30,00,000	30,00,000
Variable Cost (₹ 300 x)	300 (5,000)	300 (10,000)	300 (15,000)	300 (20,000)	300 (25,000)
Total Cost (₹)*	= ₹45 lakhs	= ₹60 lakhs	= ₹75 lakhs	= ₹90 lakhs	= ₹105 lakhs

(ii) Ranchi

Volume (x Units)	5,000	10,000	15,000	20,000	25,000
Fixed Cost (₹)	50,00,000	50,00,000	50,00,000	50,00,000	50,00,000
Variable Cost (₹ 200 x)	200 (5,000)	200 (10,000)	200 (15,000)	200 (20,000)	200 (25,000)
Total Cost (₹)*	= ₹60 lakhs	= ₹70 lakhs	= ₹80 lakhs	= ₹90 lakhs	= ₹100 lakhs

(iii) Dhanbad

Volume (x Units)	5,000	10,000	15,000	20,000	25,000
Fixed Cost (₹)	25,00,000	25,00,000	25,00,000	25,00,000	25,00,000
Variable Cost (₹ 300x)	350 (5,000)	350 (10,000)	350 (15,000)	350 (20,000)	350 (25,000)
Total Cost (₹)*	= ₹42.5 lakhs	= ₹60 lakhs	= ₹77.5 lakhs	= ₹95 lakhs	= ₹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 = ₹84 lakhs

Ranchi => 50,00,000 + 200 × 18,000 = ₹86 lakhs

Dhanbad => 25,00,000 + 350 × 18,000 = ₹88 lakhs.

Illustration 20

Monthly demand for a component is 1000 units. Setting-up cost per batch is ₹ 120. Cost of manufacture per unit is ₹ 20. Rate of interest may be considered at 10% p.a. Calculate the EBQ.

Solution:

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 2023 and 2024.

Year	No. of items (‘000)
2014	13
2015	20
2016	20
2017	28
2018	30
2019	32
2020	33
2021	38
2022	43

Solution:

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 ΣX2. If we arrange X in such a way that ΣX = 0, it will simplify our calculations. Therefore, we call the year 2018 as 0, 2017 as -1 and 2019 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
ΣX = 0	ΣY = 257	$\Sigma x^2 = 60$	ΣXY - 204

Let the equation of the best fit straight line to the given data be $Y = a_0 + a_1 x$

So the normal equations are

$\Sigma Y = a_o N + a_1 \Sigma X$ .... (1)

$\Sigma XY = a_o \Sigma X + a_1 \Sigma X^2$ .... (2)

As ΣX = 0, from (1) $\Sigma Y = a_o N$ from (2) $\Sigma XY = a_1 \Sigma X^2$

Therefore, $a_o = \Sigma Y / N = 257 / 9 = 28.56$ [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 2023, (i.e., X = 5): Y = 28.56 + 3.4 (5) = 45.56 ('000) nos.

(b) Forecast for 2024, (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) = ₹5 per order

Holding cost(H) = ₹1.25 per unit per year.

Lead time (L) = 5 days

Cost per unit (C) = ₹ 12.50

What quantity should be ordered?

Solution:

$$\text{EOQ} = \sqrt{\frac{2DS}{H}} = \sqrt{\frac{2 \times 1000 \times 5}{1.25}} = \sqrt{8,000} = 89.44 \text{ units}$$

$$\text{Re-order unit} = \quad dL = \frac{1000}{365} \times 5 = 13.7 \text{ units}$$

$$\text{Total Cost} = DC + \frac{D}{Q} \times S + \frac{Q}{2} \times H = 1000\times12.5 + (1000/89.44)\times5 + (89.44/2)\times1.25 = ₹2611.81$$

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 =25units and lead time = L=15 days. Determine the reorder point. Assume the demand is over a 250 week day year.

Solution:

d = D/no. week days = 1000/250 = 4

Re-order level(R) = dL + z L = 4×15 + 1.64 × 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 ₹ 10 and annual holding costs are ₹ 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.

Solution:

$$\text{EOQ} = \sqrt{\frac{2DS}{H}} = \sqrt{\frac{2\times(60\times365)\times10}{0.5}} = \sqrt{876000} = 936 \text{ units}$$

$$\sigma_1 = \sqrt{\sum_{i=1}^{L} \sigma_d^2} = \sqrt{6 \times 7^2} = 17.15$$

Re-order leve (R) = dL + z6L = 60×6 + 1.64 × 17.15 = 388

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.

Solution:

$$Q = d(T+L) + z\sigma_{T+L} - I = 10(30+14) + \tau\, \sigma_{T+L} - 150$$

$$\sigma_{T+L} = \sqrt{\sum_{i=1}^{TL} \sigma_d^2} = \sqrt{(T+L)\sigma^2_T} = \sqrt{(30+40)\times3^2} = 19.90$$

T for P = 0.98 is 2.05

Q = 10 (30+14)+ 2.05×19.9 - 150 = 331 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?

Solution:

Avg. Inventory = Q/2 + SS = 150 + 40 =190

$$\text{Inventory Turn} = \frac{D}{\frac{Q}{2}+SS} = \frac{1000}{190} = 5.263 \text{ tern per year}$$

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?

Solution:

Avg. Inventory = dT/2 + SS = (50 × 3)/2 + 30 = 105 units

$$\text{Inventory Turn} = \frac{52d}{\text{Avg Inventory}} = \frac{52\times50}{105} = 24.8 \text{ turns per year}$$

Illustration 28

Price Break Problem

Consider the following case, where

D = 10000 units (annual demand)

S = ₹ 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, ₹5.00 per unit; 500 to 999 units, ₹4.50 per unit; 1000 and up, ₹3.90 per unit)

What quantity should be ordered?

Solution:

$$\text{EOQ1} = \sqrt{\frac{2DS}{iC}} = \sqrt{\frac{2\times 10000\times20}{20 \times 5}} = 63.24$$

$$\text{EOQ2} = \sqrt{\frac{2\times 10000\times 20}{20 \times 4.5}} = 66.67$$

$$\text{EOQ3} = \sqrt{\frac{2\times 10000\times 20}{20 \times 3.9}} = 71.6$$

$$\text{Total Cost1} = DC + \frac{D}{Q} \times S + \frac{Q}{2}\times iC = 56323$$

TC2 = 51000

TC3 = 44585.69

1000 units should be ordered.

Illustration 29

A product is priced to sell at ₹100 per unit, and its cost is constant at ₹70 per unit. Each unsold unit has a salvage value of ₹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 follow.

Number of Units Demanded	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?

Solution:

The cost of underestimating the demand is loss of profit (Cu) or 100-70=30/unit.The cost of overestimating demand is the loss inoccured when the unit must be sold at salvage value(Co)=70-20=50

The optimal prob. Of not being sold

P<= Cu/Co + Cu = 30/30 + 50 = 0.375

From the data, this corrosponds 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

9. 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?

Solution:

$S.D = \sqrt{21(5)\times(5)} = 23$

$Z = 1.64$

$q = d\times(T + L) + Z\times S.D\text{-}I$

$= 20(14 + 7) + 1.64\times23\text{-}180$

= 278 units

Illustration 31

10. 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 (₹)	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	₹ 233450	100%

Solution:

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%

Designing of Operational System and Control

3

This Module Includes

Designing of Operational Systems and Control

SLOB Mapped against the Module

To attain knowledge on techniques and tools to be applied for product and process designing, capacity planning andproduction line balancing; and job designing; in operations management.

Module Learning Objectives:

After studying this module, the students will be able to:

- Identify the factors and importance of Product design.
- Understand the Product life cycle.
- Comprehend the importance of process strategy

Product Design

3.1

Product is an important part of the fundamental marketing mix. Customers pay for the products that best fulfil their requirement and provide them the desired value. The attributes and quality of the product triggers the demand which in turn is a reason for the existence of the value chains and hence organizations. Therefore, designing a product is an important strategic decision. Product design is a collection of interdependent directional activities that are planned and executed in a structured and planned way to develop the value propositions to be offered to the end customers for fulfilling their needs. Therefore, the basic objectives of product design include

- To develop the products as per the needs of the end customer with an objective to provide optimum value
- To minimize the cost, and lead time (i.e., design to market)
- To maximize resource utilization

Importance of Product design:

(a) To establish detailed characteristics (i.e., core and augmented) of the products in line with market demand and competitions.

(b) To provide the technical requirements for defining the technological requirements and processes

(c) To provide a guideline for production system design

(d) To provide necessary impetus to production and operations strategy

A good product design enables the organizations to stay ahead of the competition and sustain in this VUCA world and helps to build long-term relationship with the end customers. Product design has an indirect impact on employment too. In other words, a distinctive product design stands as an order winning criteria for the organizations. Some of the attributes of a good design are user-friendliness, features, aesthetics, reliability, durability, innovativeness and appropriateness.

What Does Product Design Do?

The activities and responsibilities of product design include the following:

(i) Understand and translate the requirements of the customers (Voice of the Customers) into a set of technical requirements (Voice of the Process) for design and execution planning and processes.

(ii) Differentiate the existing products to stretch the product life cycle

(iii) Developing new products

(iv) Providing inputs required for the formulation of the quality goals

(v) Help in cost optimization

(vi) Building and testing model prototypes

(vii) Documentation of the design specifications

The general product design process is depicted in figure 1.

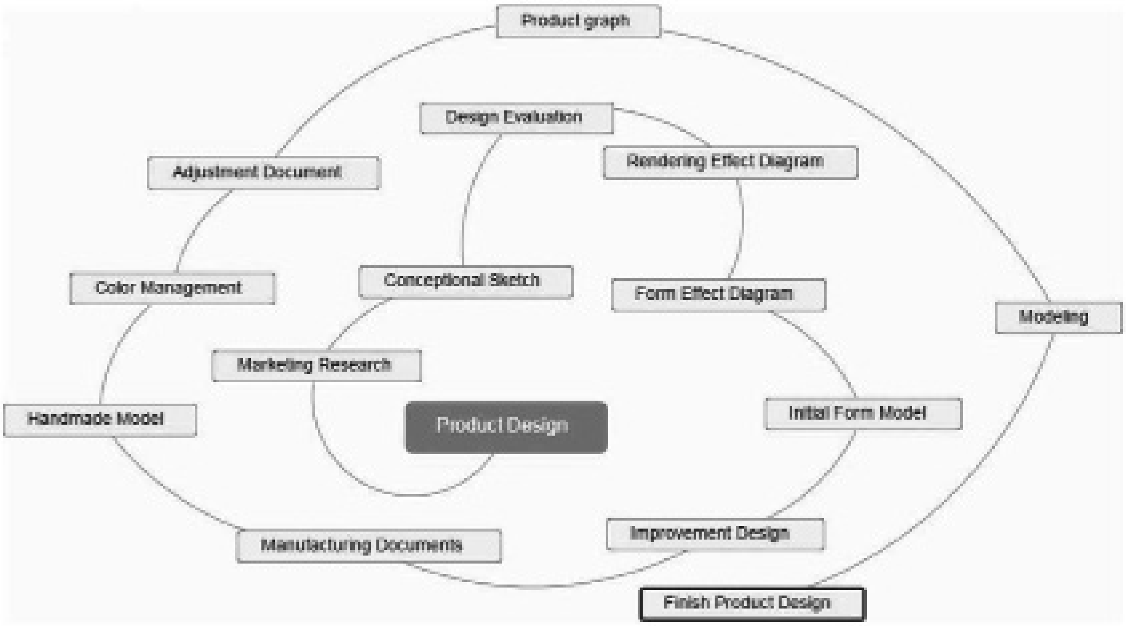


Figure 3.1: Product design process

(Adapted from "Product Design Process and Methods", written by Jinxia Cheng; http://dx.doi.org/10.5772/intechopen.80821)

Factors affecting the Product Design

(a) True understanding of the stated and unstated needs and requirements of the end customers. Sometimes it is difficult to get an idea of the unstated or latent needs. Modern day designers most often rely on social media analytics for discovering the latent needs.

(b) User-friendliness of the products attracts people from various demographic backgrounds.

(c) Striking a balance among form, function/features and cost. In other words, an appropriate balance between economies of scale and economies of scope is required.

(d) Quality of raw materials or basic ingredients

(e) Selection/design of the processes and layouts

(f) The quality and conditions of the machines/instruments used in the design process

(g) Capability and maturity of the processes

(h) Skilled resource persons

(i) Effect on the existing products

(j) Presentation (e.g., packaging) of the products

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 standardized 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

Process Design and Selection

3.2

Process Design encompasses all the activities that are performed to produce the final products as per the specifications in line with the requirements of the customers.

Typically, the process design depends on the following

(a) Characteristics/ nature of the product - Type of the product

(b) Variety: the degree of customization and standardization (Make to Order, Make to Stock, Engineer to Order and Assemble to Order)

(c) Volume: the amount to be produced and size of the lot (single piece or batch or continuous production)

(d) Level of involvement of human resource: Accordingly, the process may be automatic (least involvement of manual labour; capital intensive) or semi-automatic or manual (labour intensive).

(e) Resource requirement: Machines (special purpose and/or general), human capital, space, energy, raw materials and others

(f) Expenditure: the cost of operations- fixed and overhead

(g) Decision on the extent of In-house ('Make') or Outsource ('Buy') production

Process choice determines whether resources are organised around products or processes in order to implement the flow strategy. It depends on the volumes and degree of customisation to be provided.

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

1. Process Choice: The production manager has to choose from five basic process types — (i) job shop, (ii) batch, (iii) repetitive or assembly line, (iv) continuous and (v) project.

(i) 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 characterised 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. Firms having job shops often carry out job works for other firms. A job shop uses a flexible flow strategy, with resources organised around the process.

(ii) 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.

(iii) 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. Repetitive process is also referred to as line process as it include production lines and assembly lines in mass production. Resources are organised around a product or service and materials move in a line flow from one operation to the next according to a fixed sequence with little work-in-progress inventory. 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.

(iv) 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. The process often is capital intensive and operate round the clock to maximise equipment utilisation and to avoid expensive shut downs and shut ups. Examples of products made in continuous process systems include petroleum products, steel, sugar, flour, paper, cement, fertilisers etc.

(v) 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. Projects tend to be complex, take a long time and consist of a large number of complex activities. Equipment flexibility and labour skills can range from low to high depending on the type of projects.

Product Life Cycle

3.3

Likewise, the business organizations and human beings, each product has a life that goes through various phases or cycles. All these cycles during the usable life of a product is collectively called as Product Life Cycle (PLC). A typical PLC has five stages:

(a) **Introduction phase:** During this phase the product (either completely new product or a new variant of the existing product) gets introduced in the market for the first time. For the introduction of the new products in the market, at this stage, the volume stays low, sales are low and effect of learning curve is not realized. Hence, the return on investment is low. This phase is featured by higher level of expenditure in the promotional campaigns. The pricing depends on the innovativeness of the product, nature of the target customer segment and most often discounts are given to entice the potential customers.

(b) **Growth phase:** In this stage, the company focuses on rapid revenue generation and market growth. During this phase, the product sales intend to cover up the fixed cost and bring down the overhead costs while utilizing the learning in the previous stage. Promotional and advertising strategy is decided according to the level of the growths. The objective is to hold the existing customers and create new customers.

(c) **Maturity phase:** This phase is characterized by saturation in the market place. This is a critical phase for the organizations. In the earlier stage (i.e., growth) the objective of the company is to achieve fast growth while in this stage the company wants to flatten the curve to slow down the movement toward fall down. Further, at this stage the organizations infuse variety and differentiation in the products most often to start a new PLC from hereon for finding out a niche market. At this stage, organizations get engaged in aggressive promotional and pricing programs. Profit margin is comparatively lower at this stage.

(d) **Decline phase:** After maturity, the products start losing their attractiveness in the market and sales get falling down. Profit margin becomes increasingly narrower. The organizations take a call to scrap the product and focus on cost consolidation. Sometimes, organizations come up with revival planning with product differentiation and promotional strategy to improve the sales.

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

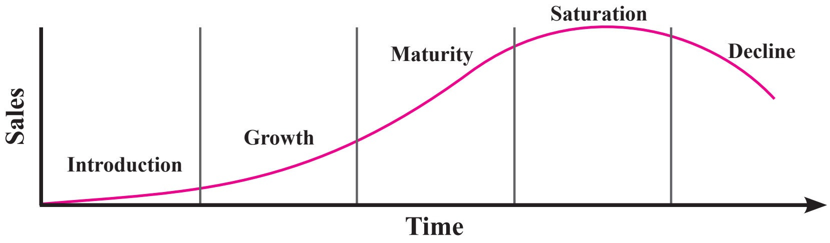


Figure 3.2: PLC for FMCG Product

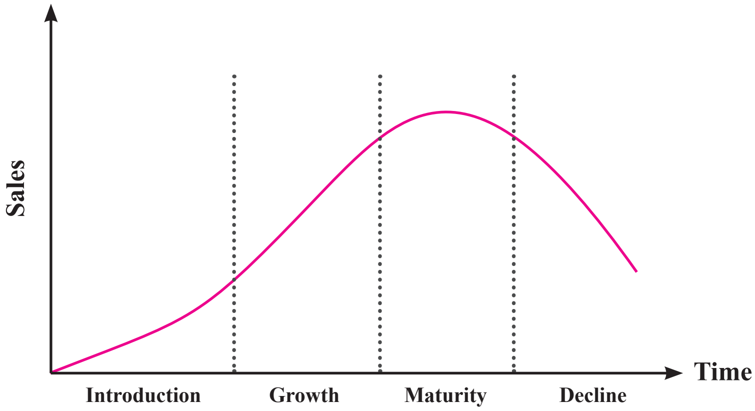


Figure 3.3: PLC for High Tech Product

Process Planning and Selection

3.4

Process planning refers to all decisions regarding facility selection, layout planning, design of work systems and defining operating procedures, capacity planning, arrangement of equipment and resources, human resource planning etc which are necessary to facilitate the smooth execution of the activities to produce the intended products as required by the customers.

Process planning depends on variety and volume of outputs of the products, degree of equipment flexibility and flow of activities.

Process Strategy

A process strategy is a decision taken by the organization vis-à-vis selection of the processes for converting the input (i.e., resources) into output (i.e., finished products and services as required by the customers) in line with the product specifications. A typical process strategy depends on long-term efficiency and productivity, resource availability, flexibility, cost and benefits, quality of the products and lead time. Accordingly, the process strategy stands on the following premises:

(a) Trade-off between Make (in house conversion, fully or partial) or Buy (outsourcing, fully or partial) decisions

(b) Degree of capital intensity that decides the optimum balance between level of automation and manual operations

(c) The extent of flexibility required in the process (i.e., the flexibility in the positioning and functioning of the machines, works stations and requisite skills for layout decisions)

Accordingly, the facilities are designed while having three focus areas such as

(a) Process focused: The facility is designed in a process centric way. Accordingly, the equipment, machines and work stations are organized. Each process is capable of carrying a wide range of activities (aka intermittent processes) and flexible enough to adopt frequent changes. This type of arrangement allows a higher level of customization, i.e., product flexibility. This type of system is also known as job shop production. Example of products: Aircraft

(b) Product focused: The facility is planned in a product centric way to allow a higher level of standardization. The products in higher volume (with lower variety) are produced to give economies of scale and learning benefits for better facility utilization rate. Examples of products: steel, glass, paper, electric bulbs, chemicals and pharmaceutical products. This type of arrangements is suited for continuous flow and batch production. However, this type of structure incurs a higher amount of fixed cost.

(c) Repetitive Focus: This structure utilizes the benefits of the above-mentioned arrangements. It uses modular production. This type of structure is also known as assembly production. Examples include automobile process, household appliances etc.

Process Layout Selection

Process layout aims to identify the necessary arrangement of facilities such as equipment/machines, material, people, and work stations for

(a) facilitating the production efficiently

(b) minimizing unnecessary movements and transportation

(c) efficient material handling

(d) effective design and organizations of the work stations

(e) identification and removal of the bottlenecks/ constraints

(f) effective utilization of the spaces.

The underlying objective is to provide the value added products and services to the end customers while minimizing the waste in the process and hence, optimizing the operational cost and resource utilization.

The classical way of categorization includes four types of layouts

(a) process layout

(b) product layout

(c) Group layout(combination layout)

(d) Fixed position layout

(a) **Process layout or functional layout:** It organizes the work stations in such a way that similar type of machines and services (i.e., facilities) are located together. Therefore, each such sub-facility is specialized in performing a particular activity of the whole conversion process. This type of layout is suitable for low volume, high variety products produced by job shop, batch production and other non-repetitive processes. Examples: Furniture, restaurants etc.

(b) **Product layout or line layout:** In this type of layout, the facility is organized as per the logical/sequential flow of the activities performed to produce the products. This type of layout is used for high volume and continuous production where level of customization is low. Typical examples include assembly line or mass production used in consumer electronics, automobile sectors etc.

(c) **Group (combination) layout:** This combines the features of both the previously mentioned layouts. In this layout the individual processes are replicated at multiple cells wherein each cell is equipped with all facilities to complete the corresponding process. This type of layout is suitable for cellular manufacturing that minimizes the cost of transportation and material handling.

(d) **Fixed position or Project layout:** In this type of layouts, main facilities are fixed at specified locations while the materials, people and work stations move as per the requirements to those locations. This type of layout is of single use and suitable for highly customized (ETO type) products. Examples: Air Craft, Ships

Each production system is uniquely suited to produce a particular mix and volume of products.Each production system provides different levels and a unique set of the manufacturing outputs: cost, quality, performance, delivery, flexibility and innovativeness.One of the tasks of the manufacturing strategy is to select the best production system for each product or product family.

The PV-LF Matrix is a useful tool for analysing the similarities and differences among the seven production systems. The PV-LF Matrix has four dimensions:

(a) Number of products produced

(b) Production volume of each product

(c) Layout or arrangement of equipment and processes used to manufacture the products

(d) Flow of material through the equipment and processes

A typical PV-LF diagram is given below

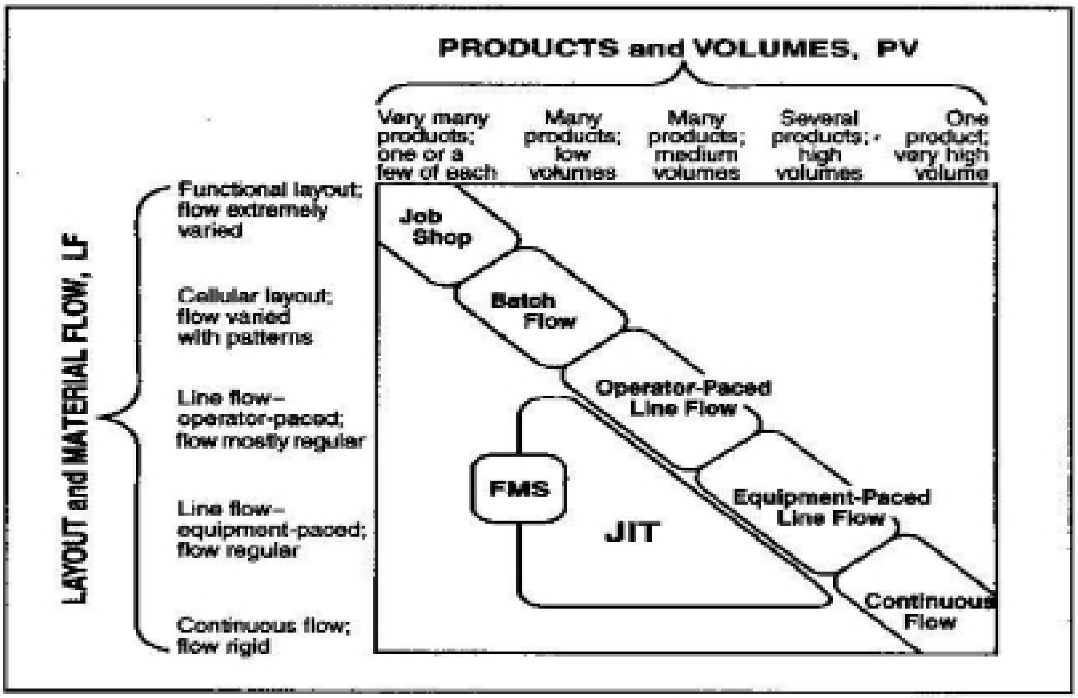


Figure 3.4: PV - LF Diagram

Design Thinking

3.5

What is Design Thinking?

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 is involving 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.

Application of Operation Research - Production Planning and Control

4

This Module Includes

Application of Operation Research - Production Planning and Control

SLOB Mapped against the Module

To attain knowledge on techniques and tools to be applied for product and process designing, capacity planning andproduction line balancing; and job designing; in operations management.

Module Learning Objectives:

After studying this module, the students will be able to:

- Understand the factors determining production planning procedures.
- Identify the production planning system.
- Understand the scope and functions of production planning and control.
- Apply LPP

Introduction

4.1

Applications of Operations Research

Application of OR is different for various fields. Depending on the specific applications, the appropriate OR technique is used to obtain the results .A few typical applications are listed below:

National planning and budgeting

- Preparation of five year plans.
- Annual budgets.
- Forecasting income and expenditure.
- Scheduling major projects of national importance.
- Estimating GNP, GDP, population, employment.
- Generation, agricultural yields, etc.

Defence service operations - Military principles lay greater importance on "economy of efforts" and "surprise"

Element to enemy to forces. Some applications are given below:

- Development of new technology.
- Optimisation of cost and time in defence projects.
- Tender evaluation technology and equipment
- Sitting and layout of defence factories.
- Assessment of "threat-analysis" from the enemy.
- Effective battle "strategies" and "tactics".
- Effective maintenance and replacement of equipments.
- Strategy of defence supplies during war and peace.
- Vendor evauation of canteen stores departments.
- Inventory control.
- Transportation problems during 'mobilisation,' 'operations.' Mock simulation exercises.'
- Ideal locations of "supply depots" to support operational units.

Industrial field OR is applied in a number of cases. Some are given here:

- Plant location and siting .
- Finance planning.

- Product and process planning.
- Facility planning and construction of factory building and layout.
- Purchasing, vendor evaluation and bid evaluation.
- Inventory control.
- Maintenance management and replacement.
- Personnel management, viz. merit rating, incentive payments, etc.

R&D and engineering

- Technology forecasting.
- Technology evaluation.
- Technology management.
- Project management of turnkey projects.
- Systems evauation.
- Preparation of tender.
- Negotiation.
- Value engineering and selection of components.
- Work/Method study and activity sampling, etc.

Business management and competition

- Taking business decisions under risk and uncertainty.
- Capita investment and returns.
- Selection of business and area of operations.
- Decision-making under competition.
- Business strategy formation.
- Optimum advertisement outlay.
- Optimum sales force and their distribution.
- Market survey and analysis.
- Market research techniques, etc.

Agriculture and irrigation

- Project management of irrigation projects and dams.
- Construction of major dams at minimum cost.
- Optimum distribution of irrigation canals.
- Optimum location of supply points of inputs like seeds and fertilizers to the farmers.
- Optimum location of "collection points" of agricultural outputs.

Education and training

- Optimum number of schools and their locations.
- Optimum mix of students/teachers ratio.

- Optimum financial outlay to meet national objectives.
- Optimum number and location of examination centers and number of students in each center.
- Location of supply depot of educational inputs.
- Demand and supply of textbooks and stationery, etc.

Public works department

- Time and cost control of roads, bridges and buildings.
- Estimate of time of completion of projects.
- Time estimate of various activities.
- Selection of machines and equipment.
- Maintenance and replacement.
- Preparation of budgets.
- Tender evaluation and selection of bids, etc.

Transportation and communication

- Forecast requirement of public transport.
- Optimum routing of buses to maximize utility
- Estimate/forecast income and expense.
- Project management of railway projects within a time frame and a cost-frame.
- Railway network distribution.
- Estimate/forecast of telephone demand.
- Optimum capacity selection of exchanges.
- Optimum number of “busy-hour-call” of telephone exchanges, etc.

Home management and budgeting

- Control of expenses to maximize saving.
- Optimum number of purchase of provisions.
- Order quantity of provisions at each purchase.
- Time-management.
- Work-study methods in kitchen activity.
- Time-study methods in kitchen activity.
- Preparation of budgets item-wise like ‘provisions,’ ‘petrol,’ ‘vegetables and meat,’ ‘dress,’ ‘entertainment,’ educational expenditure,’ etc.
- Investment of ‘surplus income’ in the most appropriate manner to earn maximum profit.
- Selection of appropriate investment from alternatives provided to minimize income tax and other taxes.
- Appropriate insurance of life and properties.
- Estimate of depreciation and optimum premium of insurance, etc.

Steps in solving a problem through Operations Research

There are six steps involved in solving a problem through Operation Research. These are discussed below:

Step 1 :

Formation of a problem: From the definition of OR, we have seen that OR is a problem solving technique. Hence, the first step is to formulate the problem. This is an important step, because accuracy of a solution

Depends to a great extent on the correct formulation of the problem in regards to definition of terms, worming

Environment, influences of environmental factors and assumptions made, intentions, objectives and constraints.

In this step, following are to be clearly defined:

- Input, output, processor, objective, constraints.
- Independent variables, which are controllable variables.
- Decision variables, which are dependent variables.
- Parameters, which are independent variables.

Step 2:

Making a model: We have seen that the models are essential to analyses the problem and identify the various

Factors like input, output, constraints, etc. In addition it will also establish the relationship between input (often referred to as parameters) and output (often referred to as decision variables). Mathematical models are often built up in this step, which give information on the following:

- Relationship of input and output.
- Constraints under which operations take place.

The objective functions of the operations. For example, the mathematical model takes the following form:

Minimise $Z = f(x)$ (objective function)

Subject to constraints

- $g(X) \leq k$
- $(X) \geq 0$

Step 3:

Solution to problems (derivation): In this step, the mathematical model development in step 2 is solved through scientific methods. A solution must satisfy the objective functions as well as the constraints. There are various scientific methods or techniques available such as LP transportation/assignment algorithm, game theory, queuing theory, statistical method, probability laws, etc.

Step 4:

Validation of model: A model is said to be valid if it gives a reliable result (output) for a set of inputs under the given conditions. Such a validation is possible for a limited period of time. In due course of time. the original assumptions and conditions in which the model was developed also change. Hence, it is essential to check the validity of a model from time to time.

Step 5:

Feedback and control on solution: Solutions are derived from the model for a set of environmental conditions. In this derivation, a number of assumptions are also made inregard to the cost and quality of inputs like labour and materials, performance characteristics and technology of plant and machinery and the market conditions like price and demand. These are called "information variables." When such variables change significantly in the field, the original solution goes out of control. Hence, these variables are applied to make the solution fall within acceptable limits. Control is applied either on the method of solution or on the design of the model itelf.

Step 6:

Implementation: Implementation of the solution is a very important step because the "proof of the pudding is in its eating."In this step, the OR specialists team must work in closed coordination with the field staff. The OR team must brief the field staff in regard to the operating conditions of the solution and basic assumptions made therein. They must also be briefed in regard to its limitations along with its advantages and capabilities. They mustalso lay down in clear terms the method of operations and procedure along with precautions and corrective mechanism wherever applicable.

Methodology in Operations Research[OR]

Basically there are three methods used for OR problems.

- Analytical method
- Trial and error method
- Simulation method

These are briefly explained below:

(a) **Analytical method:** In this method, the OR techniques are developed mostly based on mathematical modeling. The method of solution also depends on classical steps and techniques in mathematics, like the use of differential calculus, integration, sets, matrices, vector algebra and coordinate geometry. Examples are EOQ, graphical solution for product mix through LP. This is a deterministic method.

(b) **Trial and error method:** The analytical method of solution has its limitations. Some problems and models fail to yield a solution through classical, mathematical or graphical methods. Trial and error method is used here.

In this method, a certain algorithm is developed. One starting point is an initial solution, which is the first approximation, The method of solution is repeated with a certain set of rules so that the initial solution is gradually modified at each subsequent solution till an optimal solution is reached. There are certain laid down to check whether the solution has become a optimal solution. The trial solutions are called iterations and the method is linear programming. This is deterministic method.

(c) **Simulation method:** Solution of problem using the principles of statistics, sampling and probability is called simulation method. This method is applied where the data is insufficient, or where the situation is quite uncertain or when it is impossible to generate data by direct measurement. In such situations, samples are created as faithfully as possible to represent the real situation called the "universe", In order to establish the nature of events, the following devices are used:

- Random tables
- Mechanical devices
- Electronic computers

Typical examples are:

Monte-Carlo simulation in queuing problem and simulation of performance of aircraft flight.

These are stochastic models.

Operations Research (OR) Techniques

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

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

OR techniques are 'application specific.' Maximum benefit can be derived from selecting the most appropriate technique for each specific area or problem. Appropriate selection of OR is an equally important task. Each technique has its own advantages and limitations. In certain cases computation is easy. Some are amenable to computer applications. In all such cases, the ability of the manager is tested in an appropriate selection of OR technique. Some examples are listed below in Table 1.1.This is, by no means, an exhaustive list.

Sl. No.	Functional Area	Specific Problem	OR Techniques Applicable
1	Production Management	Siting and location	Location dynamics BE., Routing travel charts
		Factory layout, Product planning	Profitability analysis, Product line analysis
		Process planning	Line of balance (LOB), Routing GT
		Technology selection	Forced decision matrix- bid Evaluation
		Facility planning	Capital investment, Selection Of plant, BE, DCF.
		Workstation design	Line balancing, Heuristic Methods
		Capacity planning	Break-even, Decision tree, Statistical
		Selection of plant Product mix	BE mathematical, DCF/NPV, LP simplex, LP graphical
		Production planning & control	BE Sequencing assignment Scheduling
2	Materials Management	Warehouse/stores Layout, Inventory Control, Vendor rating	Transporation algorithm, EOQ, ABC & VED analysis
			Functional analysis, Forced decision matrix
		Value engineering, Make or buy decision	Break-even, Decision tree, DCF
3	R&D and engineering	Tecgnology selection, System analysis reliability	Forced decision matrix, Statistical probability, Statistical frequency distribution
4	Quality Management	Inwards goods inspection	Statistical, probability, AQL, OC curve.
		Outwards goods Inspection	Statistical, probability, AQL

Sl. No.	Functional Area	Specific Problem	OR Techniques Applicable
		Process inspection	Statistical, Frequency distribution, CSP
5	Servicing Industry	Optimum efficiency	Queuing theory
		Saving of waiting time	Monte-Carlo simulation
6	Maintenance Management	Maximisation of utilization and minimization of cost	Replacement theory, Statistical DCF, MAPI
7	Project management	Time estimate	Statistics, Frequency distribution
		Minimisation of time	PERT
		Minimisation of cost	CPMCPM
8	Marketing management	Forecast demand	Trend analysis, Probability, Statistics
		Marketing strategy	Game theory, Markov's chain simulation
9	Finance management	Capital investment costing	DCF,NPV,ROI, PI,Ratio analysis,Variance analysis,Signification,Decision tree

Nature and characteristics of Operations Research

Nature of OR and its characteristics are evident form the definition itself. These are given here:

- Existence of a problem.
- Intention to solve the problem.
- Application of system concept and system analysis to the problem.
- Scientific approach to the problem where research methods are used.
- Formation of a group consisting of different specialists.
- Multi-disciplinary team with common aim.
- Team is constituted by management
- OR assists the management to take decisions.
- OR's role is that of a recommendatory nature.
- Existence of a number of solutions to the problem.
- Solutions must be optimum.
- Solutions must be most appropriate.
- Solutions must meet the objective within the constrains.
- Solutions must be given in quantifiable terms.
- Solutions must be practical, application specific and result-oriented.

Scope of Operations Research

The scope of OR is not confined to any specific agency like defence services or an industrial field. The scope is wider. It is useful in every field of human activities, where optimisation of resources is required. It is perhaps easy to name areas where OR is not applpcable. The main fields where OR is extensively used are listed here.

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

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

Functions of Operations Research

In order to achieve the above objectives, the following are the functions of OR.

1. **Provides scientific basis to decision-making:** OR emphasizes scientific methods in the analysis and interpretation of facts and data.This will enable managers to take decisions based on facts scientifically arrived at. This will also improve the objectivity of analysis and assessment of situations.
2. **Reduce complex problems to simple problems:** OR techniques can reduce complex problems into a set of simple problems which can be easily visualized and solved. This will improve clarity of thought and reduce confusions and there by improve the quality of decisions
3. **Bringing in trade-offers:** Management often comes across situations in which it has to satisfy objectives which are in conflict with each other. A typical example is inventory control. A production manager would like to see that all his raw materials and components are stocked in sufficient quantities and well in time, so that there is no fear of stock-out and production 'holdups.' Materials manager on the other hand would recommend a course to order minimum quantity at a time and hold it in stores for the minimum period. Attempts to reduce the quantity of order will increase order costs since more orders will be necessary. If quantity per order is increased to reduce the number of orders and thereby the order costs, it will increase the inventory carrying cost. The optimum solution lies between these two 'objectives' as seen by production manager and material manager separately. This is the 'trade-off' decision OR finds where the trade-off takes place when total cost is the minimum. Accordingly the equation for Economic Order Quantity (EOQ) is derived.
4. **Privides system integration:** OR integrates the system. In the systems approach, the problem is seen as a 'whole' and not as parts. In the wholistic approach, the main system consists of a number of sub-systems. All such sub-systems must be fully integrated into the main system and work as a signal system to meet the same

objective. This, in other words, is called “goal congruence.” The OR team consists of experts from different disciplines, which are the sub-systems. But all of them work towards the single objective to arrive at an optimum solution to the given problem. This is an integrated approach. In order to achieve optimization of the whole system, “sub-optimisation” of sub- system may be found necessary on “trade-off” consideration.

5. **Optimisation of resources**: Resources are scarce. Conservation and optimisation of the resources are the main objectives of management. OR helps to do this. In addition, OR techniques are used in the functional analysis of materials in value engineering/analysis to find better utilization of materials.

6. **Minimising time**: Modern concepts of management have recognized time as one of the most important resources. Time costs money. OR techniques are developed to minimize the time. Some examples are given below:
   - PERT in project management.
   - Queuing theory to optimize ‘waiting’ and ‘servicing’ times.
   - Transportation algorithm, Lp, etc.

7. **Minimising cost**: The primary consideration of the management is to minimise the cost . Various OR techniques have been developed to meet this function. Some of them are:
   - Linear programming.
   - CPM in project management.
   - Assignment algorithm in loading machines.
   - EOQ concept in inventory, etc.

8. **Maximising Profit:** Success and survival of industry and business depends on their ability to make profits.

   The resulting surpluses are put back into industry and business for their growth and continued existence. OR has recognized this function and accordingly developed a number of techniques. In fact many of the cost reduction techniques are applicable here. These are LP, PERT/CPM, transportation, queuing, break- even concepts, decision tree, etc.

9. **Selection of best alternative:** Most of the problems will have a number of solutions. When such alternatives have different parameters, it is very difficult to select the best by conventional methods. A typical example is that of evaluation of global bids. Bidders from different countries offer different terms on technical, commercial and financial bids. Their comparison is difficult unless all these parameters are ‘normalised’ and brought within the same datum. Similarly, managers find it difficult to make proper decisions on investment without OR techniques. When alternatives are presented, OR techniques are able to rank them in the order of priority as per the objectives given by the management. Some examples are:
   - Game theory on competing tenders.
   - Forced decision matrix in bids evaluation.
   - NPV/DCF method on capital investment.
   - Break-even analysis in capacity and investment decision.
   - Decision tree approach in ‘make or buy’ decision, etc.

10. **Solution to specific problems:** It is one of the OR functions to provide answers to specific problems posed by the management. Some examples are:
    - Line balancing of plant.
    - Design of workstation.
    - Selection of appropriate machine.

- Decision of capacity of plant.
- Number of observations in "time study".
- Check to see whether a machine has come out of original alignment and accuracy, etc.

OR techniques are available to give answers to all the above problems and many more.

Limitations of OR techniques

Following are the limitations of OR techniques:

(a) **Information gap:** OR is a specialist's work. It involves a lot of mathematical manipulations, use of various theories like game, statistical, probability, queuing, etc. Unless the manager has a sufficient knowledge of mathematics, he will not be able to appreciate and understand the philosophy and working based on which the OR team has developed the solution. Similarly, a OR specialist is unable to understand many other aspects of business like the goodwill of the customer, the feelings, sentiments and attitude of workers or the expectations of the owners. Many of these facts cannot be quantified. Hence, there is a big gap or "information gap" between the OR specialists and the management. Due to this gap, managers look upon OR as a "theoretical solution" and reject the same without giving it a fair chance to prove its worthiness. This will also enforce the natural tendency to resist changes.

(b) **Quantification techniques:** OR works on quantifiable terms and figures. All factors like goodwill, attitude, expectations, etc. cannot be quantified. Hence the solution ignores all such factors, which are important but cannot to be expressed in quantifiable terms.

(c) **Finite variables:** OR deals with finite number of variables. Most of them deal with two sets of variables, viz. independent variable (parameters) and dependent variable (decision variable). In an actual situation, there are a large number of variables which influence the input, the processor and consequently the output. These are not considered.

(d) **Limited number of constraints:** OR can solve problem having a limited number of constraints. In practice, there are unlimited number of constraints.

(e) **Single objective function:** OR deals with a single objective function. It does not deal with sub-optimisation. In practice, more than one objective function exists.

Production Planning and Control

4.2

Production planning control can be viewed as the nervous system of a production operation. The primary concern of production planning and control is the delivery of products to customers or to inventory stocks according to some predetermined schedule. All the activities in the manufacturing or production cycle must be planned, coordinated, organised, and controlled to achieve this objective. From a long-term point of view (usually from seven to ten years or more) production planning largely deals with plant construction and location and with product-line, design and development. Short-range planning (from several months to a year) focuses on such areas as inventory goals and wage budgets. In plans projected over a two-to-five year period, capital-equipment budgeting and plant capacity and layout are the major concern. Production planning and control normally reflects the short range activities and focuses on the issues and problems that arise in the planned utilisation of the labour force, materials, and physical facilities that are required for manufacturing the products in accordance with the primary objectives of the firm.

Production systems are usually designed to produce a variety of products and are, therefore, complex. In such complex systems, anything can happen and usually it is so. Therefore, it is vital to exercise some kind of control over the production activities. Control is possible only when everything is planned. Production planning and control is thus a very important aspect of production management.

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.

Production control involves the following functions:

(i) Planning the production operations in detail,

(ii) Routing, i.e., laying down the path for the work to follow and the order in which the various operations will be carried out,

(iii) Scheduling, i.e., establishing the quantity of work to be done, and fixing the time table for performing the operations,

(iv) Dispatching, i.e., issuing the necessary orders, and taking necessary steps to ensure that the time targets set in the schedules are effectively achieved,

(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,

(vi) Inspection, i.e., conducting occasional check-ups of the products manufactured or assembled to ensure high quality of the production.

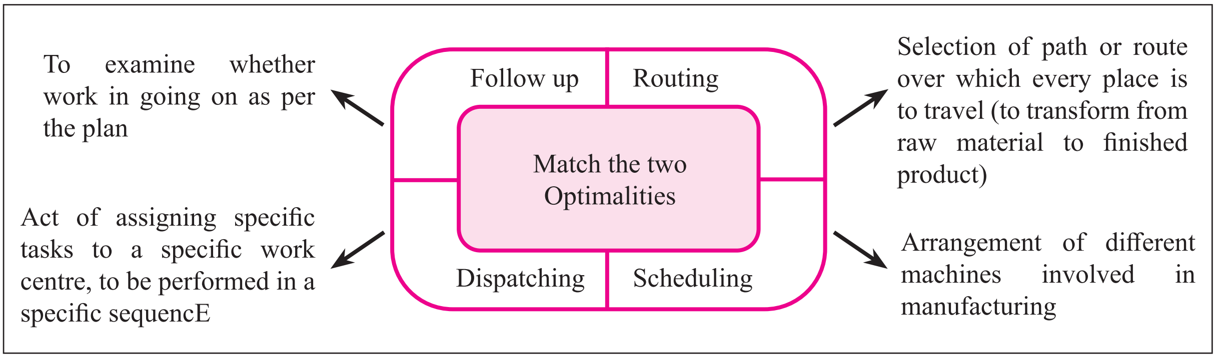


Figure 4.1 : Techniques of Production Control

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

Production planning and control in continuous-production systems.

Production systems may be continuous or intermittent. The continuous production systems are characterised by:

(i) Fixed-path material handling equipment,

(ii) High volume of production,

(iii) Product layouts,

(iv) Production of standardised products,

(v) Production to stock or long-range orders,

(vi) The use of special-purpose machines or automation.

Production planning and control in continuous-production systems involve two activities:

(i) Assuring that supply of raw materials and supplies are on hand to keep the production system supplied and assuring that finished products are moved from the production-system,

(ii) Maintaining a constant rate of flow of the production, so that the system can operate near capacity in some case or can meet the quantity requirements of the production.

Production planning in intermittent production systems:

The intermittent production systems are characterized by the following:

(i) General purpose production machines are normally utilised and process layout is favoured.

(ii) Materials handling equipment is typically of the varied path type such as hand trucks and forklift trucks.

(iii) Relatively high cost, skilled labour is needed to turn out the various quantities and types of products.

(iv) The company generally manufactures a wide variety of products; for the majority of items, sales volumes and consequently production order sizes are small in relation to the total production.

Control Measures – Time & Motion Study, Method Study, Work Study

4.3

Time Study:

Time study is defined to be a searching scientific analysis of the methods and equipment used or planned in doing a piece of work, development in practical detail of the best manner of doing it and determination of the time required.

Operation analysis is the study of the entire process to determine whether operations can be eliminated, combined or the sequence changed. Operation analysis aims to determine the one best way and can be applied to method, materials, tools equipment layout, working conditions and human requirements of each operation.

Job standardisation consists in determining the one best way of performing a job under the means at command of recording the exact method along with the time for each element of operation and establishing means to maintain the standard conditions.

Another term connected with time and motion study is the job analysis. Job analysis is the determination of essential factors in a specific kind of work and of the qualifications of a worker necessary for its performance.

Time study aims at determining the best manner of doing a job and timing the performance of the job when done in the best manner.

In motion study the work is divided into fundamental motions and in time study work is divided into elements of operations. In both cases attempts are made to remove useless motions and improve combination and sequences of motions and operations. In motion study the best way of doing a work is determined by motion analysis and operators are trained to follow the method so determined but in time study the best method is determined by analysis of the methods and equipment, used and motions only roughly considered and that too indirectly. In time study, setting of production standards, standards for cost purposes and wage incentives are emphasised. The measurement of human effort is a difficult job which can only be solved by using scientific method and industrial experience combined with knowledge of psychology.

The use of scientific method involves experiment measurement and elimination of variables connected with a job.

The variables connected with a job are the method of manufacture, tools and equipments, material, working conditions, worker concerned and time required to perform the job. In order to measure the last variable time, the other variables must be eliminated by standardising. In going to proceed for time study, it is first necessary to standardise the method and conditions of work and to define what an average worker is. Time study has two sides, mechanical and human.

Before commencing the time study, the time study man should ensure and ascertain the following:

(i) That motion studies have been carried out so that planning of work, work places and appliances are satisfactory.

(ii) That the operations can be performed in the correct; sequence without interruption.

(iii) That the human effort involved is minimum.

Work Study:

It is a general term for the techniques: methods study and work measurement which are used in the examination; of human work in all its contexts and systematically investigate all factors leading to improvement of efficiency.

Work study aims at finding the best and most efficient way of using the available resources—men, materials, money and machinery. Once the method study has developed an improved procedure for doing a work the work measurement or time study will study the time to complete a job.

Method Study:

It is the systematic investigation of the existing method of doing a job in order to develop and install an easy, rapid, efficient, effective and less fatiguing procedure for doing the same job and at minimum cost. This is achieved by eliminating unnecessary motions involved in a certain operation or by changing the sequence of operation or the process itself.

Methods study can be made by the help of both motion study and time study.

The methods study programme must include the following features:–

(a) Uniform application,

(b) Established standard practice,

(c) Continuous review,

(d) Credit distribution.

A new and improved method developed in one department should be spread out to the entire plant preferably with further improvements.

A new method must not be forgotten between orders as it happens sometimes in batch production. Methods department should always aim at improved and better ways of doing jobs.

For successful control of methods study, the enthusiastic cooperation of every employee is required. To gain employee cooperation, distribution of credit is essential. It has been correctly said that a good methods department rarely takes credit for an original idea. Its success lies in getting new ways and methods adopted promptly, universally, continuously and cooperatively towards the improvement of productivity.

Optimum Allocation of Resources - LPP

4.4

Linear Programming is an optimization technique. It is "**a technique for specifying how to use limited resources or capacities of a business to obtain a particular objective, such as least cost, highest margin or least time, when those resources have alternate uses**".

The situation which require a search for "**best**" values of the variables, **subject to** certain constraints, are amenable to programming analysis. These situations cannot be handled by the usual tools of calculus or marginal analysis. The calculus technique can only handle **exactly equal** constraints, while this limitation does not exist in case of linear programming problem.

A linear programming problem has two basic parts.

- The first part is the objective function, which describes the primary purpose of the formulation – to maximize some return (for example, profit) or to minimize some cost (for example, production cost or investment cost).
- The second part is the constraint set. It is the system of equalities and/or inequalities, which describes the restrictions (conditions or constraints) under which optimization is to be accomplished.

Definition of Linear Programming

According to Kohlar "A method of planning and operation involved in the construction of a model of a real situation containing the following elements: (a) variables representing the available choices, and (b) mathematical expressions (i) relating the variables to the controlling conditions, and (ii) reflecting the criteria to be used in measuring the benefits derivable from each of the several possible plans, and (iii) establishing the objective. The method may be so devised as to ensure the selection of the best of a large number of alternatives".

Samuelson, Dorfman and Solow defines LP as "The analysis of problems in which a linear function of a number of variables is to be maximized (or minimized) when those variables are subject to a number of restraints in the form of linear inequalities".

In the words of Loomba, "LP is only one aspect of what has been called a system approach to management wherein all programmes are designed and evaluated in terms of their ultimate affects in the realization of business objectives".

Application Areas of Linear Programme

In practice linear programming has proved to be one of the most widely used technique of managerial decision making in business, industry and numerous other fields.

1. **Industrial Applications**

   Linear programming is extensively used to solve a variety of industrial problems. In each of these applications, the general objective is to determine a plan for production and procurement in the time period under consideration. It is necessary to satisfy all demand requirements without violating any of the constraints. Few examples of industrial applications are as follows:

(a) Product Mix-Problem.

(b) Production Scheduling.

(c) Production Smoothing Problem.

(d) Blending Problems.

(e) Transportation Problems.

(f) Production distribution problems.

(g) Trim Loss.

(h) Linear programming is also used by oil refineries to determine the optimal mix of products to be produced by the refinery during a given period.

(i) Communication Industry. LP methods are used in solving problems involving facilities for transmission, switching, relaying etc.

(j) Rail Road Industry: An LP model for optimal programming of railway freight, and train movements has been formulated to handle scheduling problems as found at large terminal switching rail points.

2. Management Applications:

(a) Portfolio Selection.

(b) Financial Mix Strategy.

(c) Profit Planning.

(d) Media Selection.

(e) Travelling Salesmen Problem.

(f) Determination of equitable salaries.

(g) Staffing problem.

3. Miscellaneous Applications:

The additional application of Linear Programming are as follows:

(a) Form planning.

- The particular crops to be grown or cattle to keep during a period
- The acreage to be devoted to each, and
- The particular production methods to be used.

(b) Airline routine.

(c) Administration, Education and Politics have also employed linear programming to solve their problems.

(d) Diet Problems. The diet problem, one of the earliest applications of linear programming was originally used by hospitals to determine the most economical diet for patients.

4. Administrative applications of Linear Programming:

Linear programming can be used for administrative applications. Administrative applications of Linear Programming are concerned with optimal usage of resources like men, machine and material.

5. **Non-Industrial applications of linear programming:**

   Linear programming techniques/tools can be applied in the case of non-industrial applications as well. Examples of the use of L.P techniques for non-industrial applications are given below:

   - Agriculture.
   - Environmental Protection.
   - Urban Department.
   - Facilities Location.

6. **Further applications of Linear Programming are:**

   - In structural design for maximum product.
   - In balancing assembly lines.
   - In scheduling of a military tanker fleet.
   - In determining which parts to make and which to buy to obtain maximum profit margin.
   - In selecting equipment and evaluating methods improvements that maximize profit margin.
   - In planning most profitable match of sales requirements to plant capacity that obtains a fair share of the market.
   - In design of optimal purchasing policies.

Formulation of Linear Programming Problem:

The formulation of linear programming problem as a mathematical model involves the following basic steps:

Step 1: Find the key-decision to be made from the study of the solution. (In this connection, looking for variables helps considerably).

Step 2: Identify the variables and assume symbols x_1, x_2 …… for variable quantities noticed in step 1.

Step 3: Express the possible alternatives mathematically in terms of variables. The set of feasible alternatives generally in the given situation is:

$$[(x_1, x_2); x_1 > 0, x_2 > 0]$$

Step 4: Mention the objective quantitatively and express it as a linear function of variables.

Step 5: Express the constraints also as linear equalities/inequalities in terms of variables.

Some definitions:

(a) Solution:

Values of decision variables x_j (j = 1, 2 ….., n) which satisfy the constraints of a general L.P.P., is called the solution to that L.P.P.

(b) Feasible Solution:

Any solution that also satisfies the non-negative restrictions of the general L.P.P., is called a feasible solution.

(c) Basic Solution:

For a set of m simultaneous equations in n unknowns (n>m), a solution obtained by setting (n-m) of the variables equal to zero and solving the remaining m equations in m unknowns is called a basic solution. Zero variables (n-m) are called non basic variables and remaining m are called basic variables and constitute a basic solution.

(d) Basic Feasible Solution:

A feasible solution to a general L.P. problem which is also basic solution is called a basic feasible solution.

(e) Optimal Feasible Solution:

Any basic feasible solution which optimize (maximize or minimize) the objective function of a general L.P.P. is called an optimal feasible solution to that L.P. problem.

(f) Degenerate Solution:

A basic solution to the system of equations is called degenerate if one or more of the basic variables become equal to zero.

Limitations of Linear Programming:

Although linear programming is a very useful technique for solving optimization problems, there are certain important limitations in the application of linear programming. Some of these are discussed below:

1. Firstly, the linear programming models can be applied only in those situations where the constraints and the objective function can be stated in terms of linear expressions.
2. In linear programming problems, coefficients in the objective function and the constraint equations must be completely known and they should not change during the period of study.
3. Yet another important limitation of linear programming is that it may give fractional valued answers.
4. Linear programming will fail to give a solution if management have conflicting multiple goals.
5. Linear programming problem requires that the total measure of effectiveness and total resource usage resulting from the joint performance of the activities must equal the respective sums of these quantities resulting from each activity being performed individually.
6. Many real-world problems are so complex, in terms of the number of variables and relationships constrained in them, that they tax the capacity of even the largest computer.
7. Other limitations of LP includes:-
    - Does not take into consideration the effect of time and uncertainty.
    - Parameters appearing in the model are assumed to be constants but in real-life situations they are frequently neither known nor constants.

Formulation of Mathematical Model – At a glance

Definitions

(a) Linear programming Linear programming is a versatile mathematical technique in Operations Research and a plan of action 5 solve a given problem involving linearly related variables in order to achieve the laid down objective in the form of minimising or maximizing the objective function under a given set of constraints.

(b) Basic solution There are instances where number of unknowns ‘p’ are more than then umber of linear equations ‘q’ available. In such cases, we assign zero values to all surplus unknowns. There will be ‘N’ such unknowns. With these values, we solve ‘q’ equations and get values of ‘q’ unknowns. Such solutions are called basic solutions.

(c) Basic variables The variables whose value is obtained from the basic solution is called basic variables.

(d) Non- basic variables The variables whose values are assumed as zero in the basic solution are known as non-basic variables.

(e) **Solution** A solution to LPP is the set of values of the variables which satisfies the set of constraints of the problem.

(f) **Feasible solution** A feasible solution to a LPP is the set of values of the variables which satisfies the set of constraints as well as the non-negative constraints of the problem.

(g) **Basic feasible solution** A feasible solution to a LPP in which the vectors associated with the non-zero variables are linearly independent is called basic feasible solution.

Note: Linearly independent variables $x_{1,}$ x_2, x_3 …..are said to be linearly independent if k_1 x_1 + k_2 x_2 +…..+k_n x_n = 0; k_1 = 0, k_2 = 0…..

(h) **Optimum (optimal) solution:** A feasible solution of a LPP is said to be the optimum (optimal) solution, if it also optimizes the objective function of the problem.

(i) **Slack variables** linear equations are solved through the equality form of equations. Normally, constraints are given in the "less than or equal to" (≤) form. In such cases, we add the appropriate variable to make it an "equality" (=) equation. These variables added to the constraints to make it an equality equation in LPP are called slack variables and are often denoted by the letter S.

Example: $2x_1 + 3x_2 \leq 500$

$2x_1 + 3x_2 + S_1 =$ where $S_1 =$ slack variable

(j) **Surplus variables sometimes**, constraints are given in the "more than or equal to" (≥) form. In such cases, we subtract an appropriate variable to make it into the "equality" (=) form. Hence, variable subtracted to the constraints to make an equality equation LPP is called surplus variable and is often represented by the letter S.

Example: $3x_1 + 4x_2 \geq 100$

$3x_1 + 4x_2 - S_2 = 100$ where S_2 = surplus variable

(k) **Artificial variable** Artificial variables are fictitious variables. These are introduced to help computation and solution of equations in LPP these are also used when constraints are given in "greater than or equal to" (≥) form. As discussed, surplus variables are subtracted in such cases to convert inequality to "equality" form. In certain cases, even after introducing surplus variables, the simplex tableau may not contain an "identity matrix" or unit vector. Thus in a LPP artificial variable are introduced in order to get a unit vector in the simplex tableau to get a feasible solution. Normally, artificial variables are represented by the letter A. Problems where artificial variables are introduced can be solved by two methods, viz. Big –M method and Two- phase method.

(l) **Big –M method** Big –M method is a modified simplex method for solving LPP when high penalty cost (or profit) has been assigned to the artificial variable in the objective function. This method is applicable for minimising and maximizing problems

(m) **Two- phase method** LPP where artificial variables are added can be solved by two-phase method. This is a modified simplex method. Here the solution takes two phase as follows:

Phase I : Basic feasible solution Here apply simplex method to a specifically constructed LPP called Auxiliary LPP and obtain basic feasible solution.

Phase II: Optimum basic solution Form basic feasible solution, we obtain optimum basic feasible Solution.

(n) **Simplex tableau**: This is a table prepared to show and enter the value obtained for a basic variable at each stage of iteration. This is the derived value at each stage of calculation.

There are three forms of representing a LPP. These are:

- General form of LPP
- Canonical form of LPP
- Standard form of LPP

These are written in ‘Statement’ form or in ‘Matrix’ form as explained in the subsequent paragraphs.

General Form of LPP

(a) Statement form: This is given as:

Find the value of $x_{1,}\ x_2,\ldots\ldots x_n$ which values optimize $Z = c_1x_1 + c_2\ x_2 + \ldots + c_n\ x_n$

Subject to:

$$A_{11}x_1 + a_{12}x_2 + \ldots + a_{ln}\ x_n \le (\text{or} = \text{or} \ge)\ b_1$$

$$A_{21}x_1 + a_{22}x_2 + \ldots + a_{2n}\ x_n \le (\text{or} = \text{or} \ge)\ b_2$$

$$A_{ml}x_1 + a_{m2}x_2 + \ldots + a_{mn}\ x_n \le (\text{or} = \text{or} \ge)\ b_m$$

Where all coefficients (c_j, $a_{y,}$ b_1) are constants and all x_j’s are variables.

I =1,2,……m

J =1,2,…….n

(b) Matrix form: This is stated as:

Find the value of $x_{1,}x_{2,}\ldots..x_n$ to maximise $Z = c_1x_1 + c_2\ x_2 + \ldots + c_n\ x_n$

Let Z be a linear function on R^n defined by

(i) $Z = c_1x_1 + c_2x_2 + \ldots + c_nx_n$

where (c_j, $a_{y,}$ b_1) are constant. Let a_{ij} be an m×n matrix and let $\{b_{1,}\ b_{2,}\ldots b_m\}$be a set of constants such that

(ii)
$$\left[\begin{array}{l} a_{11}x_1 + a_{12}x_2 + \ldots + a_{ln}\ x_n \le (\text{or} = \text{or} \ge)\ b_1 \\ a_{21}x_1 + a_{22}x_2 + \ldots + a_{2n}\ x_n \le (\text{or} = \text{or} \ge)\ b_2 \\ a_{ml}x_1 + a_{m2}x_2 + \ldots + a_{mn}\ x_n \le (\text{or} = \text{or} \ge)\ b_m \end{array}\right]$$

and let

(iii) $x_j \ge 0$; j= 1,2…n, The problem of determining an n-tuple ($x_{1,}\ x_{2,}\ldots.x_n$) which make Z a minimum (or maximum) is called general linear programming problem.

Canonical Form of LPP

(a) Statement form: This form is given as:

Maximise $Z = c_1x_1 + c_2x_2 + \ldots + c_nx_n$

Subject to constraints

$$a_{il}x_1 + a_{i2}x_2 + \ldots + a_{in}\ x_n \le b_j\ (I = 1,2,\ldots m)$$

$$x_{1,}x_2\ldots\ x_n \ge 0$$

The characteristics of canonical form are:

1. Objective function is of the “maximization” type.

   Note: Minimisation of function f (x) is equivalent to maximization of function {-f(x) }. Minimise {f(x)} = Maxinise{-f(x)}

2. All constraints are of the type "less than or equal to," except the non-negative restrictions.

   Note: An inequality of greater than can be replaced by less than type by multiplying both sides by – 1and vice versa.

   e.g. $2x_1+3x_2 \geq 100$ can be written as$-2x_1-3x_2 \leq -100$.

3. All variables are non-negative, viz.$x_j \geq 0$

(b) Matrix form This is stated as:

Maximise $Z = CX$

Subject to constraints $AX \leq b$; $X \geq 0$

Where $X = (x_{1,}x_2\ldots x_n)$; $C = (c_{1,}c_2\ldots c_n)$; $b = (b_{1,}b_2\ldots b_m)$; $A = (a_{ij})$

Where I= 1,2,…m; j = 1,2,…n

The Standard Form of LPP

(a) Statement form This is stated as:

Maximise $Z = c_1x_1 + c_2x_2 +\ldots+ c_nx_n$

Subject to the constrains $a_{il}x_1+ a_{i2}x_2 + \ldots+a_{in}\ x_n \leq b_j$ (I= 1,2,…m)

$x_{1,}x_2\ldots x_n \geq 0$

The characteristics of standard form of LPP are:

1. Objective function is of maximisation type.
2. All constraints are expressed in the function of equality form except the restrictions.
3. All variables are non-negative.

Note: Constraints given in the form of "less than or equal to" can be converted to the equality form by adding 'slack' variables. Similarly, those given in "greater than or equal to" can converted to the equality form by subtracting 'surplus' variables.

(b) Matrix notations This is given as:

Maximise $Z = CX$

Subject to the constraints $AX = b$; $b \geq 0$; $X \geq 0$

Where $X = (x_{1,}x_2\ldots x_n)$; $C = (c_{1,}c_2\ldots c_{an})$; $b = (b_{1,}b_2\ldots b_m)$; $A = (a_{ij})$

Where I=1,2,3…m; j=1,2,3…n

Note: Coefficients of slack and surplus variables in objective function are always assumed to be zero.

The theoretical background of LP is given in matrix vector algebra, discussed in any standard book on the subject. We have also defined certain terms like basic solution in chapter2. These are now recalled in matrix vector form:

(a) Basic solution

(i) In a system of m equations and n unknowns where n > m

$$AX = B \text{ and } X^t \in R^n$$

When A is an m × n matrix of rank m.

Let B be any X sub-matrix formed by linearly independent columns of A, then the solution is obtained by setting (n-m) variables, not associated with the columns of B, equal to zeroes and solving the resultant system; this is called a basic solution to the given system of equations.

(ii) The value of non-zero m variable obtained by solving this system of equations is called basic variables.

(iii) The (m×n) non-singular matrix B, of the given system of equations, is called a basic matrix.

(iv) Column of B is basic vectors.

(v) B is the basic sub-matrix. Then the basic solution to the system is

$$X_B = B^{-1}b$$

Notes:

1. $X^T{}_B \in$ R and so as such cannot be called a solution of the system of equations. Therefore, in strict sense,if X_B is a basic solution, then the solution to the given system of equation is $[X_B{}^{T,}\ 0]$ when $X_B{}^T \in R^m$ and $0 \in R^{n-m}$
2. However, we follow the convention and call X_B as the basic solution of the system equation, all the same, remembering the above fact in mind.

(b) Degenerate solution A basic solution of the system is called degenerate if one or more of the basic variables become zero.

(c) Basic feasible solution A feasible solution to a LPP which is also a basic solution to the problem is called basic feasible solution (BfS) to the LPP.

In matrix vector form, the above term is defined as follows:

Given $Z = CX$; $C, X^T \in R^n$

Subject to the constraints $AX = b$; $X \geq 0$

Then X_B is a basic feasible solution (BSF) to the problem if B is a m × m non-singular sub-matrix of A and $BX_B = b$; $X_B \geq 0$

(d) Cost vector Let X be a basic feasible solution (BSF) of LPP.

Maximise Z= CX

Subject $AX = b$; $X \geq 0$

Then, the vector $C = C_{Bi},$ I= 1, 2…q are components of C associated with the basic variables, is called the cost vector associated with BFS of $X_{B.}$

Objective function of BFS is $Z_B = C_B X_B$

(e) Improved basic feasible solution (IBFS) If X_{B-p} X_{B-II} are two BFS to a standard LPP, X_{B-II} is said to be improved BFS as compared to X_{B-I} if

or $$Z_{B-II} \geq Z_{B-I}$$

$$C_{B-II} X_{B-II} \geq C_{B-I} X_{B-I}$$

Where C_{B-I} and C_{B-II} are the cost components associated with X_{B-I} and $X_{B-II'}$

(f) Optimum basic feasible solution (OBFS) A basic feasible solution (BSF),

X_B to LPP.

Maximise Z = CX

Subject to AX = b and $X \geq 0$

Is called an optimum BFS if

$$Z_o = C_B X_B \geq Z$$

Where Z is the value of the objective function for any feasible solution.

Theorems

Following theorems are applied for solution of LPP by simplex method.

(a) **Reduction theorem** If an LPP has a basic solution, then it has a basic feasible solution.

(b) **Finite solution** There exists only a finite number of basic feasible solutions to an LPP.

(c) **Replacement theorem** If we substitute one of the basis vectors with a non-basis vector in the basis set of LPP having a BFS, then the new solution of the new LPP is also a BFS.

(d) **Improving BFS theorem** Let X_{B-1} be a BFS to an LPP.

Maximise Z =CX

Subject to AX = b, $X \geq 0$

Let X_{B-II} be another BFS obtained by admitting a non basis column vector a in the basis for which net evaluation $\Delta_I = C_j - Z_j$ is positive, then X_{B-II} is an improved basic feasible solution.

$$C_{B-II}\, X_{B-II} > C_{B-I}\, X_{B-I} \text{ and } \Delta_{I^-II} > \Delta_{I-I}$$

or $\Delta_{I-II} - \Delta_{I-I} > 0$ (positive)

(e) **Sufficient condition theorem** A sufficient condition for a BFS to a LPP to become an optimum BFS (OBFS) is that $C_j - Z_j \leq 0$ for all j's for which the column vector $a_j \notin B$.

(f) **Optimality theorem No. 1** when there is an optimum basis feasible solution (OBFS) to a LPP with $C_j - Z_j \leq 0$ for all j's for which $a_i \notin B$, a necessary and sufficient condition for some other BFS to become OBFS is $X_j > 0$, $C_j - Z_j = 0$ for all j's for which $a_i \notin B$.

(g) **Optimality theorem No. II** Any convex combination of 'm' different optimum solution to an LPP is again an optimum solution to the problem.

(h) **Minimax theorem** Let f(X) be a linear function of n variables such that $f(X_i)$ is its minimum value for some point X_1^T where $X_1^T \notin R^n$, then it is said – f(X) attain its maximum value at point X_1^T where $X_1^T \in R^n$. In other words

mini f(X) = - max {- f(X)}

(i) **Undounded theorem** Let there exist a BFS to a given LPP if for at least on j

$C_j - Z_j > 0$; I = 1,2,3…

Then, there does not exist any optimum solution to this LPP.

(j) **Extreme point theorem** A basic feasible solution (BFS) to an LPP must correspond to an extreme point of the set of all feasible solutions.

Steps of simplex solution

Step 1: Formulation of LPP.

Step 2: Convert constraints into equality form.

Step 3: Construct the starting simplex tableau.

Step 4: Test optimality by analysis.

Step 5: Find "incoming" and "outgoing" variables and rewrite the tableau as per given set of rules.

Step 6: Repeat form step 4 onwards again till the optimum basic feasible solution (OBFS) is obtained.

Scope of Simplex Solution

Following are the types of problems solved by simplex method.

1. Maximise Z with inequalities of constraints in "≤" form.
2. Minimise Z with inequalities of constraints in "≤" form.
3. Maximise Z with inequalities of constraints "≥" form.
4. Maximise or minimise Z with inequalities of constraints in "≤" or "=" or "≥" form.

Solution by Two-phase Method

Linear programming problems where artificial variables are introduced can be solved by a modified simplex method known as two-phase method. Here, we obtain solution as follows:

Phase I: Design an auxiliary LPP as per a set of rules and obtain a basic feasible solution (BFS).

Phase II: Restate the LPP with auxiliary LPP of BFS as the starting tableau and obtain optimum basic feasible solution.

The following are the steps involved in two-phase method.

Phase I

Step 1: Formulation of Problems

(a) All "minimization problems" must be first converted to that of "maximizing problems." This is done by multiplying both sides by- 1.

(b) Rewrite objective function by assigning "-1" value to coefficients of artificial variables, instead of M, as in Big –M method and "0" values to all other variables.

Step 2: Initial tableau

(a) Convert inequality form of constraints to equality form by use of artificial, surplus or slack variables.

(b) Assign zero values to all variables whose coefficients are not unit vectors.

(c) Based on (a) and (b) above, develop the initial tableau.

Step 3: Iteration

(a) Examine optimality condition by checking up whether there is any positive value in (C- Z) row.

(b) If (C-Z) row has positive values, identify "optimum column" and "replacing row" as per standard rules given earlier.

(c) Obtain subsequent tableau by process of iteration as per standard rules given earlier.

Step 4: Basic feasible solution

(a) Obtain BFS by repetitive iterations as given in step 3.

(b) The BFS at (a) above is called auxillary LPP.

Phase II

Step 1:

(a) Restate the objective function without the use of artificial variables.

(b) Use constraints as obtained in auxillary LPP in phase 1.

Step 2: Initial tableau

Use auxillary LPP obtained in phase I as the initial tableau by replacing the zero values of coefficients of decision variable with actual values as per the revised objective function given in step I above.

Step 3: Obtain optimum basic feasible solution (OBFS) by iterative process.

This method is illustrated by using exercise 3.4, which is reproduced below.

The Theory

Inverse Matrix Using Simplex

We have matrix notation of standard form of LPP as:

Maximise Z = CX

Subject to constraints AX = b; $X \geq 0$

The solution obtained is $X = A^{-1}b$

Thus, we see that simplex solution obtained on the tableau which is declared as declared as Optimum Basic Feasible Solution (OBFS) contains inverse of matrix A.

Following are the steps involved in finding inverse of a given matrix A.

Step 1:

Objective function (Z) Introduce a fictitious objective function.

$$Z = CX \qquad \text{where } C = 0, X = \begin{bmatrix} X_1 \\ X_2 \end{bmatrix}$$

Introduce artificial variables $A_1 = -1$ and $A_2 = -1$.

$$Z = 0x_1 + 0x_2 - A_1 - A_2$$

Step 2:

Constraints with given vector Introduce artificial variables A_1 and A_2 and assign values of –1 to each as per method discussed in 2-phase method with the given matrix as coefficients of constraints.

Step 3:

Column vector (b) Introduce a dummy non-zero column vector b. Assume any positive integers.

Step 4:

Simplex solution Solve the above problem by 2-phase simplex method and obtain optimum solution as per phase I of computation given in the last chapter. This may be feasible or not feasible.

Step 5:

Inverse of A Follow 2-phase-method of simplex solution and carry out phase I computation and obtain a basis which contains all the variables of X. Then the inverse of A is directly obtained form the simplex tableau and consists of those column vector which are present in the initial basis.

Case of Infeasibility

This is the situation in which we get optimum solution even before all variables in X find a place in the basis viz. under column "B" of the tableau. This solution is called optimum basic infeasible solution (OBIS). When optimum is reached in which the basis contain all variables of X, viz. $x_{1,}$ $x_{2,}$… we call it an optimum basic feasible solution (OBFS).

The following problem gives an OBIS.

Maximise $Z = 4x_1 + 3x_2$

Subject to constraints $3x_1 + 4x_2 \leq 6$

$5x_1 + 6x_2 \geq 15$

$x_1 + x_2 \geq 0$

Students may take this as an exercise and satisfy themselves. In such situations, one or two of the basic variables are artificial variables. In other words, in Big-M method 2, all artificial variables do not disappear form final simplex tableau. Here, optimum value of Z can be expressed only in terms of M.

Case of Unbounded Solutions

When Lpp doed not give finite value of variables X viz. x_1, x_2… such a solution is called unbounded. Here, variable X can take very high values without violating conditions of constraints. In such cases, the final tableau shows all ratios viz. R values are negative so that no- minimum ratio condition can be applied.

Students may try the following problem and establish the unbound condition.

Maximise $Z = 2x_1 + x_2$

Subject to constraints $x_1 - x_2 \leq 10$

$2x_1 - x_2 \leq 40$

$x_1, x_2 \geq 0$

Case of More Than One Optimum Solution

This is the case where LPP given solutions which are optimum but not unique. This means more than one optimum solution is possible. Following are the characteristics of the final tableau in such cases.

1. Solution is optimum.
2. (C-Z) values of all basic variables are zero.
3. (C-Z) values of non-basic variables may or may not be zero.
4. (C-Z) values of at least one non-basic variable will be zero.
5. More than one optimum solution is possible.
6. Value of objective function Z remains the same for all possible solutions.

7. Basis in final tableau contains in addition to basic variable X viz. x_1, x_2…non-basic variables S viz.$s_{1,}$ $s_{2...}$

Case of Degeneracy

A basic feasible solution of LPP is said to degenerate if at least one of the basic variable is zero.

Types of degeneracy

Type 1 First iteration Degeneracy can occur right in the first (initial tableau). This normally happens when the number of constrains is less than number of variables in the objective function. Problem can be overcome by Trial and Error method.

Type 2 Subsequent iteration Regenercy can also occur in subsequent iteration. This is due to the fact that minimum ratio values are the same for two rows. This will make the choice difficult in selecting the "replacing row" The basis logic of simplex is to improve the solution at each iteration. Rules are accordingly formed. When the subsequent iteration shows deterioration or limitation of existing rule to further, we say 'regeneracy' has occerd. At each iteration, we select a new basis set to replace the existing set. At each phase, there is a replacement, viz. replacement of existing vector which is called 'outgoing' with an 'incoming' one. Incoming is determined by (C-Z) value viz.max. positive value in maximizing problem. There is little problem in deciding incoming vector. The real problem arises in selecting the outgoing vector,viz. the replacing row. This decision on replacing row becomes very difficult under the following cases :

(a) Initial tableau has zero values for one or more basic vectors.

(b) Value of minimum ratio is the same for two or more of the basis vectors.

In case (a), it is difficult to obtain optimum solution because; by replacement of vector, Z value does not change. In case of (b), one method is to remove the "tied vectors" from the basis. This will resuli in reduction of rows in subsequent iterations.

Case of Cycling

We have seen that when degeneracy exists the replacement of vector in the basis does not improve the objective function. Another difficulty encountered in degeneracy is that the simplex tableau gets repeated without getting optimum solution. Such occurrences in LPP is called cycling. Fortunately such occurrences in LPP's are very rare. Also in such cases, certain techniques are developed to prevent cycling and reach optimum solutions.

Case of Duality

Every LPP is associated with another LPP which is called the dual of original LPP The original LPP is called the primal. If the dual is stated as a given problem, the primal becomes its dual and vice versa. The solution of one contains the other. In other words, when the optimum solution of primal is known, the solution of dual is also obtained from the very same optimum tableau.

Characteristics

(a) If primal is a maximization problem, the dual will be a minimization problem and vice versa.

(b) Constants of the RHS of the constraints equation on the primal becomes coefficients of objective function in the dual and vice versa.

$$C^* = b^r \text{ and } b^* = C^T$$

(c) Coefficients of the constraints of dual are the transpose of coefficients of constraints of the primal and vice versa.

$$A^* = A^r \text{ and } A = (A^*)^r$$

(d) In maximization problem, constraints and in less than or equal to form whereas in minimization problem, these are in more than or equal to form.

With the above explanation we are now in a position to define formally these two viz. primal and dual.

Primal LPP "An LPP to evaluate the value of $X \in R^n$ so as to

Maximise $Z = CX$, where $C \in R^n$

Subject to the constraints $AX \leq b$ where $b^r \in R^m$ and $X \geq 0$

When A is a $(m \times n)$ real matrix, A is called a primal LPP".

Dual LPP "An LPP to evaluate the value of $Y^r \in R^n$ so as to

Mimimise $Z^* = b^T Y$ where $b^r \in R^m$

Subject to the constraints $A^T Y \geq C^r$ where $C^r \in R^n$ and $Y \geq 0$

When A is a $(m \times n)$ real matrix, A is called a primal LPP."

User There are many user of this concept. Some of these are not within the scope of this text. However, one of the most important use is to solve difficult LPP. Many times, a given LPP is complicated having a large number of constraints. Dual is now subjected to solution by simplex method. The optimum tableau of dual will have the solution of primal, form the following rule.

Rule "Solution of primal is given by the negative values of (C-Z) row under slack surplus variables of the optimum solution tableau of the dual."

A similar rule applies to the solution of dual in case the solution of primal is known from the rule.

Rule "Solution of the dual is given by the negative values of (C-Z) row under slack/surplus variables of the optimum solution tableau of the primal.

Fundamental Properties of Dual

Case 1 : Dual problem when primal is given in standard form Here the constraints are given in the standard from or in the canonical from viz. constraints are either in equality form or in less than or equal to form. This has two more conditions:

(a) Primal variables are restricted.

(b) Primal variables are unrestricted.

(a) Primal variables are restricted $X \geq 0$ primal is given as follows

Determine $X^1 \in R^n$ so as to

Maximise $f(x) = CX; C \in R^n$

Subject to $AX = b; X \geq 0; b^t \in R^n$

Where A is a $(m \times n)$ matrix

Now $AX = b$ can be written in a set of simultaneous equations.

$$AX \leq b \text{ and } AX \geq b$$

If $Y(y_1,y_2)$ are the dual variables associated with equation (4.1)the dual is given as follows:

"Determine $Y^T \in R^m$ so as to

Minimise $g(Y) = b^T Y; YX^T \in R^n$

Subject to $A^T Y \geq C^T$; Y is unrestricted and $Y = y_1 - y_2$"

(b) The primal variables are unrestricted. Here primal is given as follows:

"Determine$X^T \in R^n$ so as to

Maximise $f(X) = CX; C \in R^n$

Subject to $AX = b$; X is unrestricted"

Here we set $X = x_1 - x_2$ where $x_1 \geq 0, x_1^r, x_2^r \in R^n$

The corresponding dual is written as follows:

"Determine $Y^r \in R^m$ so as to

Minimise $g(Y) = b^T Y; Y^T \in R^m$

Subject to $A^T Y = C^{T;}$ Y is unrestricted and $Y = y_1 - y_2$"

Note: From (a) and (b) we find that if primal is standard form then dual variables will be always in unrestricted form.

Case 2 : Dual when primal is given in mixed form This is the case where the constraints are a mixture of less than equal to or equality form. Here primal is given as

"Determine $X^T \in R^n$ so as to

Maximise $f(X) = CX; C \in R^n$

Subject to $A_1 X \leq b_1$

$A_2 X = b_{2;} X \geq 0$

Where A_1 and A_2 are $(p \times n)$ and $[(m-p) \times n]$ real matrices and $b_1$and b_2 are $(p \times 1)$ and $[(m-p) \times 1]$ real vectors respectively."

The constants $A_2X = b_2$ can be written as two inequalities viz. $A_2X \leq b_2$, $A_2X \geq b_2$ so that constraints of primal equation are written in canonical form viz.

$A_1X \geq b_1$

$A_2X \leq b_2$

$- A_2X \geq - b_2$

The corresponding dual is given as follows:

"Determine Y $[y_1 \in R^p{}_, y_{2,} \; y_{3,} \; y_4 \in R^{m-p}$ so] as to

Minimise $g(y_{1,} y_4) = b_1^T y_1 + b_2^T y_4$

Subject to $A_1^T y_1 + A_2^T y_4 \geq C^T$; $y_1 \geq 0$; y_4 is unrestricted

Where $y_4 = y_2 - y_3$"

Note: For the above we may also notice that if the ith primal constraint is an equation with an equality sign, that ith dual variable will be unrestricted.

All these can be easily visualized by working out problems using numerical quantities. Hence, these cases are now illustrated in problems given below.

Example:

Let the linear equation is: $y - 3x = 4$.

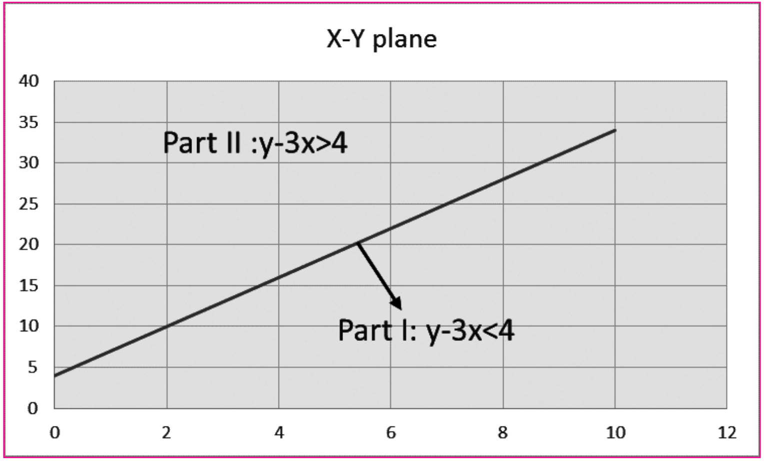
The line is graphically represented as below:

Observe

For any point below the line $y - 3x < 4$

For any point above the line $y - 3x > 4$

For any point on the line $y - 3x = 4$



This concept is very useful in Linear Programming problems (LPP)

Let is construct a General form of an LP model from an example

A manufacturer produces three products (x_1, x_2, x_3), each of which gives a certain profit per unit (₹10, ₹6 & ₹12 respectively) and each requires certain amount of two resources (Resource 1: 3hrs p.u, 4hrs p.u, 7hrs p.u, respectively & Resource 2: 5kg p.u, 2kg p.u, 6kg p.u, respectively). Resources are in limited supply (Resource 1: 50 hours & Resource 2: 80Kg respectively available in week). The manufacturer's objective is to maximise profit per week from these three products while operating in a constraints of limited resources.

This decision our manufacturer will make through application of an LP model developed as below:

Components	
Decision variable	x_1, x_2 & x_3 are the no of units produced for three products
Objective function	Maximise $Z = 10x_1 + 6x_2 + 12x_3$
Constraints	Subject to Resource 1: $3x_1 + 4x_2 + 7x_3 \leq 50$ hours Resource 2: $5x_1 + 2x_2 + 6x_3 \leq 80$ kg $x_1, x_2, x_3 \geq 0$ (Non-Negative constraints)
Feasible space	Set of value of x_1, x_2, x_3 which satisfy objective function under constraints

LP model can be solved by graphical as well as by Simplex model

Graphical Method of LP:

Say one producer produces product A and product B. Profit per unit are ₹70 for A and ₹40 respectively.

Let our producer produces q_1 & q_2 quantities respectively for A and B

So Total profit TP = $70q_1 + 40q_2$ ....(2)

Like all producers, our producer also tries to maximise (2).

Now as already mentioned our producer produces q_1 quantities of A and q_2 quantities of B with utilisation of different resources. In this world resources are not unlimited. So all producer faces restrictions on availability of resources. Let resource requirement per unit of A and B and total availability of each resources to our producer are given in the following table:

Resources	Per unit requirement for A	Per unit requirement for B	Availability
Raw material – I	2kg	1kg	120 kg
Raw material – II	0.8kg	none	40kg
Labour	3 man days	2 man days	200 man days
Machine Hour	4 hours	3 hours	360hrs

From the above table we can write

Total requirement for raw material - I for producing q_1 quantities of A and q_2 quantities of B is $2q_1 + 1q_2$

But this total requirement should never exceed the available amount i.e.120kg.

Therefore, we can write

$$2q_1 + 1q_2 \leq 120 \text{ ....(3)}$$

This sort of inequality is called linear constraints. So for our producer linear constraints are

$$2q_1 + 1q_2 \leq 120 \text{..................................(3)}$$

$$0.8q_1 + 0q_2 \leq 40 \text{...............................(4)}$$

$$3q_1 + 2q_2 \leq 200 \text{.................................(5)}$$

$$4q_1 + 3q_2 \leq 360 \text{.................................(6)}$$

$$q_1 \geq 0,\ q_2 \geq 0 \text{ as no one can produce negative quantities........(7)}$$

Now you see again the definition of LPP at the start of this note. A LPP should contain

- A linear objective function----- we have it in (2)
- Set of linear constraints-----we have it in (3) to (7)

Putting all these together our producer's Linear Programming Problem is

Maximise 70q1 + 40q2 ......objective function

Subject to constraints: linear constraints

$$2q_1 + 1q_2 \leq 120$$

$$0.8q_1 + 0q_2 \leq 40$$

$$3q_1 + 2q_2 \leq 200$$

$$4q_1 + 3q_2 \leq 360$$

$$q_1 \geq 0,\ q_2 \geq 0 \text{ -------- Nonnegative restriction}$$

Step 1: On X-Y plane first we draw the straight lines which show the region indicated by the linear constraints

Since constraints are linear we draw the straight line by finding out two coordinates.

1st constraint is written as an equation:

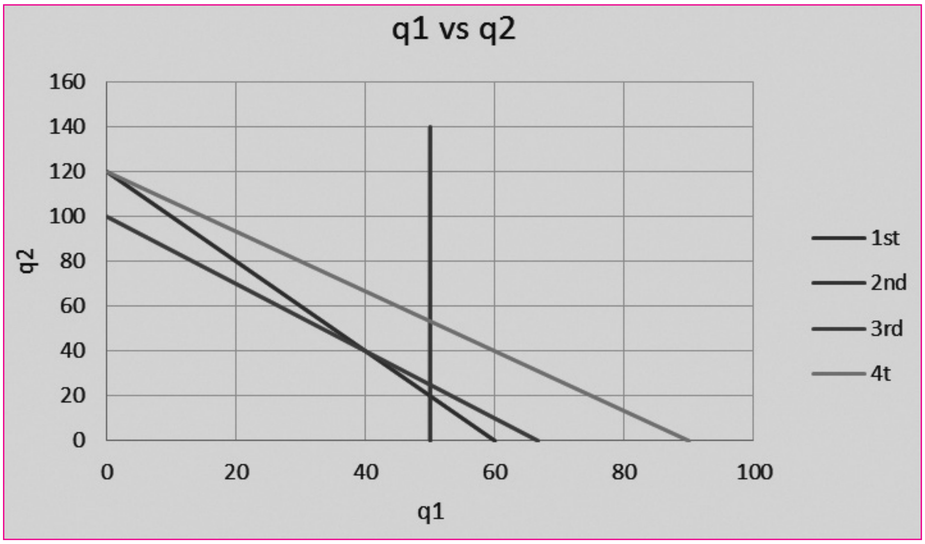
$$2q_1 + 1q_2 = 120$$

Now if $q_1 = 0$, we get $q_2 = 120$ & put $q_2 = 0$ we get $q_1 = 60$. So to draw the above straight line on X-Y plane we have two coordinates i.e. (0,120) & (60, 0)

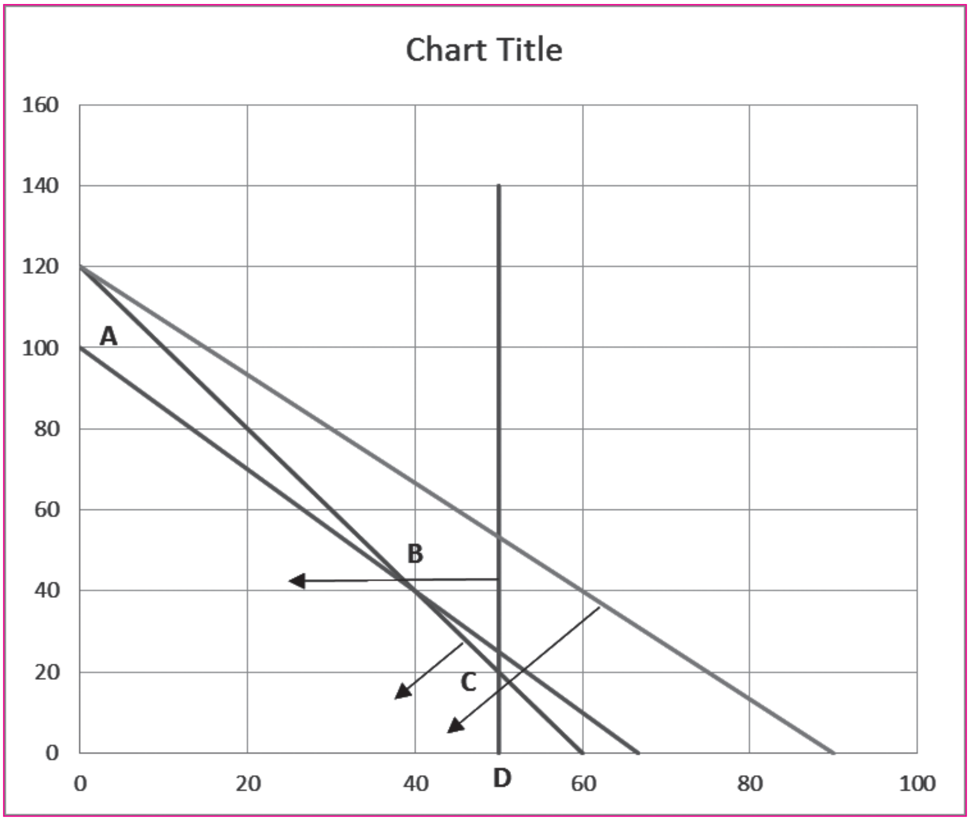
For all other constraints we could arrive at respective coordinates to have the corresponding linear equations on the X-Y plane. The result is:

	q1	q2
1st constraint	0	120
	60	0
2nd constraint	0	0
	50	0
3rd constraint	0	100
	66.67	0
4th constraint	0	120
	90	0

And the respective X-Y diagram is as follows:



Now on the above diagram find out the part of the plane for each straight line which fulfils the constraints and mark the region which satisfy all the constraints together. The resultant diagram is as follows:



Arrows show the region fulfilling the constraint corresponding to each straight line. (From our knowledge of Part I and Part II at the initial pages of this note)

Taking all the constraints taken together we are getting the region marked ABCD. This is the region where if producer produce then he or she could produce within the available resources.

Now let us search the optimal solution.

Our objective is to maximise profit. So from origin as we move North East we will get different combination of (q_1, q_2) and more and more profit we will get. So corner points of the region will give maximum profits than points of operation inside the region.

We have four corner points. They are, corresponding production and profit are:

Point A: $q_1 = 0$, $q_2 = 100$, Profit 70*0+40*100 = 4000

Point B: $q_1 = 40$, $q_2 = 40$, Profit 70*40+40*40 = 4400

Point C: $q_1 = 50$, $q_2 = 20$, Profit 70*50+40*20 = 4300

Point D: $q_1 = 50$, $q_2 = 0$, Profit 70*50+40*0 = 3500

So to maximise profit producer will produce 40 units of A and 40 units of B.

Steps of simplex solution

Step 1: Formulation of LPP.

Step 2: Convert constraints into equality form.

Step 3: Construct the starting simplex tableau

Step 4: Test optimality by analysis

Step 5: Find “incoming” and “outgoing” variables and rewrite the tableau as per given set of rules.

Step 6: Repeat form step 4 onwards again till the optimum basic feasible solution (OBFS) is obtained.

Scope of Simplex **Solution**

Following are the types of problems solved by simplex method.

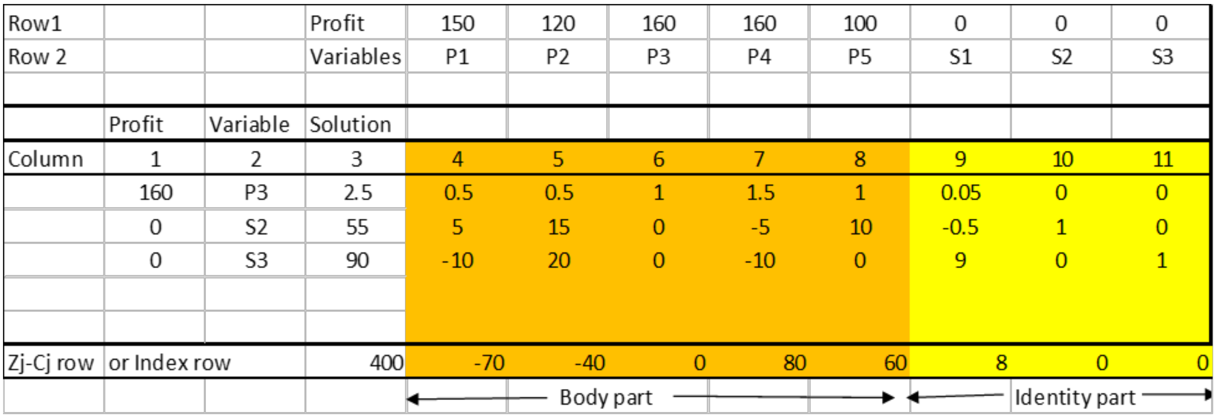
- Maximise Z with inequalities of constraints in “≤” form.
- Minimise Z with inequalities of constraints in “≤” form.
- Maximise Z with inequalities of constraints “≥” form.
- Maximise or minimise Z with inequalities of constraints in “≤” or “=” or “≥” form.

A detailed discussion is done at the end of this topic on simplex solution.

Now a days simplex problem can be easily solved with the help of software like excel.

Interpretation of a Simplex Tableau:

To an operation manager interpretation of a simplex tableau is very important. A simplex tableau looks like the following: (It’s a tableau generated from a maximisation type LP problem)



Row1			Profit	150	120	160	160	100	0	0	0
Row 2			Variables	P1	P2	P3	P4	P5	S1	S2	S3
	Profit	Variable	Solution								
Column	1	2	3	4	5	6	7	8	9	10	11
	160	P3	2.5	0.5	0.5	1	1.5	1	0.05	0	0
	0	S2	55	5	15	0	-5	10	-0.5	1	0
	0	S3	90	-10	20	0	-10	0	9	0	1
Zj-Cj row	or Index row		400	-70	-40	0	80	60	8	0	0
				←		Body part		→	←	Identity part →	

- Different parts of a simplex Tableau is shown above
- The table is not optimal as index row has negative items.
- A simplex table (maximisation type) will be optimal when no negative number exists in the index row
- If a simplex table is optimal, the optimal solution appears in the column marked “Solution” above. The variable and their respective values are shown in the column marked “Variable” and “Profit”
- The number in the index row , under the current solution column (here 400) is the value of the objective function for the solution
- A negative number in the index row under the body part or in the index row under identity part indicates

the algebraic increase in the objective function if one unit of the variable at the head of that column were introduced into the solution. For this table

  - One unit of P1 if introduced into the solution there will be increase in the objective function by ₹70

- A positive number in the index row under the body part represents algebraic reduction in the objective function if one unit of the variable at the head of that column were introduced into the solution. For this table
  - One unit of P4 if introduced into the solution there will be reduction in the objective function by ₹80
- A positive number in the index row under the identity part represents an opportunity profit or the amount of algebraic increase possible in the objective function if one more unit of the variable heading that column were available in the initial solution i.e. if the constraint of the problem for that slack variable were relaxed by one unit
- Values in the identity part of the index row basically gives the solution of the dual variables and marginal profitability of resources

Let us refer the following LPP

$$\text{Maximise } Z = 40X_1 + 35X_2$$

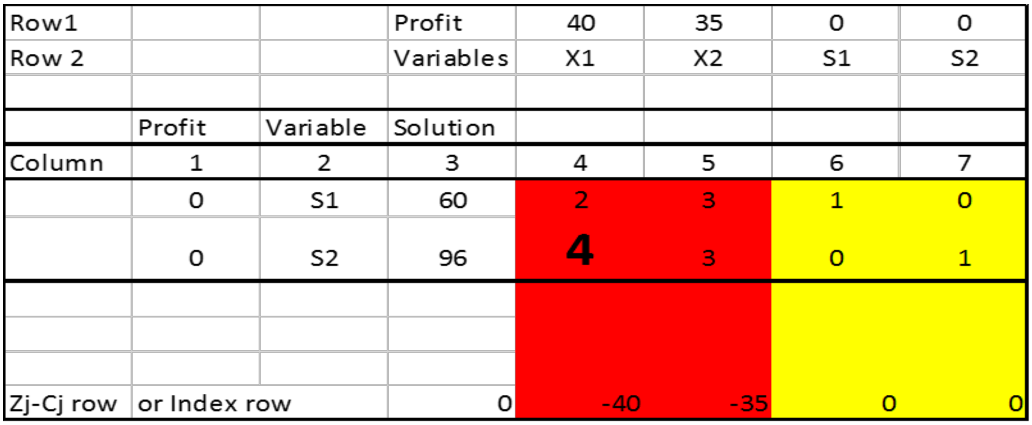
Subject to

$$2X_1 + 3X_2 \leq 60 \quad \text{Raw material Constraint}$$

$$4X_1 + 3X_2 \leq 96 \quad \text{Labour hours Constraint}$$

$$X_1, X_2 \geq 0$$

This is the most usual type of LPP. In the latter part of this discussion some complex LPPs and their treatment are deliberated upon.



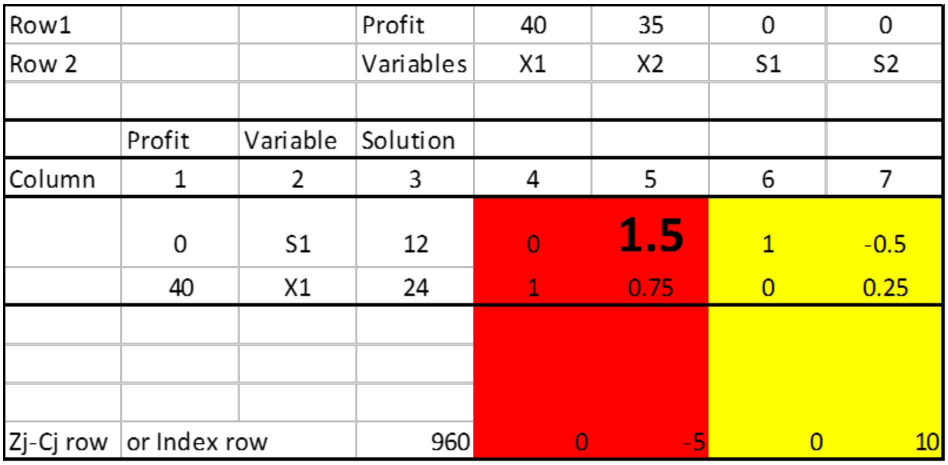
Row1			Profit	40	35	0	0
Row 2			Variables	X1	X2	S1	S2
	Profit	Variable	Solution				
Column	1	2	3	4	5	6	7
	0	S1	60	2	3	1	0
	0	S2	96	**4**	3	0	1
Zj-Cj row	or Index row		0	-40	-35	0	0

Table 1: Body part is Red Zone, Identity part is Yellow. Bold 4 is the pivot

Analysis of Table 1:

- The table is not optimal as index row has negative items.
- A simplex table (maximisation type) will be optimal when no negative number exists in the index row
- A negative number in the index row under the body part (under column X1 & X2) or in the index row under identity part (S1 & S2) indicates the algebraic increase in the objective function if one unit of the variable at the head of that column were introduced into the solution. For this table

  - One unit of X1 if introduced into the solution there will be increase in the objective function by ₹40 i.e. Not producing one unit of X1, we are losing ₹40
  - One unit of X2 if introduced into the solution there will be increase in the objective function by ₹35 i.e. Not producing one unit of X2, we are losing ₹35
- In body part under column 4, what do number 2 & pivot 4 indicate? They indicate
  - 2 as it is positive ---One unit increase in X1 requires 2 units of S1
  - 4 as it is positive--- One unit increase in X1 requires 4 units of S2
- In body part under column 5, what do number 3 & 3 indicate? They indicate
  - 3 as it is positive ---One unit increase in X2 requires 3 units of S1
  - 3 as it is positive--- One unit increase in X2 requires 3 units of S2
- In identity part under column 6, what do number 1 & 0 indicate? They indicate
  - 1 as it is positive ---One unit increase in S1 increases 1 unit in S1 but has 0 effect on availability of S2
- In identity part under column 7, what do number 0 & 1 indicate? They indicate
  - 1 as it is positive ---One unit increase in S2 increases 1 unit in S2 but has 0 effect on availability of S1



Row1			Profit	40	35	0	0
Row 2			Variables	X1	X2	S1	S2
	Profit	Variable	Solution				
Column	1	2	3	4	5	6	7
	0	S1	12	0	**1.5**	1	-0.5
	40	X1	24	1	0.75	0	0.25
Zj-Cj row	or Index row		960	0	-5	0	10

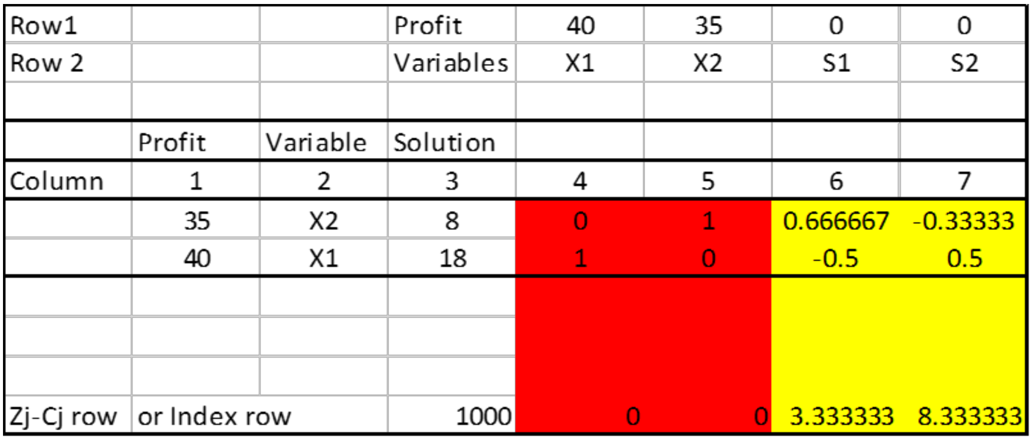
Table 2: Body part is Red Zone, Identity part is Yellow. Bold 1.5 is the pivot

Analysis of Table 2:

- The table is not optimal as index row has negative items.
- A simplex table (maximisation type) will be optimal when no negative number exists in the index row
- The negative number in the index row under the body part i.e.(-5) indicates
  - One unit of X2 if introduced into the solution there will be increase in the objective function by ₹5 i.e. Not producing one unit of X2, we are losing ₹5.
- A positive number in the index row under the identity part represents an opportunity profit or the amount of algebraic increase possible in the objective function if one more unit of the variable heading that column were available in the initial solution i.e. if the constraint of the problem for that slack variable were relaxed by one unit i.e.

  - One additional unit of Labour hours are additionally available our objective function or profit will increase by ₹10

- In body part under column 4, what do number 0 & 1 indicate? They indicate
  - One unit increase in X1 requires 1 units of replacement of X1. As one additional production replaces one unit of X1, so 0 effect on S1
- In body part under column 5, what do number 1.5 & 0.75 indicate? They indicate
  - 0.75 as it is positive ---One unit increase in X2 replaces 0.75 units of X1
  - 1.5 as it is positive--- One unit replacement of X1 releases 1.5 units of raw material. As one unit of X1 requires 2 units of Raw material. So 0.75 units releases 0.75*2 =1.5
- In identity part under column 6, what do number 1 & 0 indicate? They indicate
  - 1 as it is positive ---One unit increase in S1 increases 1 unit in S1 but has 0 effect on availability of X1. Because X1 is already produced at 24 units and it consumed 24*4 =96 labour hours. As no labour hours is available one extra unit of S1 cannot produce additional unit of X1
- In identity part under column 7, what do number -0.5 & 0.25 indicate? They indicate
  - One unit increase in S2 increases 0.25 unit in X1. Because 4 hours produce 1 unit of X1, so 1 hour produces ¼ =0.25 units of X1. Now 1 unit of X1 requires 2 units of Raw materials so 0.25 unit consumes 0.25*2 = 0.5 units of raw material. So there will be reduction of 0.5 units of S1



Row1			Profit	40	35	0	0
Row 2			Variables	X1	X2	S1	S2
	Profit	Variable	Solution				
Column	1	2	3	4	5	6	7
	35	X2	8	0	1	0.666667	-0.33333
	40	X1	18	1	0	-0.5	0.5
Zj-Cj row	or Index row		1000	0	0	3.333333	8.333333

Table 3

Analysis of Table 3:

- The table is optimal as index row has all non-negative items.
- A simplex table (maximisation type) will be optimal when no negative number exists in the index row
- A positive number in the index row under the identity part represents an opportunity profit or the amount of algebraic increase possible in the objective function if one more unit of the variable heading that column were available in the initial solution i.e. if the constraint of the problem for that slack variable were relaxed by one unit. i.e.
- One additional unit of Raw material if additionally available our objective function or profit will increase by ₹3.3333

  - Similarly One additional unit of Labour if additionally available our objective function or profit will increase by ₹8.333
  - These are the solutions of dual function. Values in the identity part of the index row basically gives the solution of the dual variables and marginal profitability of resources
- Optimal solution of the problem is that the manufacturer has to produce 18 units of X1 and 8 units of X2 & by that total profit will be ₹1000 (18*40 + 8* 35)
- In body part under column 4, what do number 0 & 1 indicate? They indicate
  - One unit increase in X1 requires 1 units of replacement of X1. As one additional production replaces one unit of X1, so 0 effect on X2
- In body part under column 5, what do number 0 & 1 indicate? They indicate
  - One unit increase in X2 requires 1 units of replacement of X2. As one additional production replaces one unit of X2, so 0 effect on X1
- In identity part under column 6, what do number 0.666 & - 0.5 indicate? They indicate
  - Decrease of 0.5 unit of X1 with one unit increase in S1. 0.5 unit decrease in X1 releases 2*0.5 = 1 unit in S1. So total available units of raw material is 1+1 =2. With 2 extra units of raw material 2/3 units of X2 could be produced as 3unit of S1 could produce 1 unit of X2
- In identity part under column 7, what do number - 0.333 & 0.5 indicate? They indicate
  - Decrease of 1/3 (0.3333) unit of X2 with one unit increase in S2. 1/3 unit decrease in X2 releases 1/3*3 = 1 unit in S2. So total available units of raw material is 1+1 =2. With 2 extra units of labour hours 2/4 units of X1 could be produced as 4unit of S2 could produce 1 unit of X2

Some Peculiarities of LPP:

1) Minimisation Problem

Minimise $Z = 40X_1 + 24X_2$ Total Cost

Subject to

$20X_1 + 50X_2 \geq 4800$ Raw material Phosphate Requirement

$80X_1 + 50X_2 \geq 7200$ Raw material Nitrogen Requirements

$X_1, X_2 \geq 0$

Generally the constraints in the maximisation problem are of the ≤ type and in the minimisation problem constraints are of the ≥ type. But in a problem there may be present both ≤ & ≥ type constraints.

Under simplex Optimal solution comes when Index row shows ≥ 0 for a maximisation problem and for a minimisation problem optimality comes when Index row shows ≤ 0 values.

However, if an LPP aims at minimising the objective function, then it can be converted into a maximisation problem simply by multiplying its objective function with (-1)

So the above problem we can solve as

Maximise $Z^* = - 40X_1 - 24X_2$ Total Cost

Subject to

$20X_1 + 50X_2 \geq 4800$ Raw material Phosphate Requirement

$80X_1 + 50X_2 \geq 7200$ Raw material Nitrogen Requirements

$X_1, X_2 \geq 0$

2) For ≤ type constraint we know that while doing simplex we have to introduce slack or surplus variable & then proceed

But for ≥ type constraint as above while doing simplex we have to first introduce slack variable and then artificial variables as follows:

1st Constraint is converted to:

$20X_1 + 50X_2 \geq 4800$

Or, $20X_1 + 50X_2 - S_1 + A_1 = 4800$

Or, by putting X_1, X_2 & S_1,we get initial solution of $A_1 = 4800$

2nd Constraint is converted to:

$80X_1 + 50X_2 \geq 7200$

Or, $80X_1 + 50X_2 - S_2 + A_2 = 7200$

Or, by putting X_1, X_2 & S_2, we get initial solution of $A_2 = 7200$

Where is slack variable and A is the artificial variable

Remember for a constraint of "=" type we use only artificial variable no slack variable is required

In the 1st tableau for artificial variable (-) M profit is associated with each artificial variables. This is called *Big M* method

3) Sometimes a LPP provides infeasible solution

- ☐ Infeasibility is said to exist when a graphical solution does not produce an area satisfying all the constraints
- ☐ Infeasibility is said to exist under simplex when an artificial variables appear under column named variable and reiteration stops

4) So far we have considered always the basic variables (i.e. variables in the objective function) ≥ 0

But sometimes a basic variable can be positive, negative & zero also. This sort of basic variable is called unrestricted variable.

An unrestricted variable can always be represented by two restricted variable as:

Say X_r is the unrestricted variable

So we can write. $X_r = X_r' - X_r''$. Because

- ☐ If $X_r' > X_r''$, then X_r will be positve
- ☐ If $X_r' < X_r''$, then X_r will be negative
- ☐ If $X_r' = X_r''$, then X_r will be zero

Example:

Minimise $Z = X_1 - 3X_2 - 2X_3$

Subject to

$3X_1 - X_2 + 2X_3 \leq 7$

$2X_1 - 4X_2 \geq 12$

$-4X_1 + 3X_2 + 8X_3 = 10$

$X_1, X_2 \geq 0$ And X_3 is unrestricted.

Arrange the above LPP for carrying out Simplex

Answer:

Step 1----

Since X_3 is unrestricted, we can write say $X_3 = X_4 - X_5$ (by point 3 above)

Now from first constraint we can write

$3X_1 - X_2 + 2X_3 \leq 7$

Or, $3X_1 - X_2 + 2(X_4 - X_5) + S_1 = 7$ (Less than type constraint we know what to do as per our LP note 2)

From 2nd constraint we can write $2X_1 - 4X_2 - S_2 + A_1 = 12$ (by point no 1 above)

From 3rd constraint we can write $- 4X_1 + 3X_2 + 8 (X_4 - X_5) + A_2 = 10$ (in case of equal type, only take artificial variable, no slack variable)

Step 2----

The given LPP has been reduced to

Maximise $Z^* = - X_1 + 3X_2 - 2 (X_4 - X_5) + 0S_1 + 0S_2 - MA_1 - MA_2$ (See Minimisation problem has been converted to maximisation type by Point 1)

$3X_1 - X_2 + 2(X_4 - X_5) + S_1 = 7$

$2X_1 - 4X_2 - S_2 + A_1 = 12$

$- 4X_1 + 3X_2 + 8(X_4 - X_5) + A_2 = 10$ &

$X_1, X_2, X_4, X_5, S_1, S_2, A_1, A_2 \geq 0$

See in objective function we have taken 0 profit for slack variables & (-) M profits for artificial

And the first tableau will be as below:

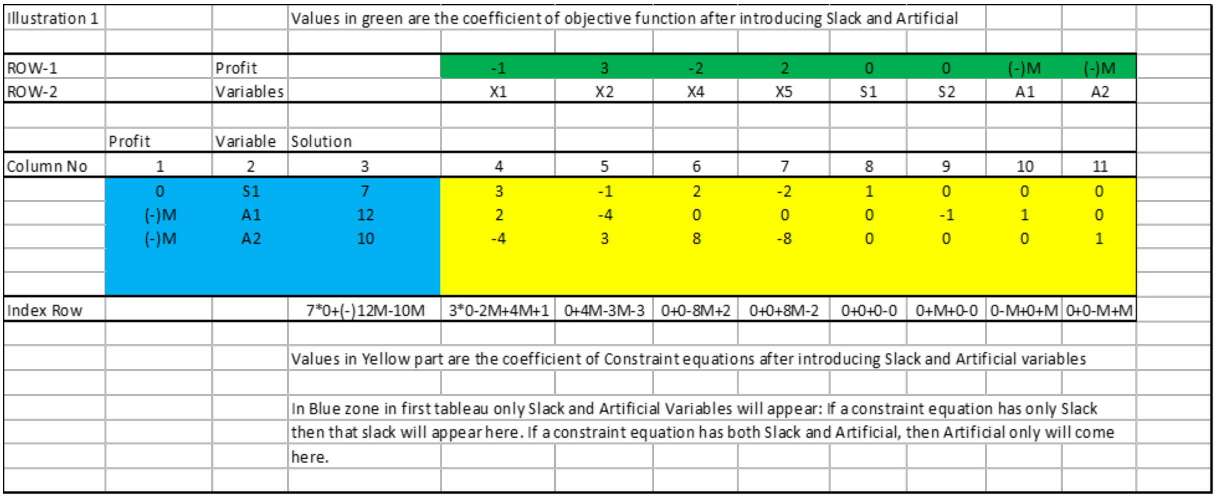


Illustration 1			Values in green are the coefficient of objective function after introducing Slack and Artificial								
ROW-1		Profit		-1	3	-2	2	0	0	(-)M	(-)M
ROW-2		Variables		X1	X2	X4	X5	S1	S2	A1	A2
	Profit	Variable	Solution								
Column No	1	2	3	4	5	6	7	8	9	10	11
	0	S1	7	3	-1	2	-2	1	0	0	0
	(-)M	A1	12	2	-4	0	0	0	-1	1	0
	(-)M	A2	10	-4	3	8	-8	0	0	0	1
Index Row			7*0+(-)12M-10M	3*0-2M+4M+1	0+4M-3M-3	0+0-8M+2	0+0+8M-2	0+0+0-0	0+M+0-0	0-M+0+M	0+0-M+M

Values in Yellow part are the coefficient of Constraint equations after introducing Slack and Artificial variables

In Blue zone in first tableau only Slack and Artificial Variables will appear: If a constraint equation has only Slack then that slack will appear here. If a constraint equation has both Slack and Artificial, then Artificial only will come here.

Example:

Maximise $Z = 2X_1 - X_2$

Subject to

$X_1 + X_2 \geq 10$

$-2X_1 + X_2 \geq 12$

$X_1, X_2 \geq 0$

Answer:

From 1st constraint equation we can write

$X_1 + X_2 \geq 10$

Or, $X_1 + X_2 - S_1 + A_1 = 10$ (By point 1 above)

From 2nd constraint equation we can write

$-2X_1 + X_2 \geq 12$

Or, $- 2X_1 + X_2 - S_2 + A_2 = 12$ (By point 1 above)

Here S are slack variables and A are artificial variables

Basic feasible solutions of $A_1 = 10$ & $A_2 = 12$

So the given LPP is reduced to

Maximise $Z = 2X_1 - X_2 + 0S_1 - MA_1 + 0S_2 - MA_2$

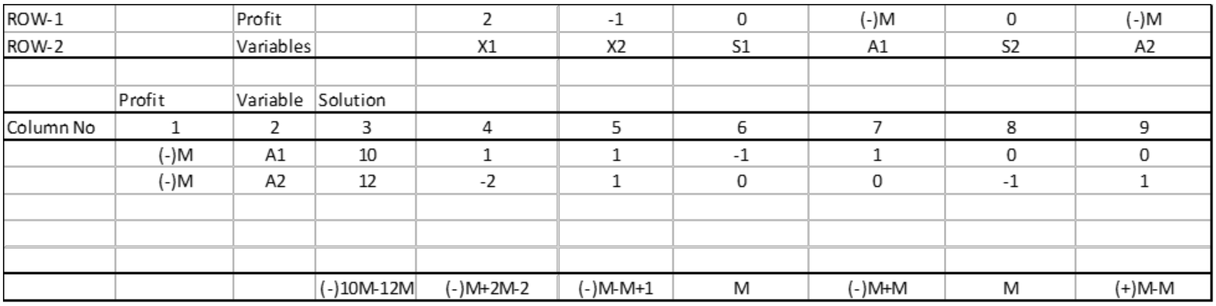
Subject to

$X_1 + X_2 - S_1 + A_1 = 10$

$-2X_1 + X_2 - S_2 + A_2 = 12$

$X_1, X_2, S_1, S_2, A_1, A_2 \geq 0$

The initial tableau of Simplex will be



ROW-1		Profit		2	-1	0	(-)M	0	(-)M
ROW-2		Variables		X1	X2	S1	A1	S2	A2
	Profit	Variable	Solution						
Column No	1	2	3	4	5	6	7	8	9
	(-)M	A1	10	1	1	-1	1	0	0
	(-)M	A2	12	-2	1	0	0	-1	1
			(-)10M-12M	(-)M+2M-2	(-)M-M+1	M	(-)M+M	M	(+)M-M

Simplex method of Linear programming, besides yielding solution to a problem, provides a host of additional information which is useful from the management viewpoint.

Duality is one such information that describes that

- Linear programming problem exist in pairs i.e. corresponding to every given linear programming problem there is another LPP

Before writing the dual to an LPP ---

- It is necessary to express the given LPP (Primal LPP) in standard form if it is not
  - ☐ By standard form it is meant that
  - ☐ All the variables in the problem should be non-negative
  - ☐ All the constraints should be of "≤" type if the problem is of maximisation type
  - ☐ All the constraints should be of "≥" type if the problem is of minimisation type

If a constraint involves an inequality in a direction opposite to the one desired, then it is multiplied by (-) 1 throughout and the direction of inequality is reversed e.g. if a constraint is given as $7x_1 - 5x_2 \geq 4$ and the desired inequality direction is ≤, then we replace this constraints as $-7x_1 + 5x_2 \leq -4$

If a constraint involves an equation then to obtain inequalities, it is replaced by a pair of inequalities in opposite direction. To understand, if $A = 20$, then neither can we express it as $A \leq 20$ nor $A \geq 20$, since both are incorrect individually. But if we consider $A \leq 20$ and $A \geq 20$ together to satisfy, then can both be satisfied for only one value of A, equal to 20. Accordingly if the linear programming problem has a constraint say $7x_1 + 5x_2 = 42$ we would replace it by a pair of constraints as $7x_1 + 5x_2 \leq 42$ and $7x_1 + 5x_2 \geq 42$. One of these would be multiplied by (-1) to bring the inequality in the desired direction

Writing the Dual:

Maximise $Z = 40x_1 + 35x_2$

Subject to

$2x_1 + 3x_2 \leq 60$

$4x_1 + 3x_2 \leq 96$

$x_1, x_2 \geq 0$

Step 1: Check whether the Primal LP is in standard form.

Answer: Yes. Because all the variables are ≥ 0, i.e. non negative & all the constraints are "≤" type

Since it's a maximisation problem, direction of inequality is ok. So the primal LPP is in Standard form

The dual to the above primal LPP will be:

Minimise $G = 60y_1 + 96y_2$

Subject to

$2y_1 + 4y_2 \geq 40$

$3y_1 + 3y_2 \geq 35$

$y_1, y_2 \geq 0$

Primal -

Maximise $Z = 40x_1 + 35x_2$

Subject to

$2x_1 + 3x_2 \leq 60$

$4x_1 + 3x_2 \leq 96$

$x_1, x_2 \geq 0$

Dual -

Minimise G = $60y_1 + 96y_2$

Subject to

$2y_1 + 4y_2 \geq 40$

$3y_1 + 3y_2 \geq 35$

$y_1, y_2 \geq 0$

Observe the changes:

- The primal problem is of maximisation problem whereas Dual is of minimisation
- The constraint values of primal (60, 96) become the coefficients of objective function of dual
- The coefficients of objective function of primal (40, 35) become the constraint value of dual
- The first column of the coefficients of constraints in primal (2,4) become the first row in the first constraints in the dual
- The second column of the coefficients of constraints in primal (3,3) become the second row in the second constraints in the dual
- The direction of inequalities in the primal has been reversed in the dual

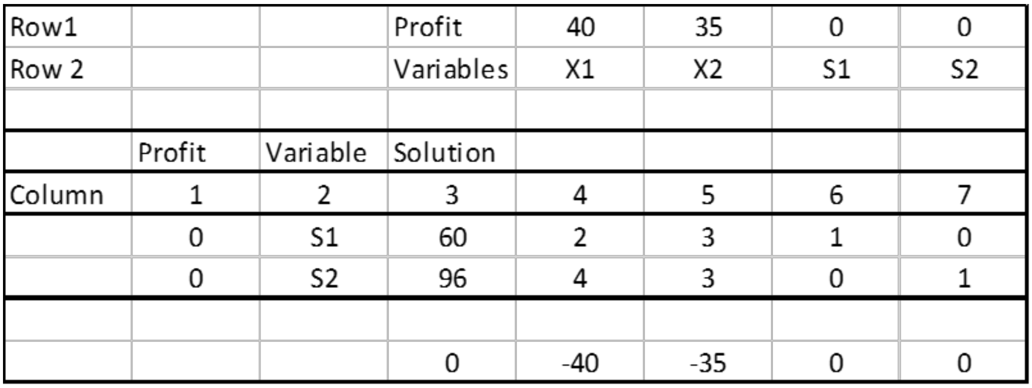
Economic interpretation of Dual:

Let the pertinent data of our primal LPP is as follows:

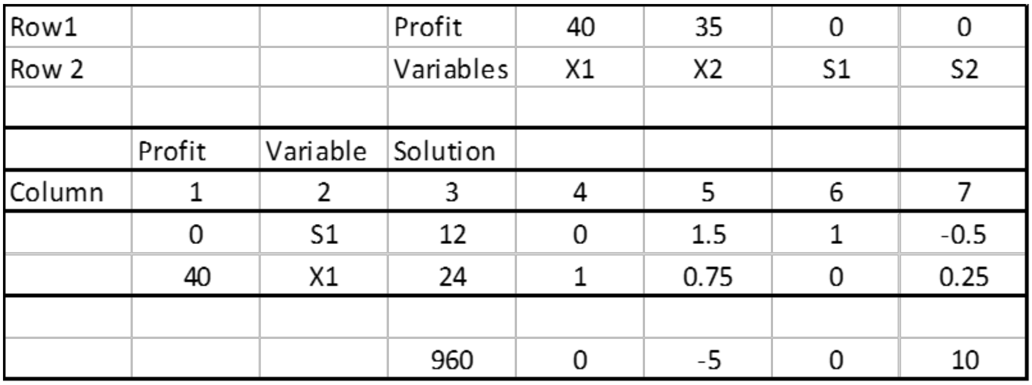
Maximise Z = $40x_1 + 35x_2$ Profit

Subject to

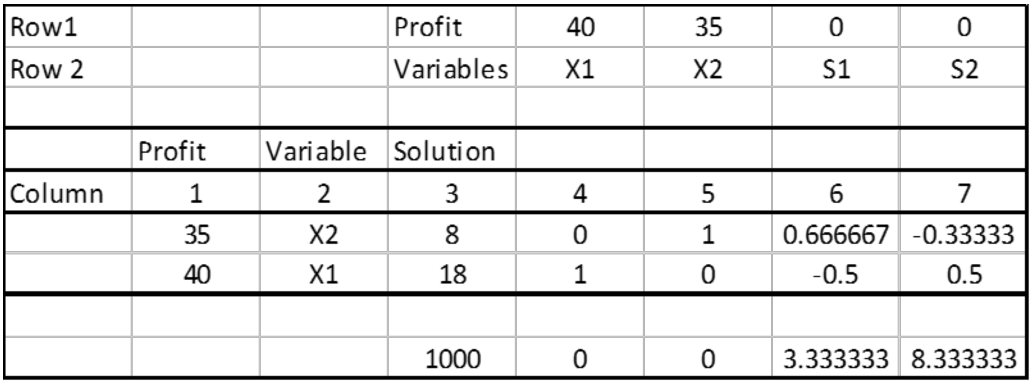
$2x_1 + 3x_2 \leq 60$	Raw material Constraint
$4x_1 + 3x_2 \leq 96$	Labour hours Constraint
$x_1, x_2 \geq 0$	Non-negative constraint



Row1			Profit	40	35	0	0
Row 2			Variables	X1	X2	S1	S2
	Profit	Variable	Solution				
Column	1	2	3	4	5	6	7
	0	S1	60	2	3	1	0
	0	S2	96	4	3	0	1
			0	-40	-35	0	0



Row1			Profit	40	35	0	0
Row 2			Variables	X1	X2	S1	S2
	Profit	Variable	Solution				
Column	1	2	3	4	5	6	7
	0	S1	12	0	1.5	1	-0.5
	40	X1	24	1	0.75	0	0.25
			960	0	-5	0	10



Row1			Profit	40	35	0	0
Row 2			Variables	X1	X2	S1	S2
	Profit	Variable	Solution				
Column	1	2	3	4	5	6	7
	35	X2	8	0	1	0.666667	-0.33333
	40	X1	18	1	0	-0.5	0.5
			1000	0	0	3.333333	8.333333

The optimal solution by simplex of the primal is shown above.

The optimal to this problem indicates that producing 18 units of x_1 and 8 units of x_2 per week would yield the maximum profit equal to ₹1,000.

Now suppose that the firm is approached by an individual who would like to rent the facilities of the firm for one week. The firm has its assets in the form of 60 kg of raw material and 96 labour hours. If we let y_1 represent the rental rate per kg of raw material and y_2 the rental rate per labour hour, the firm would receive a total rental of $60y_1 + 96y_2$. We shall compute the minimum rate of the rental so that the firm will know as to what minimum offer shall be economically acceptable to it. The constraints can be set up by keeping in mind that the alternative of renting must be at least as favourable as the other ones. The rental rates for resources should be at least as attractive as producing product x_1 and x_2.

We know that production of one unit of x_1 requires 2kg of raw material and 4 labour hours. Thus the total rental for these resources should be greater than or equal to the profit obtainable from one unit of the product i.e. ₹40.

Thus we should have following constraints under dual

$2y_1 + 4y_2 \geq 40$

$3y_1 + 3y_2 \geq 35$

Besides our rental cannot be negative. So our dual is

Minimise $G = 60y_1 + 96y_2$

Subject to

$2y_1 + 4y_2 \geq 40$

$3y_1 + 3y_2 \geq 35$

$y_1, y_2 \geq 0$

The solution to this LP is $y_1 = 10/3 = 3.333333$ & $y_2 = 25/3 = 8.333333$

These same values can be obtained from the $Z_j - C_j$ row of the simples of the primal as shown above.

The individual rental rates y_1, y_2 the dual variables corresponding to the slack variables of optimal solution of primal LP are called the shadow prices or imputed prices, indicating the worth of the resources.

Of the two products x_1 & x_2 we know each unit of product x_1 contributes ₹40 to the profit. The imputed price of material and labour being respectively ₹10/3 per kg & ₹25/3 per hour, we observe that the total imputed cost of the resources used in the making a unit of the product would be

2 kg of material at ₹ 10/3 = ₹ 20/3 + 4 hours of labour at ₹ 25/3 = ₹ 100/3 = 120/3 = 40

Similarly

3 kg of material at ₹ 10/3 = ₹ 30/3 + 3 hours of labour at ₹ 25/3 = ₹ 75/3 = 105/3 = 35

The shadow prices are also called the marginal value product or marginal profitability of the resources.

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 drawn 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	

Solution:

Let x_1 be the no. of units of A

Let x_2 be the no. of units of B

Objective function: Min.$Z = 4x_1 + 6x_2$

Subject to Constraints:

$x_1+2x_2 \geq 80$ (Constraint on requirement of Ingradient C)

$3x_1+x_2 \geq 75$ (Constraint on requirement of ingradient 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 ₹1 invested and in B 40 paise per ₹1 invested.

He requires investing the minimum total sum which will give:

Dividend income of at least ₹600 per annum and growth in one year of at least ₹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.

Solution:

Shares	Dividend	Growth in ₹
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: 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 ₹
	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.

Solution:

Let α be no. of hours of plant A in use

Let β be no. of hours of plant B in use

Objective function: Min $Z = 9\alpha + 10\beta$

Subject to constraints:

$2\alpha + 4\beta \geq 50$ (Constraint relating to Product X)

$4\alpha + 3\beta \geq 24$ (Constraint relating to Product Y)

$3\alpha + 2\beta \geq 60$ (Constraint relating to Product Z)

And $\alpha, \beta \geq 0$ (Non negativity constraint)

Illustration 4

The products P, Q and R are being produced in a plant having profit margin as ₹ 3, ₹ 5 and ₹ 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.

Solution:

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: 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 ₹ 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

Solution:

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

$= 0.17x_1 + 0.14x_2 + 0.11x_3 + 0.1x_4 + 0.13x_5 – (0.10x_1 + 0.07x_2 + 0.05x_3 + 0.08x_4 + 0.06x_5)$

$= (0.17 - 0.10)x_1 + (0.14 - 0.07)x_2 + (0.11 - 0.05)x_3 + (0.10 - 0.08)x_4 + (0.13 – 0.06)x_5$

$= 0.17x_1 + 0.07x_2 + 0.06x_3 + 0.02x_4 + 0.07\ x_5$

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) $0.1x_1 + 0.07x_2 + 0.05x_3 + 0.08x_4 + 0.06 \times 5 \leq 0.06$ 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 – ₹40, B – ₹35 and C – ₹30.

Formulate a linear programming model to determine how many chairs should be produced to maximize profit.

Solution:

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.

Solution:

DATA SUMMARY CHART

Decision variables	Products	Type of raw material			Profit per unit (₹)
		A	B	C	
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.

Solution:

$x, + x_3 \geq 15$, $x_3 + x_4 \geq 8$, $x_4 + x_5 \geq 20$, $x_5 + x_6 \geq 6$, 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 ₹ 20,000 in two media vehicles A and B. The unit cost of a message in media A is ₹ 1,000 and that of B is ₹ 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

Solution:

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 ₹7 and requires 3 units of raw material and 2 hours of labour. One unit of product B contributes ₹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.

Solution:

i. The mathematical formulation of the linear programming problem is

Maximise Z = $7x_1 + 5x_2$

Subject to $3x_1 + x_2 \leq 48$

$2x_1 + x_2 \leq 40$

$x_1, x_2 \geq 0$

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:

Minimize Z* = $48y_1 + 40y_2$

$3y_1 + 2y_2 \geq 7$

$y_1 + y_2 \geq 5$

$y_1, y_2 \geq 0$

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.

Solution:

Raw Materials	x_1	x_2	x_3	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

$2x_1 + 3x_2 \leq 8$

$3x_1 + 2x_2 + 2x_3 \leq 10$

$5x_2 + 4x_3 \leq 15$

And $x_1, x_2, x_3 \geq 0$

Dual

Min. $Z = 8y_1 + 10y_2 + 15y_3$

Subject to

$2y_1 + 3y_2 \geq 3$

$3y_1 + 2y_2 + 5y_3 \geq 5$

$2y_2 + 4y_3 \geq 4$

And $y_1, y_2, y_3 \geq 0$

$2x_1 + 3x_2 + S_1 = 8$

$3x_1 + 2x_2 + 2x_3 + S_2 = 10$

$5x_2 + 4x_3 + S_3 = 15$

Max $Z = 3x_1 + 5x_2 + 4x_3 + 0.S_1 + 0.S_2 + 0.S_3$

$\therefore\ x_1 = 23/20 \qquad x_2 = 19/10 \qquad x_3 = 11/8$

$Z = 18.45$

Illustration 12

Four Products A,B,C and D have ₹ 5, ₹ 7, ₹ 3 and ₹ 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.

Solution:

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

$4x_1+3x_2+8x_3+2x_4 \leq 800$ (Constraint on availability of Material type I)

$x_1+2x_2+0.x_3+x_4 \leq 300$ (Constraint on availability of Material type II)

$8x_1+5x_2+0.x_3+4x_4 \leq 500$ (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 ₹ 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

Solution:

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 x6 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)

Linear Programming for Product-Mix Decisions

Illustration 14

What is the slope of the objective function Max $Z = 15X + 45Y$?

Solution:

The slope form is $Y = mX + b$ where m = 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 ₹10 per unit and the calculator ₹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 a 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?

Solution:

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

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.

$$4R + 2C \leq 3,000$$

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:

For Diodes: $4R + 10C = 8000$

If R = 0, then C = 800

If C = 0, then R = 2,000

For Resistors: $4R + 2C = 3,000$

If R = 0, then C = 1500

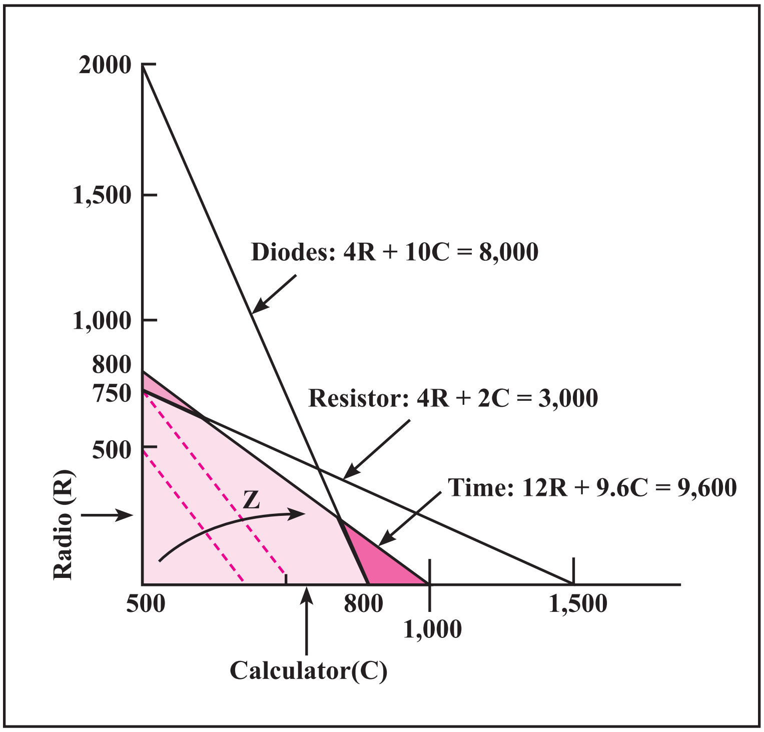
If C = 0, then R = 750

For Testing: $12R + 9.6C = 9,600$

If R = 0, then C = 1,000

If C = 0, 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 from, where the Y axis corresponds to R and the X axis to C.

$$Z = 10R + 15C$$

Or, $10R = -15C + Z$

$$R = -\frac{15}{10}C + \frac{z}{10} = -\frac{3}{2}C + \frac{z}{10}$$

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 hi 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 o 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:

$$4R + 10(705) = 8{,}000$$

$$\therefore R = \frac{8{,}000 - 7{,}050}{4} = 237 \text{ radios}$$

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 `5 on each model X and `20 on each model Y. Each calculator requires the following time (in minutes) on the cleaning and testing machines.

	X Reqirements	Y Requirements	Time Available
Cleaning Testing	2 6	4 3	10 12

(a) State the objective function and constraints.

(b) Arrange the equations in a simplex format.

Solution:

(a) Objective function 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 → ↓ **Variables in solution**	4	8	6	0	0	0	RHS
	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.

Solution:

(a) $5A + 9B \leq 36$, $8B + 5C \leq 24$, and $2A + 5C \leq 7$

(b) Three

(c) Max Z = 4A + 8B + 6C

Comprehensive Example

Solve the following problem by Simplex Method:

Example 1

Product /Machine	Per Unit Resource Matrix			Profit per unit in (₹)
	M1	M2	M3	
P1	4	3	2	20
P2	4	4	1	12
P3	4	3	1	08
Maximum capacity of the matrix	1200	900	400	

Solution:

Step 1: formulate the problem of a Generalized LPP

Let: X_1 Units be produced for product P_1.

X_2 Units be produced for product P_2.

X_3 Units be produced for product P_3.

∴ Max $Z = 20x_1 + 12x_2 + 08x_3$.

Subject to the constraints

$4x_1 + 4x_2 + 4x_3 \leq 1200.$

$3x_1 + 4x_2 + 3x_3 \leq 900.$

$2x_1 + x_2 + x_3 \leq 400.$

$x_1 \leq = 0, x_2 \leq = 0, x_3 \leq = 0$

Step 2: Convert generalized LP. To Standardized LP by introducing Slack Variables.

Matrix $z = 20x_1 + 12x_2 + 8x_3 + 0.x_4 + 0.x_5 + 0.x_6$

Subject to:

$4x_1 + 4x_2 + 4x_3 + 1.x_4 + 0.x_5 + 0.x_6 = 1200$ .... (i)

$3x_1 + 4x_2 + 3x_3 + 0.x_4 + 1.x_5 + 0.x_6 = 900$ ....(ii)

$2x_1 + x_2 + x_3 + 0.x_4 + 0.x_5 + 1.x_6 = 400$ .... (iii)

For all $x_i \geq 0$ $i = 1, 2, 3, 4, 5, 6.$

Where x_4, x_5 & x_6 are Slack variables.

Step 3: To solve the problem given in Step 2. We take the help of Simplex Method in Tabular format.

For simplicity of the problem we take the help of some useful notations.

1. C_j = Coefficient Max Z
2. B = Basis which forms the unit or identity matrix.
3. C_B = Coefficients of basis in C_j

$C_B \times x_i$ =

C = Coefficient of the capacity matrix

MR = Mini Ratio

$$= \frac{\text{Element of C}}{\text{Element of Key coloumn}}$$

Where Key column = Most negative of $(Z_j - C_j)$ Column

Simplex is an Iterative Algorithm. for getting optimal solution there is one stopping rule i.e., all $Z_j - C_j \leq = 0$

To generate new tables, we apply two rules i.e., Rule 1 & Rule 2.

Rule (I) (Key Row):

Dividing the key row by the key elements [key row is that row which contains Keu element & Key element is the intercepting point of minimum MR and most negative of $Z_j - C_j$ column.

Rule 2 (Non key rows):

Old row no. – [corresponding no. in the key row × FR of that old row]

$$\text{Where FR = Fixed Ratio} = \frac{\text{Element of Key coloumn}}{\text{Key element}}$$

No. of columns = 3 + no of variables + 2 (The rule for counting the no. of columns in Tabular Format)

Table 1

Cj			20	12	8	0	0	0		
B	C_B	C	x_1	x_2	x_3	x_4	x_5	x_6	MR	FR
x_1	0	1200	4	4	4	1	0	0	300	2
x_2	0	900	3	4	3	0	1	0	300	3/2
x_3	0	400		1	1	0	0	1	200	1
	Z_j	0	0	0	0	0	0	0		
	$Z_j - C_j$		-20	-12	-08	0	0	0		

(2) Is the key element which occurs in 3rd row & 1st column. Therefore, x_1 will enter as a basis & x_6 will be excluded from the basis. For the calculation of new table. We calculated FR.

In the table 1 row 3 is the key row and row 1 & row 2 are non-key rows.

Applying Rule 1 & Rule 2 , we get table 2

Table 2

Cj			20	12	8	0	0	0		
B	C_B	C	x_1	x_2	x_3	x_4	x_5	x_6	XIR	FR
x_1	0	400	0	2	2	1	0	-2	200	4/5
x_2	0	300	0	(5/2)	3/2	0	1	-3/2	120	
x_3	20	200	1	½	½	0	0	1/2	400	1/5
	Z_j	4000	20	10	10	0	0	10		
	$Z_j - C_j$		0	-2	+2	0	0	10		

(5/2) is the key elements which occurs in 2nd row & 2nd column. Hence x_2 will enter as a basis and X_5will be excluded from basis.

In Table 2 Row 2 is the key Row & Row 1 & Row 3 are the non key rows.

Table 3

Cj			20	12	8	0	0	0
B	C_B	C	x_1	x_2	x_3	x_4	x_5	x_6
x_1	0	160	0	0	4/5	1	-4/5	-4/5
x_2	12	120	0	1	3/5	0	2/5	-3/5
x_3	20	140	1	0	1/5	0	-1/5	4/5
	Z_j	4240	20	12	56/5	0	4/5	44/5
	$Z_j - C_j$		0	0	16/5	0	4/5	44/5

Since all $Z_j - C_j \leq = 0$, our Solution is optimal

Therefore, product mix

$x_1 = 140$ units

$x_2 = 120$ units

$x_3 = 0$ units (no production)

Therefore

Max Z $= 20 \times 1 + 12 \times 2 + 8 \times 3$

$= 20 \times 140 + 12 \times 120 + 8 \times 0$

= ₹ 4240

Transportation

4.5

The basic transportation problem was originally developed by F.L. Hitchcock (1941) in his study entitled "the distribution of a product from several sources to numerous locations". In 1947, T.C. Koopmans independently published a study on "optimum utilization of the transportation system".

Transportation models deals with the transportation of a product manufactured at different plants or factories (supply origins) to a number of different warehouses (demand destinations). The objective is to satisfy the destination requirements within the plants capacity constraints at the minimum transportation cost. Transportation models thus typically arise in situations involving physical movement of goods from plants to warehouses, warehouses to wholesalers, wholesalers to retailers and retailers to customers. Solution of the transportation models requires the determination of how many units should be transported from each supply origin to each demands destination in order to satisfy all the destination demands while minimizing the total associated cost of transportation.

Transportation Table (Matrix)

It is convenient to represent the various data of a transportation problem in a tabular or matrix form, called the transportation table or matrix (9) as follows.

D O	b_1	b_2	…	b_n
a_1	x_{11} c_{11}	x_{12} c_{12}	…	x_{1n} c_{1n}
a_2	x_{21} c_{21}	x_{22} c_{22}	…	x_{2n} c_{2n}
…	…	…	…	…
a_m	x_{m1} c_{m1}	x_{m2} c_{m2}	…	x_{mn} c_{mn}

(1)

The table contain mn number of cells, and each cell, and each cells contain a sub-cell, called the north- westcorner or upper left corner. The elements a_1, a_2,……, a_m in the column under the source O are called the rim supplies and the elements b_1, b_2,…,b_n in row along the destination D are called the rim requirements. The notation (r,s) means the cell in the rth row and sth column.

Initial Basic Feasible Solution

Though the ultimate aim of the theory is to determine the optimal (minimal) solution, it is better to start with a basic feasible solution, and then proceed step by step to optimality. There are various methods of obtaining the initial basic feasible solution. Some of them are as follows:

(i) Cooper charnes method of north- west corner rule, or, upper left corner rule, or, stepping stone rule;

(ii) Minimum row cost method;

(iii) Minimum column cost methods;

(iv) Minimum cost matrix method;

(v) Vogel approximation method (VAM) or unit penalty method. These methods are discussed in the following subsections. The methods are such that even though only feasible solutions are obtained by them, it can be proved that the solutions become basic also. If a tie occurs between two or more items in any methods, we can choose one of the items arbitrarily.

North – West Corner Rule of Cooper and charnes (Stepping Stone Method)

In this rule, we prepare a transportation table as in (1), keeping the sub cells vacant. Then we fill up the sub-cells by x_{ij} by the following method. We take x_{11} to be the value which is minimum of a_1 and b_1, i.e., we put $x_{11} = \min(a_1,b_1)$. If $a_1 \leq b_1$, then we take $x_{11}=a_1$ and hence there will be no more materials left at the origin O_1. If $b_1 \leq a_1$, then we take $x_{11} = b_1$ and hence the capacity of the destination D_1 is exhausted, but the supply of $(a_1–x_{11})$ is still available at O_1. Then we take $x_{12} = \min (a_1\text{-}x_{11},b_2)$. If $a_1–x_{11}<b_2$, we take $x_{12} = a_1–x_{11}$, and then the capacity of the source O_1 is exhausted. If $b_2 \leq a_1 – x_{11}$, then we take $x_{12} = b_2$, and then the capacity at D_2 is exhausted, but the supply $(a_1–x_{11}–x_{12})$ is still available at O_1. Then we proceed to determine x_{13} in the same way. This process is continued till the supply at O_1 is exhausted, and it is bound to be exhausted as per formula (5). Some sub- cells in the first row may remain vacant. We put the zero values there.

Then we start with the source O_2 and proceed in the same way as was done for the source O_1 keeping in view whether any destination is exhausted or not. Thus,we exhaust the supply from O_2. Similarly, the other sources O_m are to be exhausted. Thus, we get all values of x_{ij}.

Using these values of x_{ij} in (3), the corresponding total cost function or objective function z is evaluated. Evidently, this is a feasible solution, since all rim requirements and all rim supplies are satisfied.

We not that in each allocation (i.e, determination of x_{ij}) at least one row or one column is discarded for further consideration, while the last allocation discards both a row and a column, to satisfy the rim requirements and rim supplies. Since there are m rows and n columns, the total number of positive (non-zero) allocations will be at most (m+n-1), while other allocations are all zero. Hence, there is at most (m+n-1) positive (non-zero) values of x_{ij}. Hence the solution is basic. Thus, This rule gives a basic feasible solution.

[In this method, the allocations of x_{ij} are done by the principle “first come, first served”, without considering the cost coefficients c_{ij}.]

Example 2

A company has three factories O_1, O_2,O_3 whose daily production of a material are respectively 7,9,18 units. It has four warehouses D_1, D_2, D_3, D_4 whose capacities of storage are respectively 5,8,7,14 units, so that all units of productions can be stored there. The cost (in rupees) per unit materials of transporting the materials from O_1 to the four warehouses are respectively 19,30,50,10. The cost from O_2 to the warehouses are respectively 70,30,40,60. The cost from O_3 to the warehouses are respectively 40,8,70,20. Find a basic feasible solutions (allocations) and the corresponding total cost, by the method of north- west corner rule.

Solutions:

The transportation table will be as follows.

D O	$b_1 = 5$	$b_2 = 8$	$b_3 = 7$	$b_4 = 14$
$a_1 = 7$	5 19	2 30	0 50	0 10
$a_2 = 9$	0 70	6 30	3 40	0 60
$a_3 = 18$	0 40	0 8	4 70	14 20

Since $a_1 = 7$, $b_1 = 5$, we take $x_{11} = 5$, and the remaining 2 units of a_1 as $x_{12} = 2$. It shows that

$x_{13} = 0$, $x_{14} = 0$, $x_{21} = 0$, $x_{31} = 0$.

Similarly, we deal with the values of a_2, a_3. Thus, by the north-west corner rule, we get the basic feasible solution

$x_{11} = 5$, $x_{12} = 2$, $x_{23} = 3$, $x_{33} = 4$, $x_{34} = 14$,

While other values of x_{ij} are zero. The corresponding total cost z is given by

$Z = 19 \times 5 + 30 \times 2 + 30 \times 6 + 40 \times 3 + 70 \times 4 + 20 \times 14 =$ ₹ 1015.

[Here m =3, n=4 and hence (m+n-1) = 6. The table shows that there are six non-zero values of x_{ij}. Hence the feasible solution is a non – degenerate basic feasible solution. The values of x_{ij} are obtained without any reference to the cost of transport c_{ij}.]

Minimum Row cost Method

Let c_{1k} be the smallest cost in the first row of the transportation table (1). Then we take $x_{1k} = \min(a_1, b_k)$. If $a_1 \leq b_k$, then we take $x_{1k} = a_1$, and hence the supply at O_1 exhausted. If $b_k < a_k$, then we take $x_{1k} = b_k$, so that there is still $(a_1 - b_k)$ units available at O_1. Then we consider the next smallest cost of the first row, and proceed as above. This process is continued till the source O_1 is exhausted.

Then we consider the second row and proceed as in the first row, till the supply at O_2 is exhausted, keeping in view the capacities of the destinations. In the same way, all m rows are dealt with. This will give the values of x_{ij}. Then the total cost z is calculated by the formula (3). [In this method, the smallest costs of the rows are considered to evaluate x_{ij}, whereas in the north – west corner rule, the costs were not considered at all to get the values of x_{ij}.]

Example 3

Solve example 2 by the minimum row cost method.

Solution:

The transportation table is as follows.

D O	$b_1 = 5$	$b_2 = 8$	$b_3 = 7$	$b_4 = 14$

$a_1 = 7$	0 19	0 30	0 50	7 10
$a_2 = 9$	0 70	8 30	1 40	0 60
$a_3 = 18$	5 40	0 8	6 70	7 20

The smallest cost in the first row is ₹ 10 in the fourth column, and hence we take x_{14}= 7, which is the minimum of (7, 14) Hence $x_{11} = 0$, $x_{12} = 0$, $x_{13} = 0$.

The smallest cost in the second row is ₹ 30 occurring in the second column, and hence we take $x_{22} = 8$, since $b_{22} = 8$. The remaining 1 unit at O_2 is taken as $x_{23} = 1$ (Since the next smallest cost in the second row is ₹ 40 in the third column).

The smallest cost in the third row is ₹ 8 in the second column, but we take x_{32}= 0, since $b_2$has already the value 8 in the second row. The next smallest cost of third row is ₹ 20 in the fourth column and hence we take $x_{34} = 7$, since $b_4 = 14$ and 7 is already taken in the first row. The remaining 11 units at O_3 is distributed as $x_{31} = 5$, $x_{33} = 6$, considering the remaining capacities of D_1 and D_3.

Thus we get

x_{14}= 7, x_{22}= 8, x_{23}= 1, x_{31}= 5, x_{33}= 6, x_{34} = 7,

While other values of $x_{ij}$are zero. The corresponding total cost z is

Z = 10 × 7 + 30 × 8 + 40 × 1 + 40 × 5 + 70 × 6 + 20 × 7 = ₹ 1110.

[The value of z is higher than the value ₹ 1015 given by the north – west corner rule. Note that m = 3, n = 4 and hence (m+n-1) = 6, and the table shows six non-zero values of x_{ij} and hence the solution is a non-degenerate basic feasible solution.]

Minimum Column Cost Method

Let c_{r1}be the smallest cost in the first column of the transportation table (9). Then we take x_{r1} = min (a_r,b_1). If b_1<$a_r$then we take x_{r1}= b_1, and hence the capacity at D_1 is exhausted. If a_r<$b_1$then we take $x_{r1} = a_r$ so that there is still ($b_1 – a_r$) units demand at D_1. Then we consider the next smallest cost of the first row and proceed as above. This process is continued till the demand at D_1 is exhausted.

Then we consider the second column and proceed as in the first column, till the demand at D_2 is exhausted keeping in view of the supply and demand at the sources and destinations. Similarly,other columns are dealt with. This will give the values of x_{ij}. Then the costs z is calculated by the formula (3). [In this method, the smallest costs of the columns are considered to evaluate x_{ij}.]

Example 4

Solve example 2 by the minimum column cost method.

Solution

The transportation table is as follows.

D O	$b_1 = 5$	$b_2 = 8$	$b_3 = 7$	$b_4 = 14$
$a_1 = 7$	5 19	0 30	0 50	2 10
$a_2 = 9$	0 70	0 30	7 40	2 60
$a_3 = 18$	0 40	8 8	0 70	10 20

The smallest cost in the first column is ₹ 19 in the first row and hence we take $x_{11} = 5$, which is the minimum of (7, 5). Hence $x_{21} = 0$, $x_{34} = 0$. The smallest cost in the second column is ₹ 8 in the third row and hence we take x_{32}= 8, since 8 is the minimum of (18,8) and hence $x_{12} = 0$, x_{22}= 0.Similarly, we consider the third and fourth columns and get other entries in the subcells. Thus, we finally get.

$x_{11} = 5$, $x_{14} = 2$, x_{23}=7, $x_{24} = 2$, $x_{32} = 8$, $x_{34} = 10$.

Hence the corresponding cost z is

Z = 19 × 5 + 10 × 2 + 40 × 7 + 60 × 2 + 8 × 8 + 20 × 10 = ₹ 779.

[This cost is much less than those obtained by the previous two methods.]

Minimum Cost Matrix Method

Let c_{rs} be the smallest cost in the whole of the cost matrix of the transportation table (9). Then we take x_{rs} = min (a_r, b_s). If $a_r < b_8$ then we take $x_{rs} = a_r$ and then the supply at O_r is exhausted. If $b_s < a_r$, then we take $x_{rs} = b_s$ and then the capacity at b_s is exhausted but there is still $(a_r - b_s)$ units available at Or. Then we consider the next smallest cost in the whole of the cost matrix and allot the materials in the similar way. This process is continued till sources are exhausted. Thus, we get x_{ij}. Then the total cost z is calculated by formula (3). [in this method the smallest cost in the whole of the cost matrix is considered to find x_{ij}, whereas in the minimum row (or column) methods, the smallest cost of a row (column) was considered.]

Example 5

Solve example 2 by the minimum cost matrix methods.

Solution:

The Transportation table is as follows.

D O	$b_1 = 5$	$b_2 = 8$	$b_3 = 7$	$b_4 = 14$
$a_1 = 7$	0 19	0 30	0 50	7 10

$a_2 = 9$	2 70	0 30	7 40	0 60
$a_3 = 18$	3 40	8 8	0 70	7 20

The smallest cost in the table is ₹ 8 in the third row and second columns, and hence we take $x_{32} = 8$ so that $x_{12} = 0$, $x_{22}=0$. The next smallest cost in the table is ₹ 10 in the first row and fourth column and hence we take $x_{14}= 7$, so that $x_{11}=0$, $x_{13}=0$. The next smallest cost in the table is ₹ 19 in the first row and first column, but $x_{11} = 0$ already. The next smallest cost is ₹ 20 in the third row and fourth column and hence we take $x_{34} = 7$ (as $x_{14} = 7$ already and $b_4 =14$), and hence $x_{24} =0$. The next smallest cost in table is ₹ 30 in the first row and second column, but $x_{12}=0$ already. The smallest cost ₹ 30 is also in the second row and second column, but $x_{22}= 0$ already. The next smallest cost of the table is ₹ 40 in second column, but $x_{22} = 0$ already. The next smallest cost of the table is ₹ 40 in second row and third column and hence we take $x_{23} = 7$, $x_{33} =0$. The smallest cost ₹ 40 is also in third row and first column and hence we take $x_{31} = 3$ as $x_{34} = 7$ already. Now it is seen that $x_{21} = 2$.

Thus, we finally get

$x_{14} = 7, x_{21} = 2, x_{23}=7, x_{31} = 3, x_{32}=8, x_{34}=7,$

and all other x_{ij} are zero. Hence

$Z = 10 \times 7 + 70 \times 2 + 40 \times 7 + 40 \times 3 + 8 \times 8 + 20 \times 7 =$ ₹ 814.

[This cost is lower than the cost by first and second methods, but higher than the cost of third method.]

Vogel Approximation or Unit Penalty Methods

(i) For better understanding of Vogel approximation method, we recapitulate the principles on which the previous four methods were based. In the north – west corner methods, the cost matrix is not consulted at all, but the allocations of the items to the various destinations are done on the principle of "first come, first served". In the minimum row cost method, the allocations is done first to the destinations to which the row cost is minimum, and if the source is still not exhausted, then the next allocation is done to the destinations to which the row cost is just higher than the minimum, and so on. In the minimum column cost methods, the same principals is taken with the column instead of the rows. In the minimum matrix cost method, neither the rows nor the columns are given any preference for selection, but the whole cost matrix is considered, and its minimum cost is given the first preference for allocations, and if the corresponding supply is not exhausted, the remaining materials are kept for further allocations. After the first allocations, the next higher cost in the whole matrix is given the preference, and so on.

These methods indicate that the total cost of transportation increases as the difference between the minimum cost and the next higher cost increases. Thus, the total cost depends upon the cost difference rather than their individual absolutevalues. This idea is utilized in Vogel method, and hence Vogel method gives a better initial basic feasible solution than the above other four methods.

(ii) In Vogel approximation method, the principle is to consider the relative minimum cost of each row and each column, computed as the difference between the minimum row (or column) cost and the next higher row (or column) cost. Then we choose the greatest of all these row and column cost difference, and the minimum cost corresponding to this greatest difference is taken as the minimum cost of the whole cost matrix (even though it may be higher than the actual minimum cost). fs The first allocation is done to the destination for which this supposed minimum cost happens.

After the first allocation made in this way it will be seen that there will be at least one row or one column for which no further allocations are possible, and hence this row or column is omitted in the considerations of the next allocation. After this omission, there will be a truncken or shrunken transportation matrix. We calculate the relative row and column costs of this new matrix and make allotment as in above method. This process is continued one after another, till all allocations are completed.

(iii) The explanation for selecting the highest cost difference is given as follows. Let R_1be the difference of the minimum cost and the next higher cost in the first row. Then R_1 is the relative minimum cost of the first row. It is also called the penalty or loss in the first row. [For, if he supply a_1 in the first row is not exhausted, when the allocation is done to the destination corresponding to the minimum cost of the first row, then, the next higher cost is chosen for the purpose of the second allocation, and since R_1 is the difference between the two costs, a loss or penalty of R_1 unit of cost per unit amount of material has to be done.]

The penalties or losses for the second, third, … mth rows are calculated in the same way as R_2, R_3, …., R_m. The set

$$R_q = (R_1, R_2, \ldots., R_m)$$

is called the set of the row penalties, similarly, the set of the column penalties $Cp = (C_1, C_2, \ldots., C_n)$ of the first, second, …., nth column are calculated.

The greatest of these row and column penalties is chosen for the first allocation to avoid this greatest penalty in future. It means that the destination which yields the greatest penalty or loss is to be supplied first, even if the corresponding cost is higher than the actual minimum cost. If this destination is supplied first, then the other destinations will involve less penalties. This is the reason why the greatest pen*alty* is chosen first.

Example 6

Solve example 2, by Vogel approximation or unity penalty method.

Solutions:

The transportation table is as follows.

D O	$b_1 = 5$	$b_2 = 8$	$b_3 = 7$	$b_4 = 14$	row penalty R_4
$a_1 = 7$	0 (19)	0 30	0 50	7 (10)	R_1 9 9 40 40
$a_2 = 9$	0 70	0 30	7 40	2 60	R_2 10 20 20 20
$a_3 = 18$	5 40	0 (8)	6 70	7 (20)	R_3 12 20 50 x
Column Penalty C_p	C_1 21 (21) X x	C_2 (22) X X X	C_3 10 10 10 10	C_4 10 10 10 (50)	

The penalties for the first, second, third rows are respectively

$$R_1 = 19\text{-}10 = 9,\ R_2 = 40\text{-}30 = 10, \quad R_3 = 20\text{-}8 = 12.$$

The penalties for the four columns are respectively

$$C_1 = 40 - 19 = 21,\ C_2 = 30\ \text{-}8 = 22,\ C_3 = 50 - 40 = 10,\ C_4 = 20\text{-}10 = 10 \text{ units.}$$

The greatest of these row and column penalties is $C_2 = 22$, and it corresponds to the minimum cost 8 in the third row and second column. Hence, we choose the subcell of the cell (3,2) for first supply. Thus, we get $x_{32}=8$, and hence $x_{12}=0$, $x_{22}=0$. Then the second column is omitting the second column is omitted in the next consideration of allotment, as this column has been filled up.

Now, we calculate the penalties again by omitting second columns. The new row penalties are

$$R_1 = 19 - 10 = 9,\ R_2 = 60 - 40 = 20,\ R_3 = 40 - 20 = 20.$$

the new column penalties are

$$C_1 = 40 - 19 = 21,\ (C_2 = 0),\ C_3 = (50\text{-}40) = 10,\ C_4 = 20 - 10 = 10.$$

The greatest of these new row and column penalties is $C_1 = 21$, and it corresponds to the minimum cost 19 in the first row and first column. Hence, we choose the subcell in the cell (1,1) for supply. Thus we get $x_{11} = 5$ and hence $x_{21}=0$, $x_{31}= 0$. Then the first column is omitted in the next consideration of allotment, as it has been filed up.

Now, we calculate the penalties again by omitting the first and second columns. The new row penalties is are

$$R_1 = 50\text{-}10 = 40,\ R_2 = 60\text{-}40 = 20,\ R_3 = 70 - 20 = 50,$$

and the new column penalties are

$$C_1=0,\ C_2=0,\ C_3 = 50\text{-}40 = 10,\ C_4 = 20\text{-}10 = 10.$$

The greatest of these new row and column penalties is $R_3 = 50$ and it corresponds to the minimum cost 20 in the third row and fourth column. Hence, we choose the subcell in the cell (3,4) for supply. Thus we get $x_{34} = 10$ and hence $x_{33} = 0$. Then the third row is omitted in the next consideration of allotment, as it has been filled up.

Then we calculate the penalties again by omitting the first and second columnsand third row. The new row penalties are $R_1 = 50 - 10 = 40$, $R_2 = 60 - 40 = 20$, $R_3 = 0$, and the new column penalties are $C_1 = 0$,$C_2 = 0$, $C_3 = 50 - 40 = 10$, $C_4 = 60 - 10 = 50$. The greatest of these row and column penalties is $C_4 = 50$ and it corresponds to the minimum cost 10 in the first row and fourth column. Hence we choose the subcell in the cell (1,4) for supply. Thus, we get $x_{14} = 2$ and hence $x_{13} = 0$, $x_{24} = 2$, $x_{23} = 7$.

Thus, all subcells have been supplied and the capacities of sources and destinations have been exhausted. The final result is

$$x_{11} = 5,\ x_{14} = 2;\ \ x_{23} = 7,\ \ x_{24} = 2;\ \ x_{32} = 8,\ \ x_{34} = 10,$$

and all otherx_{ij} are zero. The corresponding total cost z is

$$z = 19 \times 5 + 10 \times 2 + 40 \times 7 + 60 \times 2 + 8 \times 8 + 20 \times 10 = ₹\ 779.$$

[The solution of example 1 by the above five methods gives the total cost *z* as *z* = (1015, 1110, 779, 814, 779). The third and fifth methods give the less total cost and hence one of them is preferable.]

Example 7

By Vogel approximation (or unit penalty) method, solve the following transportation problem.

O \ D	14	8	23
17	13	15	16
12	7	11	2
16	19	20	9

(i)

Solution:

The transport table is as follows.

O \ D	$b_1 = 5$	$b_2 = 8$	$b_3 = 7$	row penalty R_q
$a_1 = 17$	9 13	8 15	0 16	R_1 9 9 40 40
$a_2 = 12$	5 7	0 11	7 2	R_2 9 9 40 40
$a_3 = 16$	0 19	0 20	16 9	R_3 9 9 40 40
Column Penalty C_p	C_1 6 6 6	C_2 4 4 4	C_3 7 14 x	

Hence $x_{11} = 9$, $x_{12} = 8$, $x_{21} = 5$, $x_{23} = 7$, $x_{33} = 16$, and all other x_{ij} are zero. The total cost z is

$$z = 27 + 120 + 35 + 14 + 144 = 340 \text{ units.}$$

Complexities in transportation

Unbalanced:

In a transportation problem when aggregate supply ≠ aggregate demand then the problem becomes an unbalanced problem

When aggregate supply > aggregate demand---a column representing dummy destination is added to the transportation tableau with a requirement equal to the amount of excess supply and the transportation costs equal to zero

When aggregate supply < aggregate demand---a row representing dummy origin is added to the transportation tableau with a capacity equal to the amount of excess demand and the transportation costs equal to zero

Thereby transportation tableau is balanced and its solution proceeds in exactly the same manner

Prohibited roots:

Sometimes in a given transportation problem some route(s) are notified unavailable.

To handle a situation of this type we assign a very large cost represented by M to each of such routes which are not available. Then the problem is solved in the usual way.

Degeneracy:

We already know that if no. of occupied cells in a basic feasible solution $\neq m+n-1$ then the solution is infeasible and the transportation problem degenerates

Actually degeneracy in a transportation problem can figure in two ways. The problem may become degenerate in the first instance when an initial feasible solution is obtained with above result.

Secondly the problem may become degenerate when two or more cells are vacated simultaneously in the process of transferring units along the closed path while doing MODI

A degeneracy could be resolved by assigning an infinitely small amount ε, close to zero, to one (or more if the need be) empty cell and treat the cell/s as an occupied cell and solve the problem in the usual manner. Always remember

$$k + \varepsilon = K, \varepsilon + \varepsilon = \varepsilon, k - \varepsilon = k, \varepsilon - \varepsilon = 0, 0 + \varepsilon = \varepsilon, k * \varepsilon = 0$$

When the initial basic feasible solution is degenerate we assign ε to an independent empty cell. An independent cell is the one originating from which a closed loop cannot be traced

An ε may be assigned to any of the independent cells but preferably to one with the minimum per unit cost

Maximisation Problem:

A classical transportation problem is one of the minimisation type. However a transportation tableau may contain unit profits instead of unit costs and the objective function be the maximisation of profits. In such and other maximisation types problems, the transportation method is applied as in the case of the minimisation type of problems, except for the difference that in the first stage all the values of the profit matrix are subtracted from the highest profit value in the matrix. Then proceed in the usual manner. Maximum profit is to be calculated referring the original profit value of the assigned cells.

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 tones 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?

Solution:

(i) Table: 1 Cost Matrix

To From	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 and total Demand = 740 tonnes i.e., Supply ≠ Demand.

So this is an unbalanced problem of transpartation. 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)

To From	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~~ ~~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

∴ Penalty = 6 – 0 = 6

(b) For 2nd Row, 2nd lowest cost = 4 and Lowest cost = 0

∴ Penalty = 4 – 0 = 4

(c) For 3rd Row, 2nd lowest cost = 5 and Lowest cost = 0,

∴ 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, ∴ Penalty = 7 – 5 = 2

(b) For 2nd column, 2nd lowest cost = 5 and Lowest cost = 4, ∴ Penalty = 5 – 4 = 1

(c) For 3rd column, 2nd lowest cost = 6 and Lowest cost = 5, ∴ 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 fullfilled, 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 (₹)
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
M_3 - C_3	40 tonnes	40 × 5 = 200
Total	850 tonnes	₹ 3820

Here, m = No. of rows of the matrix = 3

n = No. of columns of the matrix = 4

∴ 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	$C_{14} = 0$	$C_{14} = u_i + v_4$	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	$C_{31} = 7$	$\Delta_{31} = C_{31} - (u_3 + v_4) = 7 - (-1 + 7) = 1$
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 ₹ 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	₹2.5	₹4.0	₹5.0	₹2.0
B	₹3.0	₹3.5	₹5.5	₹1.5
C	₹2.0	₹4.5	₹4.5	₹2.5

Required:

(a) 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.

(b) Explain how you know there is no further improvement possible.

Solution:

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 ≠ 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~~	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~~	0	0	0
Demand		~~100~~	~~200~~	~~450~~	~~150~~	900			
Column Penalties	1st	0.5	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

∴ m + n – 1 = 4 + 4 – 1 = 7

Also no. of allocated cells = 6 ≠ (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	**3** (100)	**1.5**	**0.5** (3)	**3.5** (50)	**150**	$u_1 = 0$
B	**2.5**	**2**	**0** (450)	**4**	**450**	$u_2 = -0.5$
C	**3.5**	**1** (200)	**1**	**3** (50)	**250**	$u_3 = -0.5$
DUMMY	**5.5**	**5.5**	**5.5**	**5.5** (50)	**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}	$C_{11}= 3$	$C_{13}= 0.5$	$C_{14}= 3.5$	$C_{23}= 0$	$C_{32}= 1$	$C_{34}= 3$	$C_{44}= 5.5$

$C_{11} = u_1 + v_1$ or, $3 = 0 + v_1$ [$u_1 = 0$, Assumed] or, $v_1 = 3$

$C_{13} = u_1 + v_3$ or, $0.5 = 0 + v_3$ or, $v_3 = 0.5$; $C_{14} = u_1 + v_4$ or, $3.5 = 0 + v_4$ or, $v_4 = 3.5$

$C_{23} = u_2 + v_3$ or, $0 = u_2 + 0.5$ or, $u_2 = -0.5$; $C_{34} = u_3 + v_4$ or, $3 = u_3 + 3.5$ or, $u_3 = -0.5$

$C_{32} = u_3 + v_2$ or, $1 = -0.5 + v_2$ or, $v_2 = 1.5$; $C_{44} = u_4 + v_4$ or, $5.5 = u_4 + 3.5$ or, $u_4 = 2$

Opportunity Loss figures (Δ_{if}) 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	$\Delta_{24} = C_{24} - (u_2 + v_4) = 4 - (-0.3 + 3.5) = 1$
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 (₹)	Total (₹)
(i)	(ii)	(iii)	(iv)	(v) = (iii) × (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**	–	**₹ 3850**

Maximum Profit = ₹ 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

(a) Find out a distribution plan of products from plants to the warehouses at a minimum cost. What is the minimum cost?

(b) Is there any surplus capacity of the plants? If so, in which plant should we associate that surplus capacity?

(c) Is there any alternate solution for the optimum solution achieved in

Solution:

(a) 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		W_1	W_2	W_3	W_4	W_5	Dummy	Plant Capacity	Raw Penalities					
									1	2	3	4	5	6
F_1		74	56 280	54	62 120	68	0	~~120~~ ~~400~~	54	2	6	6	6	6
F_2		58 200	64	62	58	54 200	0 100	~~400~~ ~~500~~ ~~200~~	* 54	4	4	4	4	-
F_3		66	70	52 240	60 240	60 120	0	~~600~~ ~~360~~ ~~240~~	52	* 8	0	0	0	0
Warehouse Demand		~~200~~	~~280~~	~~240~~	~~360~~	~~120~~ ~~320~~	~~100~~	1500						
Column Penalities	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 = No. of rows = 3

n = 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)

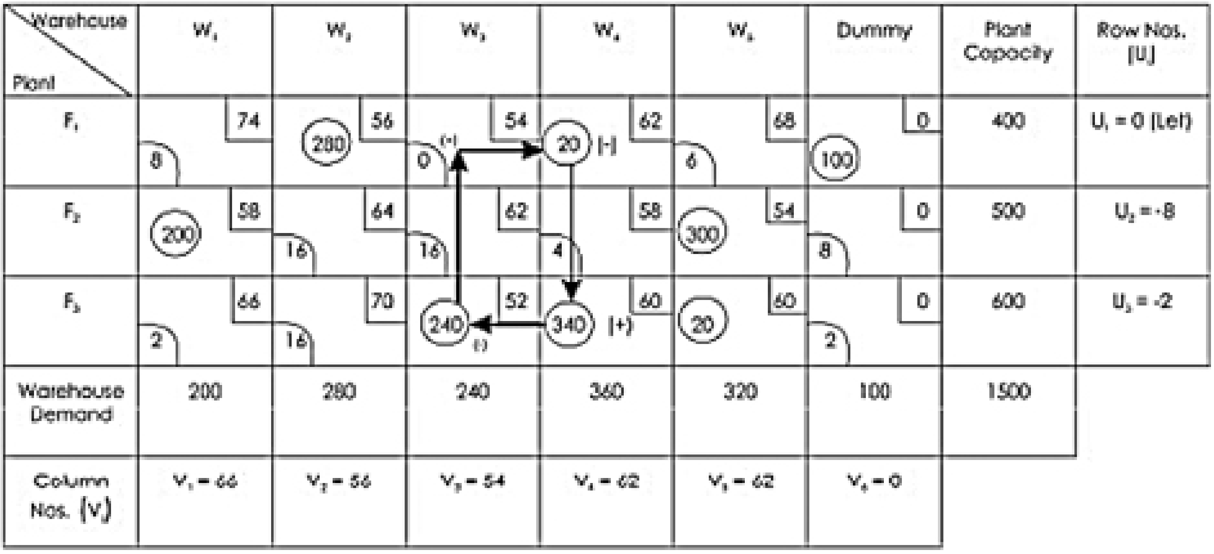
Warehouse / Plant	W_1	W_2	W_3	W_4	W_5	Dummy	Plant Capacity	Row Nos. (U_j)
F_1	74	56 280	54	62 120 (-)	68	0 (+)	400	$u_1 = 8$
F_2	58 200	64	62	58	54 200 (+)	74 100 (-)	500	$u_2 = 0$ (left)
F_3	66	70	52 240	60 240 (+)	60 120 (-)	0	600	$u_3 = 6$
Warehouse Demand	200	280	240	360	320	100	1500	
Column Nos. (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 [$\Delta_{ij} = Cij - (u_i + v_j)$]
$F_1 - W_1$	$\Delta_{11} = C_{11} - (u_1 + v_1) = 74 - (8+58) = 8$
$F_1 - W_3$	$\Delta_{13} = C_{13} - (u_1 + v_3) = 54 - (8+46) = 0$
$F_1 - W_5$	$\Delta_{15} = C_{15} - (u_1 + v_5) = 68 - (8+54) = 6$
F_1 - Dummy	$\Delta_{16} = C_{16} - (u_1 + v_6) = 0 - (8+0) = - 8$
$F_2 - W_2$	$\Delta_{22} = C_{22} - (u_2 + v_2) = 64 - (0+48) = 6$
$F_2 - W_3$	$\Delta_{23} = C_{23} - (u_2 + v_3) = 62 - (0+46) = 16$
$F_2 - W_4$	$\Delta_{24} = C_{24} - (u_2 + v_4) = 58 - (0+54) = 4$
$F_3 - W_1$	$\Delta_{31} = C_{31} - (u_3 + v_1) = 66 - (6+58) = 2$
$F_3 - W_2$	$\Delta_{32} = C_{32} - (u_3 + v_2) = 70 - (6+48) = 16$
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 (F_1 - 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	56 280	54 0 (+)	62 20 (-)	68 6	0 100	400	$U_1 = 0$ (Let)
F_2	58 200	64 16	62 16	58 4	54 300	0 8	500	$U_2 = -8$
F_3	66 2	70 16	52 240 (-)	60 340 (+)	60 20	0 2	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 (D_{ij}) 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 (₹)	Total (₹)
(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	–	₹ 78800

Minimum Cost of Transportation is ₹ 78800

(b) Plant F_1 is having a surplus quantity of 100 units.

(c) Presence of zero opportunity cost (in the cell F_1 -W_3) indicates that alternative optimum solution is possible for the problem. To get the solution, we form a loop starting from the cell F_1 - W_3. 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	56 280	54 20	62	68	0 100	400
F_2	58 200	64	62	58	54 300	0	500
F_3	66	70	52 220	60 360	60 20	0	600
Warehouse Demand	200	280	240	360	320	100	1500

Table-6: Showing Alternative Optimum Distribution Plan

From Plant	To Warehouse	Quantity (Units)	Cost/Unit (₹)	Total (₹)
(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**	–	**₹ 78800**

So the alternative solution is given above.

Illustration 21

A company has 4 factories F_1, F_2, F_3, & F_4 manufacturing the same product. Production & row 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 S_1, S_2, S_3, 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.	F_1	F_2	F_3	F_4	Sales price/unit	Requirement
Production cost/unit	15	18	14	13		
Row 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.

Solution :

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	Availibility
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	Availibility
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, $C_{ij} = ui + v_j$

After getting all u_i and v_j then we calculate the unoccupied cell using the formula given below:

$C_{ij\ -}(ui + v_j)$

where, C_{ij} is the cost of unoccupied cell.

Illustration 22

Departmental store wishes to purchase the following quantities of Sprees:

Types of sprees	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 sprees 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	Sprees				
	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?

Solution:

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:

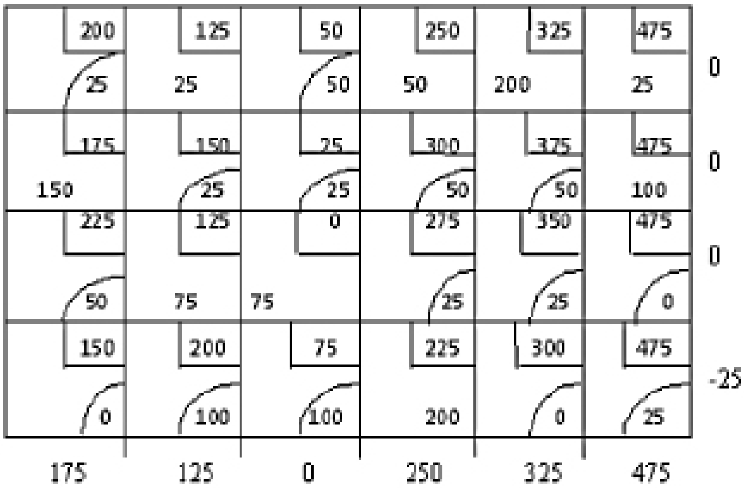
200	125 25	50	250 50	325 200	475 25	**300/275/225/25**
175 150	150	25	300	375	475 100	**250/100/0** **25/25/125/75/5**
225	125 75	0 75	275	350	475	**150/75/0** **125* 100***
150	200	75	225 200	300	475	**200/0**

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
			25	25	0
			50	50	0

M + n – 1 allocation s are there, optimality test can be performed.



200 25	125 25	50 50	250 50	325 200	475 25	0
175 150	150 25	25 25	300 50	375 50	475 100	0
225 50	125 75	0 75	275 25	350 25	475 0	0
150 0	200 100	75 100	225 200	300 0	475 25	-25
175	125	0	250	325	475	

As $\Delta_{ij} \geq 0$, maximum profit is as follows.

			Qty		Maximum Profit
W	⟶	B	25 × 350	=	8750
		D	50 × 225	=	11250
		E	200 × 150	=	30000
		F	25 × 0	=	0
X	⟶	A	150 × 300	=	45000
		F	100 × 0	=	0
Y	⟶	B	75 × 350	=	26250
		C	75 × 475	=	35625
Z	⟶	D	200 × 250	=	50000
Max. Profit.			900	₹	**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	₹ 7, to X	₹ 3, to Y	₹ 6
From B to W	₹ 4, to X	₹ 6 to Y	₹ 8
From C to W	₹ 5, to X	₹ 8 to Y	₹ 4
From D to W	₹ 8 to X	₹ 4 to Y	₹ 3

Solve the above transportation problem.

Solution:

7	3	6	0	5/0	3	3*	-	-	-
4 5	5 6 3	8	0 2	10/8/3/0	4*	2	2*	2	2
5	8	4 7	0	7/0	4	1	1	4	-
8	4	3 3	0	3/0	3	1	1	1	1
5	8	10	2						

0	3	3	0
	0	0	
1	1	1	0
1	1	1	-
1	2	1	
-	2	1	-
-	2	5	-

	W	X	Y	Z	Ui
A	7 6	3 5	6 4	0 3	-3
B	4 5	6 3	8 3	0 2	0
C	5 2	8 3	4 7	0 1	-1
D	8 6	4	3 3	0 1	-2

	W	X	Y	Z	Ui
A	7 6	3 5	6 4	0 3	-3
B	4 5	6 3	8 3	0 2	0
C	5 2	8 3	4 7	0 1	-1
D	8 6	4	3 3	0 1	-2
Vj	4	6	5	0	

As $\Delta_{ij} \geq 0$, the solution is optimum.

Allocation:

				Minimum Cost		
A	→ X	→	5 × 3	=	15
B	→ W	→	5 × 4	=	20
	→ X	→	3 × 6	=	18
	→ Z	→	2 × 0	=	0
C	→ Y	→	7 × 4	=	28
D	→ Y	→	3 × 3	=	9
			25		**₹ 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 (₹)**	**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.

(a) Introduce a suitable dummy warehouse / plant so as to match the capacities of plants and warehouses.

(b) Find distribution pattern so as to maximise profit / minimise loss.

(c) Interpret zero value of square evaluation of an empty cell and find alternative solutions.

Solution:

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 **40**	**8** **40**	**3**	**80/40/0**	**3/3/5**
0 **110**	**8**	**4**	**110/2**	**4***
5	**10** **20**	**4** **130**	**150/20/0**	**1/1/6***
6	**6** **40**	**6**	**10/0**	**0/0/0**
150	**100**	**130**		
40	**0**	**0**		

0		
0	**2**	**1**
5*	**2**	**1**
	2	**1**

			U
0 40	8 40	3 1	0
0 110	8 0	4 2	0
5 3	10 20	4 130	2
6 4	6 40	6 6	-2
0	8	2	

As there are m+n-1 allocations, optimality test can be performed since $\Delta_{ij} \geq 0$,

		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	**₹ 1000**

Profit ₹ 1,000/-

Job Evaluation, Job Allocation - Assignment

4.6

Job Evaluation:

Job evaluation is the ranking grading, and weighing of essential work characteristics of all jobs in order to find out or rate the worth of jobs. It is a systematic approach to ascertain the labour worth of each job and is a very important concern of all employers.

Job evaluation aims at fairness and consistency so far as all wages and salaries are concerned within an organisation and when systematic and impartial, it stimulates, confidence of the employees. There are three steps for evaluations of all jobs :–

(i) Preparation of preliminary description of each existing job.

(ii) Analysing each job to arrive at final job descriptions and specifications.

(iii) Analysing each job according to its approved description in order to determine its worth or value.

Job Description and Specifications: The understanding of the job content or job description is the primary requirement.

Job specifications are derived from the job descriptions which have already been approved. The specification help determining the qualification required of the individual desired for the position. This in turn guides the personnel department in the selection of employees and also guides shop executives in the placement of workmen.

Systems of Valuation: There are several systems of job evaluation.

The fundamental criteria in valuation of a job into account are to make a specific list of factors which affect job values. The many factors are:

(i) Qualifications required of the worker,

(ii) Job difficulties,

(iii) Job responsibilities,

(iv) Working conditions.

All these factors are to be analysed in detail in order to complete the job description. The list of factors, the manner in which they are apprised and the method of finding out relative worth and money values distinguishes the various systems of valuation.

The systems of valuations which are commonly adopted are given below:

1. The ranking or grading method,
2. The factor comparison method,
3. Point rating method.

Ranking or Grading Method: Under this system the titles of all jobs are written on cards and the grading is done by several competent judges. The hourly rates to be paid for different jobs are suggested by the judges without any consideration to the existing wage. The ranks or grades assigned to each job by all the judges are averaged and this average is considered the "score" for that job. Hourly rates are then fixed for jobs according to their ranking.

Factor Comparison Method: The factor comparison method analyses the job into much greater detail than the grading method. It ranks each job with respect to each factor that characterise the job and the factors are taken one at a time.

All jobs are compared and ranked first with respect to mental requirements, then skill, then physical requirements and after that responsibility and lastly working conditions. The total worth of the job is obtained by adding together money values which are assigned separately to the various levels of rank in each factor. Factor comparison method is more accurate than the simple ranking systems, since the separate factors are analysed comparatively. This method is flexible.

Point Rating Method: There are three methods of analytical evaluation of a job. They are:

1. Straight point method.
2. Weighted point method.
3. Valuation of jobs directly in money method, not specifying any maximum weight.

(i) Straight Point Method:

This method assigns equal weights for each characteristic. When evaluating a job under this system, it is assumed that all the characteristics have ranges of values between same maximum and minimum points.

(ii) Weighted Point Method:

In this method different points are assigned to the different characteristics of doing jobs.

(iii) Direct to Money Methods:

After selecting the job characteristics, ten key jobs whose rates are believed to be correct, are taken and the present wage rates of these jobs are distributed to the job characteristics by each analyst. The jobs are then ranked by the analysts for each characteristic in order of the degree to which that characteristic is present. This serves as a check to show up any errors made in the original distribution of the wages rate to the various characteristics.

Assignment

Assignment is a special linear programming problem. There are many situations where the assignment of people or machines etc. may be called for. Assignment of workers to machines, clerks to various check-out counters, salesmen to different sales areas are typical examples of these. The Assignment is a problem because people possess varying abilities for performing different jobs and therefore the costs of performing jobs by different people are different. Thus, in an assignment problem, the question is how the assignments should be made in order that the total cost involved is minimized.

There are four methods of solving an assignment problem and they are:

1. Complete Enumeration Method
2. Simplex Method
3. Transportation Method and
4. Hungarian Method

Hungarian Method:

The following are the steps involved in the minimization of an assignment problem under this method:

Step 1: Row Operation

Locate the smallest cost element in each row of the given cost table. Now subtract this smallest element from each element in that row. As a result, there shall be at least one zero in each row of this new table, called the reduced cost table.

Step 2: Column Operation

In the reduced cost table obtained, consider each column and locate the smallest element in it. Subtract the smallest value from every entry in the column. As a consequence of this action, there would be at least one zero in each of the rows and columns of the second reduced cost table.

Step 3: Optimality

Draw the minimum no. of horizontal and vertical lines (not the diagonal ones) that are required to cover all the zero elements. If the no. of lines drawn is equal to 'n' (the no. of rows/columns of the given Cost Matrix) the solution is optimal and proceed to step 6. If the no. of lines drawn is smaller than 'n' go to step 4.

Step 4: Improved Matrix

Select the smallest uncovered (by the lines) cost element. Subtract this element from all uncovered elements including itself and add this element to each value located at the intersection of any two lines. The cost elements through which only one line passes remain unaltered.

Step 5: Repeat step 3 and 4 until an optimal solution is obtained.

Step 6: Given the optimal solution, make the job assignments as indicated by the 'zero' elements. This is done as follows:

(a) Locate a row which contains only one zero element. Assign the job corresponding to this element to its corresponding person. Cross out the zero's if any in the column corresponding to the element, which is indicative of the fact that the particular job and person are no more available.

(b) Repeat (a) for each of such rows which contain only one zero. Similarly, perform the same operation in respect of each column containing only one 'zero' element, crossing out the zero(s), if any, in the row in which the elements lies.

(c) If there is no row or column with only a single 'zero' element left, then select a row/column arbitrarily and choose one of the jobs (or persons) and make the assignment. Thus in such a case, alternative solutions exist.

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					
		1	2	3	4	5	6
Men	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.

Solution:

Job 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 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 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

Job Man	**1**	**2**	**3**	**4**	**5**	**6**
1	$\boxed{0}$	7	0	4	1	0
2	4	6	5	3	6	$\boxed{0}$
3	2	4	3	$\boxed{0}$	0	0
4	2	$\boxed{0}$	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 ≠ 6, the solution is non optimal.

Table - 4

Job Man	**1**	**2**	**3**	**4**	**5**	**6**
1	$\boxed{0}$	7	0	4	1	1
2	3	5	4	2	5	$\boxed{0}$
3	2	4	3	$\boxed{0}$	0	1
4	2	$\boxed{0}$	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 ≠ 6 (order of the matrix). So the solution is non optimal.

Table - 5

Job Man	**1**	**2**	**3**	**4**	**5**	**6**
1	$\cancel{0}$	9	$\boxed{0}$	6	3	3
2	1	5	2	2	5	$\boxed{0}$
3	$\boxed{0}$	4	1	$\boxed{0}$	$\cancel{0}$	1
4	0	0	3	0	2	1
5	0	$\boxed{0}$	4	1	3	$\cancel{0}$
6	4	5	7	9	$\boxed{0}$	$\cancel{0}$

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

Job Man	**1**	**2**	**3**	**4**	**5**	**6**
1	$\xcancel{0}$	9	$\boxed{0}$	6	3	3
2	1	5	2	2	5	$\boxed{0}$
3	$\boxed{0}$	4	1	$\xcancel{0}$	$\xcancel{0}$	1
4	$\xcancel{0}$	$\xcancel{0}$	3	$\boxed{0}$	2	1
5	$\xcancel{0}$	$\boxed{0}$	4	1	3	$\xcancel{0}$
6	4	5	7	9	$\boxed{0}$	$\xcancel{0}$

Table - 7 Showing Optimum Solution - 2

Job Man	**1**	**2**	**3**	**4**	**5**	**6**
1	$\xcancel{0}$	9	$\boxed{0}$	6	3	3
2	1	5	2	2	5	$\boxed{0}$
3	$\xcancel{0}$	4	1	$\boxed{0}$	$\xcancel{0}$	1
4	$\boxed{0}$	$\xcancel{0}$	3	$\xcancel{0}$	2	1
5	$\xcancel{0}$	$\boxed{0}$	4	1	3	$\xcancel{0}$
6	4	5	7	9	$\boxed{0}$	$\xcancel{0}$

Table - 8 Showing Optimum Solution - 3

Job Man	**1**	**2**	**3**	**4**	**5**	**6**
1	$\xcancel{0}$	9	$\boxed{0}$	6	3	3
2	1	5	2	2	5	$\boxed{0}$
3	$\xcancel{0}$	4	1	$\boxed{0}$	$\xcancel{0}$	1
4	$\xcancel{0}$	$\boxed{0}$	3	$\xcancel{0}$	2	1
5	$\boxed{0}$	$\xcancel{0}$	4	1	3	$\xcancel{0}$
6	4	5	7	9	$\boxed{0}$	$\xcancel{0}$

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:

		Batting Position				
		III	**IV**	**V**	**VI**	**VII**
Batsmen	**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.

Solution:

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.

	Batting Position				
Batsman	**III**	**IV**	**V**	**VI**	**VII**
A	40	40	35	25	50

	Batting Position				
Batsman	**III**	**IV**	**V**	**VI**	**VII**
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*

	Batting Position				
Batsman	**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 matrixfrom the highest element (60) of it.

Row Operation Matrix

	Batting Position				
Batsman	**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 Batsman	III	IV	V	VI	VII
A	10	10	14	25	$\boxed{0}$
B	$\boxed{0}$	12	25	17	15
C	10	12	19	$\boxed{0}$	10
D	5	$\boxed{6}$	4	7	0
E	2	0	0	5	7

Minimum no. of horizontal and vertical straight lines to cover all the zeros = 4 ≠ 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	$\boxed{0}$
B	$\boxed{0}$	8	21	17	15
C	10	8	15	$\boxed{0}$	10
D	5	2	$\boxed{0}$	7	~~0~~
E	6	$\boxed{0}$	~~0~~	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?

Solution:

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 ≠ order of the matrix (6). So the solution is non optimal.

Improved matrix

Operator	Machines					
	M_1	M_2	M_3	M_4	M_5	M_6
01	$\xcancel{0}$	2	$\boxed{0}$	1	4	5
02	$\boxed{0}$	1	2	1	$\xcancel{0}$	3
03	$\xcancel{0}$	5	2	$\boxed{0}$	3	2
04	3	3	1	2	$\boxed{0}$	6
05	3	$\boxed{0}$	$\xcancel{0}$	3	2	1
06	2	3	3	6	7	$\boxed{0}$

Minimum no. of horizontal and vertical straight lines to cover all the zeros = 6 = Order of the matrix. So the solution is optimal.

Optimal Assignment

Operators	01	→	M_3	-	2
	02	→	M_1	-	4
	03	→	M_4	-	4
	04	→	M_5	-	3
	05	→	M_2	-	3
	06	→	M_6	-	1

17 Hours Minimum Operation Time

(b) & (c)

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
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 coresponding 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	$\boxed{0}$	2	0	0	5	6	7
02	0	1	2	$\boxed{0}$	1	4	0
03	2	7	4	1	6	5	$\boxed{0}$
04	2	2	0	0	$\boxed{0}$	6	1
05	3	$\boxed{0}$	0	2	3	2	11
06	1	2	2	4	7	$\boxed{0}$	5
Dummy	0	1	$\boxed{0}$	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	0	2	$\boxed{0}$	0	5	6	7
02	0	1	2	$\boxed{0}$	1	4	0
03	2	7	4	1	6	5	$\boxed{0}$
04	2	2	0	0	$\boxed{0}$	6	1
05	3	$\boxed{0}$	0	2	3	2	11
06	1	2	2	4	7	$\boxed{0}$	5
Dummy	$\boxed{0}$	1	0	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	0	2	0	$\boxed{0}$	5	6	7
02	$\boxed{0}$	1	2	0	1	4	0
03	2	7	4	1	6	5	$\boxed{0}$
04	2	2	0	0	$\boxed{0}$	6	1
05	3	$\boxed{0}$	0	2	3	2	11
06	1	2	2	4	7	$\boxed{0}$	5
Dummy	0	1	$\boxed{0}$	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	M_1	2	01	M_3	5	01	M_4	1
02	M_4	3	02	M_4	1	02	M_1	4
03	New	1	03	New	6	03	New	1
04	M_5	3	04	M_5	0	04	M_5	3
05	M_2	3	05	M_2	3	05	M_2	3
06	M_6	1	06	M_6	7	06	M_6	1
Dummy	M_3	0	Dummy	M_1	3	Dummy	M_3	0
Total	–	13*	**Total**	–	13*	**Total**	–	13*

* Minimum Operation Time

From above it can be said that replaement 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 M_3 should be replaed by a New Machine and as per Solution (iii), M_1 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:

		Region					
		I	**II**	**III**	**IV**	**V**	**VI**
Salesmen	**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)

(a) Find the allocation to give minimum cost. What is the minimum cost?

(b) 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.

(c) 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.

Solution:

Salesman	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

Matrix after Row Operation

Salesman	Region					
	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	15	10	25	0	15	50
E	25	65	35	0	35	45
F	0	15	20	30	40	5

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 ≠ Order of the matrix (6). So the solution is non optimal.

Improved Matrix (Optimal)

Salesman	Region					
	I	II	III	IV	V	VI
A	~~20~~	~~35~~	$\boxed{0}$	~~30~~	$\cancel{0}$	~~45~~
B	~~40~~	$\boxed{0}$	~~40~~	~~20~~	$\cancel{0}$	~~15~~
C	~~20~~	~~50~~	$\cancel{0}$	~~60~~	~~5~~	$\boxed{0}$
D	15	5	20	$\cancel{0}$	$\boxed{0}$	45
E	25	60	30	$\boxed{0}$	~~20~~	40
F	$\boxed{0}$	~~10~~	~~15~~	~~30~~	~~30~~	$\cancel{0}$

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 (₹)
A	III	0
B	II	5
C	VI	10
D	V	25
E	IV	5
F	I	10
Total		**₹ 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

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

Matrix after Row Operation

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 ≠ Order of the matrix (6). So the solution is non optimal.

Improved Matrix

Salesman	Region					
	I	II	III	IV	V	VI
A	5	10	25	20	35	0
B	0	60	0	15	50	45
C	15	5	35	0	40	55
D	10	40	5	50	35	0
E	15	0	10	65	30	20
F	15	25	0	10	0	35

Here minimum no. of horizontal and vertical straight lines to cover all the zeros = 5 ≠ Order of the matrix (6). So the solution is optimal.

Improved Matrix (Optimal)

Salesman	Region					
	I	II	III	IV	V	VI
A	$\boxed{0}$	10	20	20	30	$\cancel{0}$
B	$\cancel{0}$	65	$\boxed{0}$	50	50	50
C	10	5	30	$\boxed{0}$	35	55
D	5	40	$\cancel{0}$	50	30	$\boxed{0}$
E	10	$\boxed{0}$	5	65	25	20
F	15	30	$\cancel{0}$	15	$\boxed{0}$	40

Table Showing Optimal Allocation

Salesman	Region	Earning (₹)
A	I	15
B	III	45
C	IV	65
D	VI	60
E	II	70
F	V	50
Total		**₹ 305**

Maximum Earning

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	α	45
	B	40	5	45	20	15	10
	C	25	60	10	65	25	10
	D	25	20	35	10	25	60
	E	30	α	40	5	40	50
	F	10	25	30	40	50	15

Cost (figures are in ₹)

(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			
		A	**B**	**C**	**D**
Jobs	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.

Solution:

Relative Loss Matrix

M/cs **Jobs**	**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 Maximisation, the same is converted to one of Minimisation 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 42 in this case)

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 ≠ 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 ≠ 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	$\boxed{0}$	2	4	7
II	$\cancel{0}$	$\boxed{0}$	$\cancel{0}$	1
III	$\cancel{0}$	$\cancel{0}$	$\boxed{0}$	1
IV	2	1	$\cancel{0}$	$\boxed{0}$

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)

M/cs Jobs	A	B	C	D
I	$\boxed{0}$	2	4	7
II	$\cancel{0}$	$\cancel{0}$	$\boxed{0}$	1
III	$\cancel{0}$	$\boxed{0}$	$\cancel{0}$	1
IV	2	1	$\cancel{0}$	$\boxed{0}$

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**

Maximum Profit ₹ 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 minimised?

Solution:

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 elemen 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	–	$\boxed{0}$	4	5	2
B	$\cancel{0}$	–	2	4	$\boxed{0}$
C	$\cancel{0}$	1	–	$\boxed{0}$	1
D	$\cancel{0}$	3	$\boxed{0}$	–	1
E	$\boxed{0}$	1	3	5	–

* This matrix is obtained by subtracting minimum clement 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 bleow.

To / From	A	B	C	D	E
A	–	$\boxed{0}$	4	5	2
B	$\cancel{0}$	–	2	4	$\boxed{0}$
C	$\boxed{0}$	1	–	$\cancel{0}$	1
D	$\cancel{0}$	3	$\boxed{0}$	–	1
E	$\cancel{0}$	1	3	$\boxed{5}$	–

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 omplete route of the Salesman is : A → B → E → D → C → A

Total distance travelled = 12 + 7 + 25 + 22 + 10 = 76 Kms.

This is the optimum distance.

Scheduling and Queuing Models

4.7

Scheduling: 'Scheduling' is the next important function of production planning and control after 'Routing'. It determines the starting and the completion timings for each of the operations with a view to engage every machine and operator of the system for the maximum possible time and; without imposing unnecessary burden over them. Scheduling is the determination of the time that should be inquired to perform each operation and also the time that should be required to perform the entire series as routed. Scheduling involves establishing the amount of work to be done and the time when each element of the work will start or the order of the work.

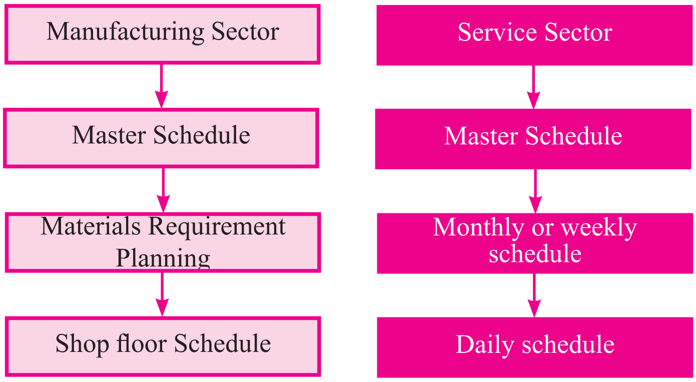
Scheduling technique is an important technique of determining the starting and the completion timings of each operation and that of the total manufacturing process so that the man and machines can be utilised to the maximum.

Scheduling depends upon a number of factors, e.g., routing, the method of production, quantity of production, transportation of raw materials, production capacity, the probable data of delivery specified by customers in their orders and the past records.

Relationship between Routing and Scheduling: 'Routing' and 'Scheduling' are interconnected and either of these activities cannot be undertaken independently. It is very difficult to prepare schedules without determining the routing of sequence of operations. Routing is a prerequisite for scheduling while time to be taken 'may form the basis of routing and that is fixed by scheduling. Unless route or sequence of operations, tools, equipment and plants and the persons by when operations are to be performed, are established, the time taken by each operation, the idle time of men and machine and total time for the whole process cannot be ascertained in a convincing manner.

Conversely, scheduling is equally important for routing. It is quite difficult to route an item efficiently through a plant without consulting previously-designed schedules. The main aim of routing is to pass the item through the process of manufacture by a route which is the best and the most economical. And a route or sequence of operations may be considered best which utilises the men, materials and machines to the maximum and which consumes the shortest time during the process of production. This information (time schedule of each operation) can be obtained from schedules. So, scheduling is necessary for effective routing.

Thus, we can conclude that routing and scheduling are inter-related, inter-connected and inter-dependent activities of production planning and control.



Principles of Scheduling:

The principles of scheduling are:

(a) **The principle of optimum task size:** Scheduling tends to achieve its maximum efficiency when the task sizes are small and all tasks are of the same order of magnitude.

(b) **The principle of the optimum Production plan:** Scheduling tends to achieve its maximum efficiency when the work is planned, so that it imposes an equal/even load on all the plants/facilities.

(c) **The principle of the optimum operation sequence:** Scheduling tends to achieve its maximum efficiency when the work is planned so that the work centers are normally used in the same sequence.

The first principle has a tendency when applied, not only give good results but also to be self-correcting if it is ignored. For example, if in a functional batch production machine shop the loads imposed by different operations vary greatly in length then it is possible that it will be necessary to break many of the long operations into one or more small batches, in order to get the other orders completed by due date. In effect, this principle only repeats the known advantage of maintaining a high rate of stock turn over, and of single phase ordering. The second principle merely states the obvious fact that there will be less idle time and waiting time, if all the plant is evenly loaded by the production planners, even if some of the machines are over loaded perhaps because of direct labour cost on them being lower and others are idle for part of the time due to shortage of work. The third principle says about principle of flow. Some times it is also true if we sequence some jobs, which need the same machine set up, at a time, this avoids machine ancillary time needed, in case, the jobs of the above type are done at different times. For example, consider drilling a 10 mm hole in five different jobs may be done at a time so that the set up time required for five jobs can be reduced.

Forms of Schedules:

Here we shall discuss the presentation of production schedules. Depending on the need and use, the Schedules can be prepared in different forms.

A Production Flow Program:

If a number of components or assemblies have to be manufactured for the final assembly line and those components are to be made concurrently, the production master flow program is prepared taking into account the sequence of operations and the time of starting and ending of each component in order to comply with the required date of completion of the product. The necessary document for this is Operation Process Chart and the Sequence of Operation.

Scheduling Systems:

Scheduling Systems may be classified into various groups as shown below:

(i) **Unit scheduling system:** This is used for scheduling when jobs are produced one by one and are of different types that is for job production.

(ii) **Batch scheduling system:** When jobs are produced to order, in batches, this is used.

(iii) **Mass scheduling system:** When large number of items of similar type are produced that is in mass production, this is used.

Unit Scheduling System:

Here we have two types of scheduling, one is Project scheduling and the other is Job Shop Scheduling.

Project Scheduling: Generally, a project consists of number of activities managed by different Apartments or individual supervisors. It can also be considered as a complex output made up of many interdependent activities. Examples are: Railway coach building, Shipbuilding etc. The scheduling methods used are:

(i) Project Evaluation and Review Technique (PERT),

(ii) Critical Path Method (CPM),

(iii) Graphical Evaluation and Review Technique (GERT).

We can also use Bar charts, GANTT charts, Milestone chart, but these are less superior to the above.

Job Shop Scheduling:

In Job shop scheduling, we come across varieties of jobs to be processed on different types of machines. Separate records are to be maintained for each order. Only after receiving the order, one has to plan for production of the job. The routing is to be specified only after taking the order. Scheduling is done to see that the available resources are used optimally. The following are some of the factors taken into consideration for job shop scheduling. (i) Arrival pattern of the job, (ii) Processing pattern of the job, (iii) Depending on the type of machine used, (iv) Number of workers available in the shop, (v) Order of sequencing.

Arrival pattern of the job:

This is done in two ways. Firstly, as and when the order is received, it is processed on the principle of First in First Out (FIFO). Otherwise, if the orders are received from single customer at different points of time in a week/ month, then the production manager pile up all the orders and starts production depending on the delivery date and convenience (This situation is generally known as static situation).

Processing Pattern of the Job:

As the layout of Job shops is of Process type and there may be duplication of certain machines, the production planner, after receiving the order thinks of the various methods of converting the requirement of customer / order into a production plan to suit the available facilities. Depending on the process required, there may be backtracking, which is unavoidable. When facilities are busily engaged, in process inventory may be a common problem.

Machine varieties available:

Facilities available in the production shop will affect the scheduling. Here the size, capacity, precession and other factors of machines will have their influence on the scheduling.

Number of Men in the production shop:

Many a time we see that the number of workers available in the job shops are very much limited, that is sometimes they are less in number than the machines in the shop (these shops are known as labour limited shop). Depending on the availability of labour, the scheduling is to be done. In case the machines available are limited and have more men (known as machine limited shops), then availability of machine dictates the scheduling.

Objectives of scheduling are to achieve trade-offs, among conflicting goals which include efficient utilisation of staff, equipment and facilities and minimisation of customer waiting time, inventories and process times.

$$\text{Scheduling} = f\,(\text{volume of output from a system})$$

In high volume systems (like car manufacturing, toy manufacturing, petroleum refining, news broadcasts etc) *flow shop scheduling* is followed where decisions of loading and sequence of operation of highly sophisticated machines, tools, division of labor etc are determined at the time of designing the system. A major aspect in flow shop scheduling is *Line balancing* which concerns allocating the required tasks to work stations in order to satisfy technical constraints and are balanced to avoid bottlenecks.

In low volume or Job shop systems (where products are made to order), since scheduling/sequencing decisions are not designed at onset, there are two basic issues for scheduling:

- Distribution of workload among work centers
  - ➢ Loading of work centers with assignment of jobs—mainly done through Assignment method
- Job process sequencing
  - ➢ When more than one job is assigned to a machine or activity, the operator needs to know the order in which to process the jobs. The process of prioritizing jobs is called Sequencing.

Scheduling are of two types

- Forward scheduling—scheduling ahead from a point of time
  - ➢ Used if the issue is “How long will it take to complete the job”
- Backward Scheduling—scheduling backward from a due date
  - ➢ Used if the issue is “When is the latest the job can be started and still be completed by the due date?”

Assignment method was discussed earlier. In this chapter Sequencing is exemplified.

After the work center has been loaded (i.e. after identifying specific jobs which are to be processed in a work center) dispatching of jobs i.e. sequencing is carried out according to Priority Rules.

Priority rules are simple heuristics used to select the order in which the jobs will be processed. Priority rules can be classified as either local or global. Local priority rules take into account information pertaining only to a single workstation. Global priority rules take into account information pertaining to multiple workstation.

Some of the most common priority rules are:

- First Come First Served (FCFS): Jobs are run in the order in which they are received;
- Shortest Operations Time (SOT): Run the job with the shortest completion time first, next shortest second and so on. This is also referred to as Shortest Processing Time (SPT);
- Due Date (DDATE): Run the jobs in the order of their due dates starting with the job with the earliest due date first;

- Slack Time Remaining (STR): It is the difference between the time remaining to due date and the remaining processing time. Jobs are scheduled in the order of the slack time remaining with the one having the least slack time remaining scheduled first.
  - ➢ STR = (Due Date – Today's date) – Remaining processing time;
- Critical Ratio (CR): It is the ratio between the time remaining and the work remaining. The job with the least critical ratio is scheduled first.
  - ➢ $CR = \frac{\text{(Due Date)-(Today's date)}}{\text{Remaining Processing Time}}$;
  - ➢ If CR > 1, then the job is ahead of schedule;
  - ➢ If CR < 1, then the job is behind the schedule;
  - ➢ If CR = 1, then the job is exactly on schedule;
- Last Come First Served (LCFS): This generally occurs by default. As jobs arrive they are put on top of the stack. The operator usually picks up the job on top to run first;
- Longest Processing Time (LPT): Jobs are run as per their processing time, the one with the longest processing time being run first.

FCFS, SOT, DDATE are local priority rules whereas STR, CR are global priority rules.

A number of assumptions apply when using the priority rules:

➢ The set of jobs is known. No new jobs arrive after processing begins and no jobs are cancelled;

➢ Set up time is considered negligible;

➢ Processing time and due dates are fixed;

➢ There will be no interruption in processing such as machine breakdowns, accidents or worker illness;

In effect priority rules pertain to static sequencing. In practice jobs may be delayed or cancelled and new jobs may arrive, requiring schedule revisions.

Let us apply these rules with the help of an illustration applicable to sequencing of a number (n) of jobs on one machine.

In the following illustration we will see that the completion time (also called Flow Time) of each job will differ depending on its place in the sequence but the overall completion time for the set of jobs (called the Makespan) will not change.

Job flow time is the amount of time it takes from when a job arrives until it is completed.

Makespan is the total time needed to complete a group of jobs.

Tardiness (delay) measures the difference between a job's due date and its completion time for jobs completed after their due date.

Example: The following table contains information regarding jobs that are to be scheduled through one machine.

Job	Processing time (days)	Due date (days hence)
A	11	16
B	10	15

C	2	12
D	4	20
E	12	30
F	6	10
G	3	5

Draw up the schedule using different priority rules and compare the results.

Answer:

i) Scheduling the jobs on First Come First Served (FCFS) basis will result in the following schedule:

Job Sequence	Processing Time(Days)	Due Date (days hence)	Start Date	Finish Date	Delay
A	11	16	0	11	0
B	10	15	11	21	6
C	2	12	21	23	11
D	4	20	23	27	7
E	12	30	27	39	9
F	6	10	39	45	35
G	3	5	45	48	43

Start date of Job A = 0, Finish Date of Job A = 0 + processing time

Start date of subsequent job = Finish date of preceding job.

Finish date of subsequent job = Start date + Processing time.

Delay of a job = Finish date – Due date.

Flow time = (11+21+23+27+39+45+48) = 214 days

From the above table it is clear that Job A is completed in time. Jobs B, C, D, E, F, G are delayed and average delay time is

$$\frac{(0+6+11+7+9+35+43)}{7} = 15.86 \text{ days}$$

ii) Shortest Operation Time (SOT) method schedules jobs according to their operations time running the one with the shortest operations time first. The result is shown below:

Job Sequence	Processing Time(Days)	Due Date (days hence)	Jobs Scheduled First	Start Date	Finish Date	Delay
A	11	16	C	0	2	0
B	10	15	G	2	5	0
C	2	12	D	5	9	0
D	4	20	F	9	15	5
E	12	30	B	15	25	10
F	6	10	A	25	36	20
G	3	5	E	36	48	18

Job C is having the least processing time (2) followed by G(3), D(4), F(6), B(10), A(11) and E(12)

Start date of Job C = 0, Finish Date of Job C = 0 + processing time

Start date of subsequent job = Finish date of preceding job.

Finish date of subsequent job = Start date + Processing time.

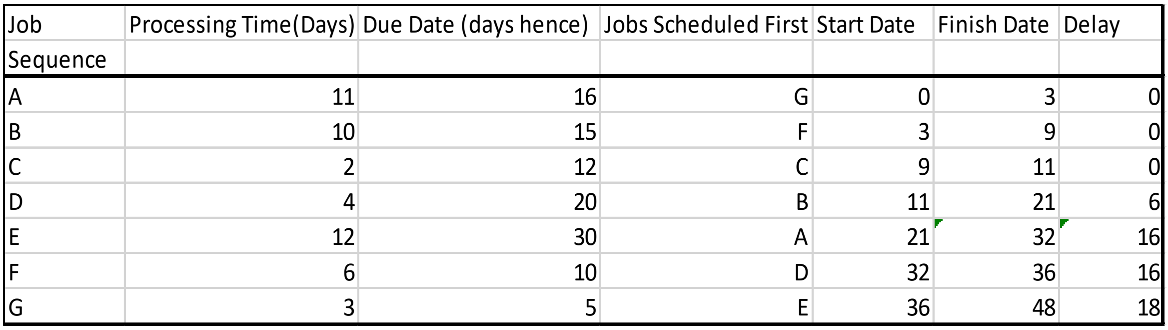
Delay of a job = Finish date – Due date.

Flow time = (2+5+9+15+25+36+48) = 140 days

From the above table it is clear that Jobs C, G and D are completed in time. Jobs F, B, A, E are delayed and average delay time is

$$\frac{(0+0+0+5+10+20+18)}{7} = 7.57 \text{ days}$$

iii) Due Date (DDATE) method schedules jobs with the earliest due date first. Under this method the result is shown below:



Job Sequence	Processing Time(Days)	Due Date (days hence)	Jobs Scheduled First	Start Date	Finish Date	Delay
A	11	16	G	0	3	0
B	10	15	F	3	9	0
C	2	12	C	9	11	0
D	4	20	B	11	21	6
E	12	30	A	21	32	16
F	6	10	D	32	36	16
G	3	5	E	36	48	18

Job G is having the earliest due date (5) followed by F(10), C(12), B(15), A(16), D(20) and E(30)

Start date of Job G = 0, Finish Date of Job G = 0 + processing time

Start date of subsequent job = Finish date of preceding job.

Finish date of subsequent job = Start date + Processing time.

Delay of a job = Finish date – Due date.

Flow time = (3+9+11+21+32+36+48) = 160 days

From the above table it is clear that Jobs G, F and C are completed in time. Jobs B, A, D, E are delayed and average delay time is

$$\frac{(0+0+0+6+16+16+18)}{7} = 8 \text{ days}$$

iv) Slack Time Remaining (STR) method schedules job on slack time basis with job with least slack time scheduled first.

Slack Time Remaining of a job = (Due date- Today's Date) – Processing time

The result under this method is shown below

Job sequence	Processing times (days)	Due date (day hence)	Slack time remaining	Job schedule first	Start date	Finish date	delays
A	11	16	5	G	0	3	0
B	10	15	5	F	3	9	0
C	2	12	10	B	9	19	4
D	4	20	16	A	19	30	14
E	12	30	18	C	30	32	20
F	6	10	4	D	32	36	16
G	3	5	2	E	36	48	18

Job G is having the least slack time remaining (2) followed by F(4), B(5), A(5), C(10), D(16) and E(18)

Start date of Job G = 0, Finish Date of Job G = 0 + processing time

Start date of subsequent job = Finish date of preceding job.

Finish date of subsequent job = Start date + Processing time.

Delay of a job = Finish date – Due date.

Flow time = (3+9+19+30+32+36+48) = 177 days

Slack time remaining for Job A and B are equal. We have chosen B first than A, as B has less processing time than that required by A. If A is chosen first then Average delay time will come around 10.42 days

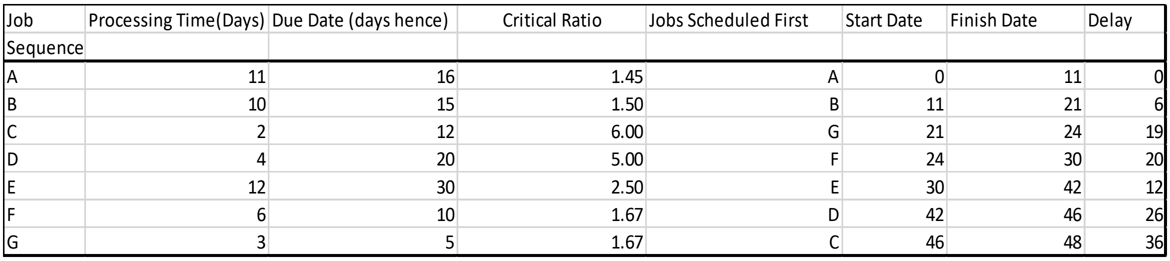
From the above table it is clear that Jobs G, F are completed in time. Jobs B, A, C, D, E are delayed and average delay time is

$$\frac{(0+0+4+14+20+16+18)}{7} = 10.29 \text{ days}$$

v) Critical Ratio (CR) schedules job with least critical ratio first.

$$\text{Critical Ratio of a job} = \frac{\text{Due Date-Today's Date}}{\text{Remaining Processing time}}$$

Under this method the result is given below:



Job Sequence	Processing Time(Days)	Due Date (days hence)	Critical Ratio	Jobs Scheduled First	Start Date	Finish Date	Delay
A	11	16	1.45	A	0	11	0
B	10	15	1.50	B	11	21	6
C	2	12	6.00	G	21	24	19
D	4	20	5.00	F	24	30	20
E	12	30	2.50	E	30	42	12
F	6	10	1.67	D	42	46	26
G	3	5	1.67	C	46	48	36

Job A is having the least CR (1.45) followed by B(1.50), G(1.67), F(1.67), E(2.5), D(5) and C(6)

Start date of Job A = 0, Finish Date of Job A = 0 + processing time

Start date of subsequent job = Finish date of preceding job.

Finish date of subsequent job = Start date + Processing time.

Delay of a job = Finish date – Due date.

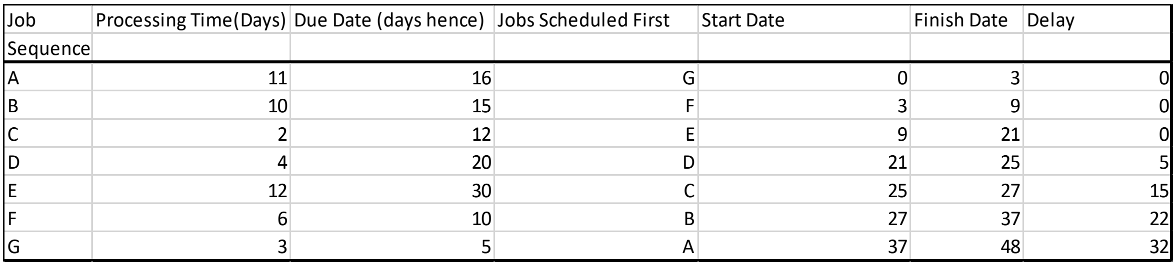
Flow time = (11+21+24+30+42+46+48) = 222 days

CR for Job F and G are equal. We have chosen G first than F, as G has less processing time than that required by F. If F is chosen first then Average delay time will come around 17.43 days

From the above table it is clear that Job A is completed in time. Jobs B,G, F, E, D and C are delayed and average delay time is

$$\frac{(0+6+19+20+12+26+36)}{7} = 17 \text{ days}$$

vi) Last Come First Served (LCFS) schedules jobs on last come first served basis assuming jobs arrive in alphabetic order i.e. A came first and G came last. The result is given below:



Job Sequence	Processing Time(Days)	Due Date (days hence)	Jobs Scheduled First	Start Date	Finish Date	Delay
A	11	16	G	0	3	0
B	10	15	F	3	9	0
C	2	12	E	9	21	0
D	4	20	D	21	25	5
E	12	30	C	25	27	15
F	6	10	B	27	37	22
G	3	5	A	37	48	32

Start date of Job G = 0, Finish Date of Job G = 0 + processing time

Start date of subsequent job = Finish date of preceding job.

Finish date of subsequent job = Start date + Processing time.

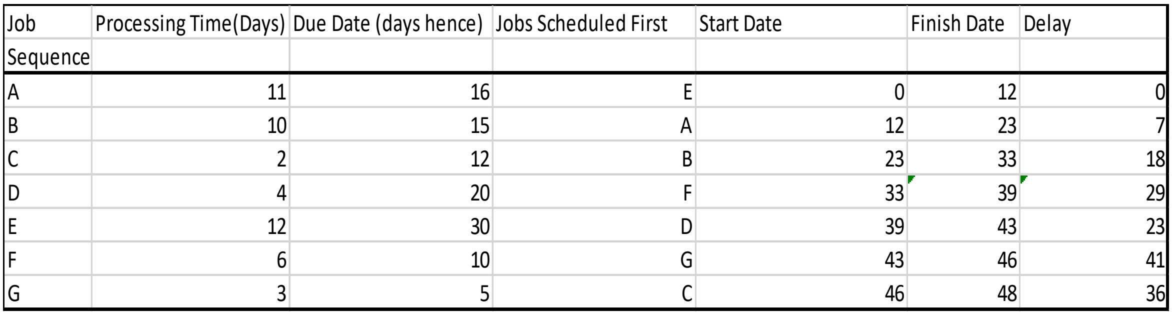
Delay of a job = Finish date – Due date.

Flow time = (3+9+21+25+27+37+48) = 170 days

From the above table it is clear that Jobs G, F & E are completed in time. Jobs D, C, B, A are delayed and average delay time is

$$\frac{(0+0+0+5+15+22+32)}{7} = 10.57 \text{ days}$$

vii) Longest Process Time (LPT) schedules jobs with job having longest processing time scheduled first. The result is as follows:



Job Sequence	Processing Time(Days)	Due Date (days hence)	Jobs Scheduled First	Start Date	Finish Date	Delay
A	11	16	E	0	12	0
B	10	15	A	12	23	7
C	2	12	B	23	33	18
D	4	20	F	33	39	29
E	12	30	D	39	43	23
F	6	10	G	43	46	41
G	3	5	C	46	48	36

Start date of Job E = 0, Finish Date of Job E = 0 + processing time

Start date of subsequent job = Finish date of preceding job.

Finish date of subsequent job = Start date + Processing time.

Delay of a job = Finish date – Due date.

Flow time = (12+23+33+39+43+46+48) = 244 days

From the above table it is clear that Job E is completed in time. Jobs A, B, F, D, G and C are delayed and average delay time is

$$\frac{(0+7+18+29+23+41+36)}{7} = 22 \text{ days}$$

The following table is a comparison of different methods:

Scheduling method	Average Delay or Tardiness (days)
FCFS	15.86
SOT	7.57
DDATE	8
STR	10.29
CR	17
LCFS	10.57
LPT	22

In the given case if we schedule jobs under Shortest Operations Time (SOT) method we could achieve least average delay time.

Makespan in all the above cases is 48days.

Average number of jobs

Jobs that are in a shop are considered to be work-in-process inventory. The average work-in-process for a group of jobs can be computed using the following formula:

$$\text{Average number of jobs} = \frac{\text{Total flow time}}{\text{Makespan}}$$

For our illustration Flow time details and Makespan are as follows with corresponding WIP inventory

Scheduling method	Total Flow time (days)	Makespan (days)	WIP (Average no of jobs)
FCFS	214	48	214/48 = 4.46
SOT	140	48	2.92
DDATE	160	48	3.33
STR	177	48	3.69
CR	222	48	4.63
LCFS	170	48	3.54
LPT	244	48	5.08

Basic Scheduling Problems:

The production planner may face certain problems while preparing production plans or Schedules. Some important problems are discussed below:

(a) Flow production scheduling for fluctuating demand (known smoothening problem),

(b) Batch production scheduling, when products are manufactured consecutively,

(c) The assignment problem,

(d) Scheduling orders with random arrivals and

(e) Product sequencing.

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 minimise the mean flow time and find the mean flow time.

Determine the sequence which will minimise 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 (Wj)	1	2	1	2	3

Solution:

(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 minimises 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 $(\bar{F}_j)$ is equal to C_j for all j.

Mean flow time $= (\bar{F}) = \frac{1}{n}\sum_{j=1}^{n} F_j = \frac{1}{5}[8 + 18 + 34 + 62 + 92] = \frac{1}{5}[214] = 42.8$ 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

The weighted processing time $= \dfrac{\text{Processing time } (t_j)}{\text{Weight } (W_j)}$

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 line (t_j/W_j)	4	5.31	10	14	30

optimal sequence that minimises the weighted mean flow time is 2-5-3-4 -1.

Weighted Mean flow time $\left(\bar{F}_w\right) : \bar{F}_w = \dfrac{\sum_{j=1}^{n} W_j F_j}{\sum_{j=1}^{n} W_j}$

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 x 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

$$\bar{F}_w = \frac{(16 + 72 + 34 + 124 + 92)}{(2 + 3 + 1 + 2 + 1)} = 37.55 \text{ hrs.}$$

Elements of Scheduling

(i) Demand forecasts/customer's firm orders-determine the delivery dates for finished products.

(ii) Aggregate scheduling : Tentative schedule based on demand for quarterly or monthly requirements. Enables employment of available resources in meeting the demand by adjusting the capacity. Needs rough-cut capacity planning.

(iii) Production plan : Showing output levels planned, resource requirements, and capacity limitations and inventory levels.

(iv) Master production schedule : Dates committed and desired quantity to be produced on a daily, weekly, monthly or quarterly basis.

(v) Priority planning : Master schedule is exploded into components and parts that are required to produce the product.

(vi) Capacity planning: Regulates loading of specific jobs on specific work centres or machines for specific periods of time.

(vii) Facility loading or machine loading: Loading work centres/Machines after deciding which job to be assigned to which work centre/machine i.e., actual assignment of jobs to machines taking into consideration priority sequencing and machine utilisation.

(viii) Evaluation of workload : To balance the workload on various work centres /machines when resources are scarce or limited. Excess load in one work centre or machine has to be transferred to other work centre or machine having spare capacity.

(ix) Sequencing : Priority sequencing of jobs is done to maximise workflow through work-centres or machines to minimise delay and cost of production.

Queuing models

General Structure of Queuing System

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

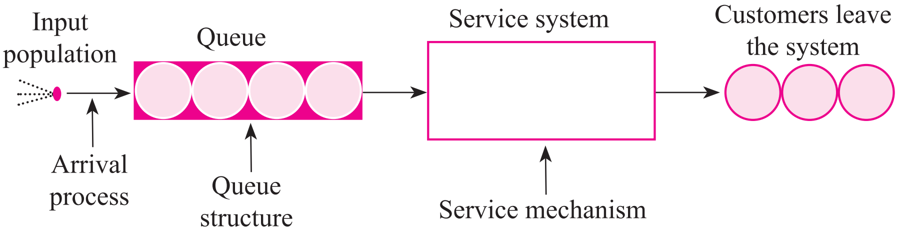


Figure 4.3: General Structure of the Queuing System

We shall discuss in more details the various elements of a queuing system and then present mathematical results for some specific systems. The elements of a system are:

1. **Arrival process:**

   The arrivals from the input population may be classified on different basis as follows:

   (a) **According to source:** The source of customers for a queuing system can be infinite or finite. For example, all people of a city or state (and others) could be the potential customers at a superbazar. The number of people being very large, it can be taken to be infinite. On the other hand, there are many situations in business and industrial conditions where we cannot consider the population to be infinite — it is finite. Thus, the ten machines in a factory requiring repairs and maintenance by the maintenance crew would exemplify finite population. Removing one machine from a small, finite, population like this will have a noticeable effect on the calls expected to be made (for repairing) by the remaining machines than if there are a large number of machines, say 500.

   (b) **According to numbers:** The customers may arrive for service individually or in groups. Single arrivals are illustrated by customers visiting a beautician, students reaching at a library counter, and so on. On the other hand, families visiting restaurants, ships discharging cargo at a dock are examples of bulk, or batch, arrivals.

   (c) **According to line:** Customers may arrive in the system at known (regular or otherwise)'times, or they might arrive in a random way. The queuing models wherein customers' arrival times are known with certainty are categorized as deterministic models (insofar as this characteristic is concerned) and are easier to handle. On the other hand, a substantial majority of the queuing models are based on the premise that the customers enter the system stochastically, at random points in time.

With random arrivals, the number of customers reaching the system per unit time might be described by a probability distribution. Although the arrivals might follow any pattern, the frequently employed assumption, which adequately supports many real world situations, is that the arrivals follow Poisson distribution.

2. **Service system:**

There are two aspects of a service system—

(a) structure of the service system, and

(b) the speed of service.

(a) Structure of the service system:

By structure of the service system we mean how the service facilities exist. There are several possibilities. For example, there may be

(i) A single service facility

A library counter is an example of this. The models that involve a single service facility are called single server models. Figure 4.2(a) illustrates such a model.

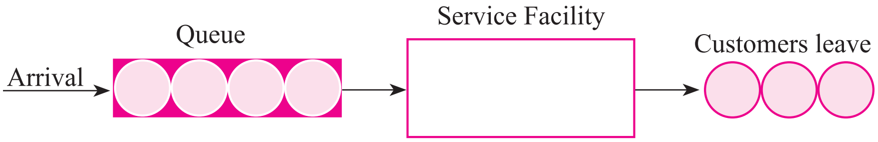


Figure 4.2 (a): Single Server, Single Queue Model

(ii) Multiple, parallel facilities with single queue:

That indicates there is more than one server. The term parallel implies that each server provides the same type of facility. Booking at a service station that has several mechanics, each handling one vehicle, illustrates this type of model. It is shown in Figure 4.2 (b).

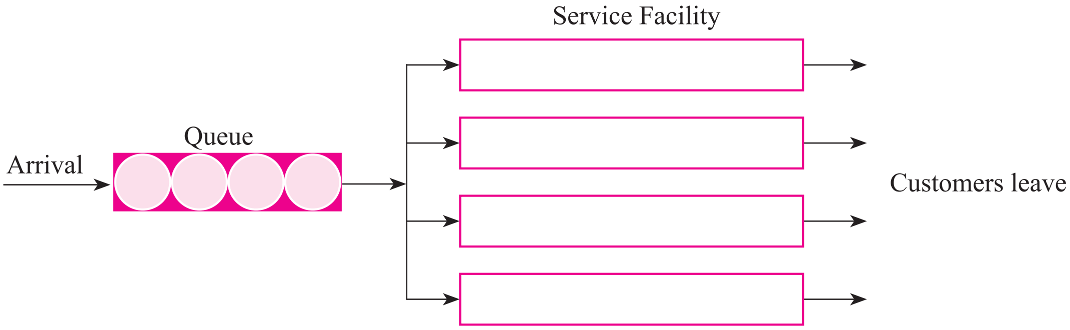


Figure 4.2 (b): Multiple, Parallel Servers, Single Queue Model

(iii) Multiple, parallel facilities with multiple queues:

This type of model is different from the earlier one only in that each of the servers has a different queue. Different cash counters in an electricity office where the customers can make payment in respect of their electricity bills is an example of this type of model. Figure 4.2 (c) portrays such a model.

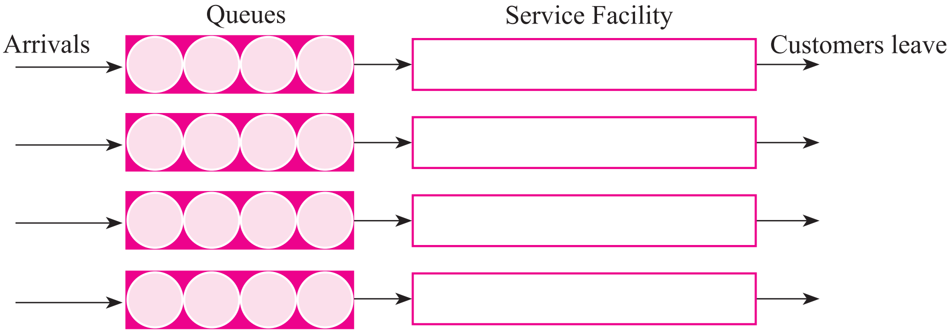


Figure 4.2 (c): Multiple, Parallel Servers, Multiple Queues Model

(iv) Service facilities in a series:

In this, a customer enters the first station and gets a portion of service and then moves on to the next station, gets some service and then again moves on to the next station . . . and so on, and finally leaves the system, having received the complete service. For example, machining of a certain steel item may consist-of cutting, turning, knurling, drilling, grinding, and packaging operations, each of which is performed by a single server in a series. Figure 4.2 (d) shows such a situation.

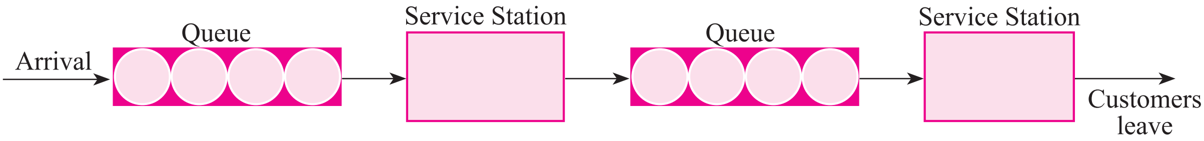


Figure 4.2 (d): Multiple Servers in Series

Besides these, there may be other possibilities as well.

(b) Speed of service:

In a queuing system, the speed with which service is provided can be expressed in either of two ways—as service rate and as service time. The service rate describes the number of customers serviced during a particular time period. The service time indicates the amount of time needed to service a customer. Service rates and times are reciprocals of each other and either of them is sufficient to indicate the capacity of the facility. Thus, if a cashier can attend, on the average, to 10 customers in an hour, the service rate would be expressed as 10 customers/hour and service time would be equal to 6 minutes/customer, Generally, however, we consider the service time only,

If these service times are known exactly, the problem can be handled easily. But, as generally happens, if these are different and not known with certainty, then we have to consider probabilities the distribution of the service times in order to analyse the queuing system. Generally, the queuing models are based on the assumption that service times are exponentially distributed about some average service time.

3. **Queue structure:**

   Another element of a queuing system is the queue structure. In the queue structure, the important thing to know is the queue discipline which means the order by which customers are picked up from the waiting line for service. There are a number of possibilities. They are:

   (a) **First-come-first-served:** When the order of service of customers is in the order of their arrival, the queue discipline is of the first-come-first-served type. For example, with a queue at the bus stop, the people who came first will board the bus first.

   (b) **Last-come-first-served:** Sometimes, the customers are serviced in an order reverse of the order in which they enter so that the ones who join last are served first. For example, assume that letters to be typed, or order forms to be processed accumulate in a pile, with each new addition being put on the top of them. The typist or the clerk might process these letters or orders by taking each new task from the top of the pile. Thus, a just arriving task would be the next to be serviced provided that no fresh task arrives before it is picked up. Similarly, the people who join an elevator last are the first ones to leave it.

   (c) **Service-in-random-order (SIRO):** Random order of service is defined as: whenever a customer is chosen for service, the selection is made in a way that every customer in the queue is equally likely to be selected. The time of arrival of the customers is, therefore, of no consequence in such a case.

   (d) **Priority service:** The customers in a queue might be rendered service on a priority basis. Thus, customers may be called according to some identifiable characteristic (length of job, for example) for service. Treatment of VIPs in preference to other patients in a hospital is an example in point.

   For the queuing models that we shall consider, the assumption would be that the customers are serviced on the first-come-first-served basis.

   Another thing to consider in the queuing structure is the behaviour or attitude of the customers entering the queuing system. On this basis, the customers may be classified as being (a) patient or (b) impatient. If the customers join a queue, when it exists, and wait till they enter the service station for getting service they are called patient customers. On the other hand, the queuing systems may enjoy customer behaviour in the form of defections from the queue. The customers may not select queues randomly (if there are multiple queues) and look for the shortest queue. There may be jockeying among the many queues, that is the customers may switch to other queues which are moving 'fast', and also reneging is possible—when a customer stands in the queue for sometime and then leaves the system because it is working 'too slowly'. There may also be bribing or cheating by some customers for queue positions. Besides, some customers may, upon their arrival, not join the queue for some reason and decide to return for service at a later time, or may even abandon the input population altogether. In terms of the queuing theory, this is known as balking, and occurs particularly when there are limits on the time and the extent of storage capacity available to hold waiting customers. Unless otherwise specified, the storage capacity is taken to be infinite. In the queuing models that we consider, we shall assume that there is no balking or jockeying and that the customers leave the system only after receiving service, and not before. Mathematical models give way to simulation when this assumption breaks.

Operating Characteristics of Queuing System

An analysis of a given queuing system involves a study of its different operating characteristics. This is done using queuing models. Some of the more commonly considered characteristics are discussed below:

1. **Queue length —** the average number of customers in the queue waiting to get service. Large queues may indicate poor server performance while small queues may imply too much server capacity.

2. **System length** — the average number of customers in the system, those waiting to be and those being serviced. Large values of this statistic imply congestion and possible customer dissatisfaction and a potential need for greater service capacity,
3. **Waiting time in the queue** — the average time that a customer has to wait in the queue to get service. Long waiting times are directly related to customer dissatisfaction and potential loss of future revenues, while very small waiting times may indicate too much service capacity.
4. **Total time in the system** — the average time that a customer spends in the system, from entry in the queue to completion of service. Large values of this statistic are indicative of the need to make adjustment in the capacity.
5. **Server idle time** — the relative frequency with which the service system is idle, Idle time is directly related to cost. However, reducing idle time may have adverse effects on the other characteristics mentioned above.

We now proceed to discuss some of the queuing models. It may be mentioned here that the results obtained from various models are based on the assumption that the service system is operating under equilibrium or steady state conditions. For many systems, the operating day begins in transient state with no customers in the system. It takes some initial time interval for enough customers to arrive such that a steady state balance is reached. It should be clearly understood that a steady state does not mean that the system will reach a point where the number of customers in the system never changes. Even when the system reaches equilibrium, fluctuations will occur. A steady state condition really implies that various system performance measures (the operating characteristics) would reach stable values.

Characteristics of Waiting Lines

There are numerous queuing models from which an analyst can choose. Naturally, much of the success of the analysis will depend on choosing an appropriate model. Model choice is affected by the characteristics of the system under investigation. The main characteristics are—

1. Population source.
2. Number of servers (channels)
3. Arrival and service patterns.
4. Queue discipline (order of service).

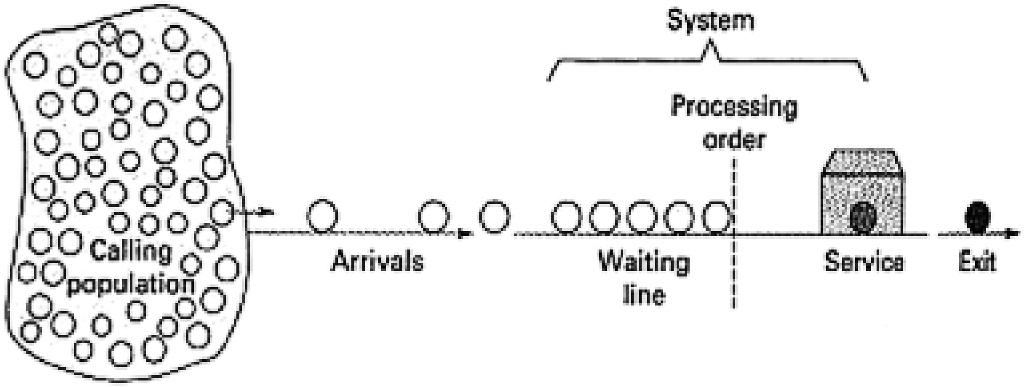


Figure 4.3: A simple queuing system

Population source

The approach to use in analyzing a queuing problem depends on whether the potential number of customers is limited. There are two possibilities: infinite-source and finite-source populations. In an infinite-source situation, the potential number of customers greatly exceeds system capacity. Infinite-source situations exist whenever service is unrestricted. Examples are supermarkets, drugstores, banks, restaurants, theaters, amusement centers, and toll bridges. Theoretically, large numbers of customers from the "calling population" can request service at any time. When the potential number of customers is limited, a finite-source situation exists. An example is the repairman responsible for a certain number of machines in a company. The potential number of machines that time cannot exceed the number of machines assigned to be repairer. Similarly, an operator may be responsible for loading and unloading a bank of four machines, a nurse may be responsible for answering patient calls for a 10-bed ward, a secretary may be responsible for taking dictation from three executives, and a company shop may perform repairs as needed on the firm's 20 trucks.

Number of servers (Channels)

Channel indicates a server in a service system: The capacity of queuing systems is a function of a capacity of each server and the number of servers being used. The terms server and channel are synonymous, and it is generally assumed that each channel can handle one customer at a time. Systems can be either single-or multiple-channel. (A group of servers working together as a team, such as a surgical team, is treated as a single-channel system.) Examples of single-channel systems are small grocery stores with one checkout counter, some theaters, single-bay car washes, and drive-in banks with one teller. Multiple-channel systems (those with more than one server) are commonly found in banks, at airline ticket counters, at auto service centers, and at petrol pumps.

A related distinction is the number of steps or phases in a queuing system. For example, at theme parks, people go from one attraction to another. Each attraction constitutes a separate phase where queues can (and usually do) from.

Figure 4.5 illustrates some of the most common queuing systems. Because it would not be possible to cover all of these cases in sufficient detail in the limited amount of space available here, our discussion will focus on single-phase systems.

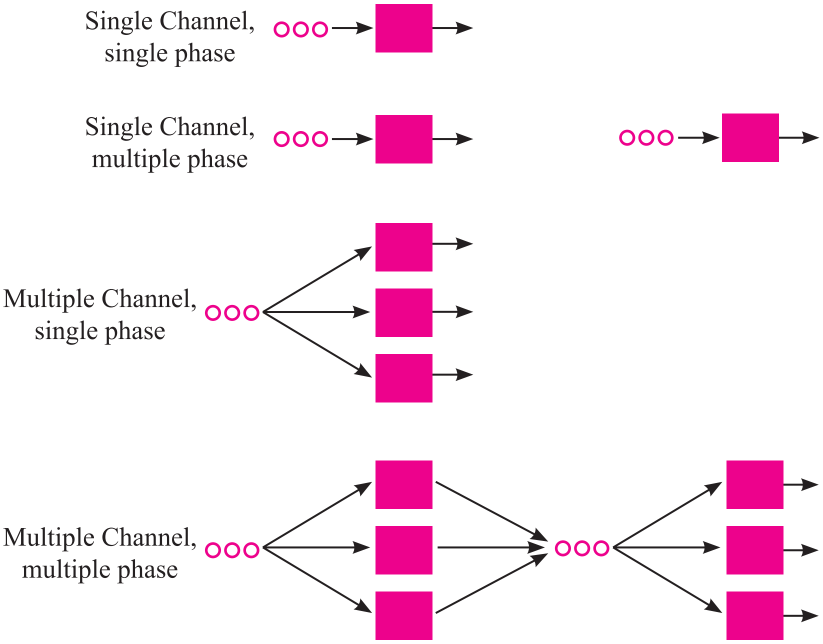


Figure 4.4: Four common variations of queuing systems

Queue Discipline

Queue discipline refers to the order in which customers are processed. All but one of the models to be described shortly assume that service is provided on a first-come, first-served basis. This is perhaps the most commonly encountered rule. There is first-come service at banks, stores, theaters, restaurants, four-way stop signs, registration lines, and so on. Examples of systems that do not serve on a first-come basis include hospital emergency rooms, rush orders in a factory, and main frame computer processing of jobs. In these and similar situations, customers do not all represent the same waiting costs; those with the highest costs (e.g., the most seriously ill) are processed first, even though other customers may have arrived earlier.

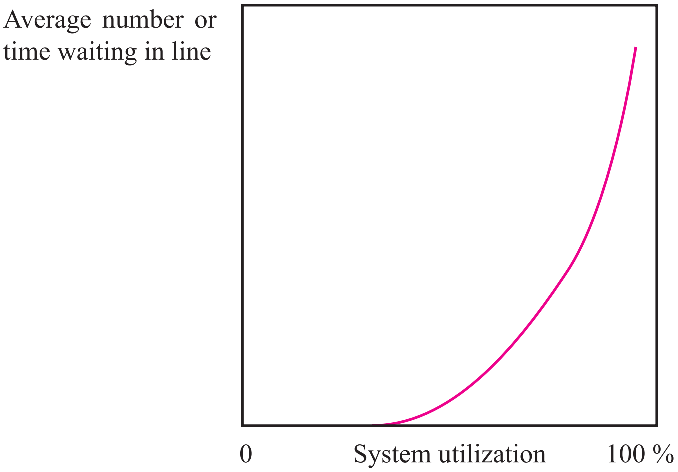


Figure 4.5: The average number waiting in line and the average time customers wait in line increase exponentially as the system utilization increases

Measures of waiting-line performance

The operations manager typically looks at five measures when evaluating existing or proposed service systems. They relate to potential customer dissatisfaction and costs:

1. The average number of customers waiting, either in line or in the system.
2. The average time customers wait, either in line or in the system.
3. System utilization, which refers to the percentage of capacity utilized.
4. The implied cost of a given level of capacity and its related waiting line.
5. The probability that an arrival will have to wait for service.

Of these measures, system utilization bars some elaboration. It reflects the extent to which the servers are busy rather than idle. One the surface, it might seem that the operations manager would want to seek 100 percent utilization. However, as Figure 2.8.7 illustrates, increases in system utilization are achieved at the expense of increases in both the length of the waiting line and the average waiting time. In fact, these values become exceedingly large as utilization approaches 100 percent. The implication is that under normal circumstances, 100 per cent utilization is not a realistic goal. Even if it were, 100 per cent utilization of service personnel is not good; they need some slack time. Thus, instead, the operations manager should try to achieve a system that minimizes the sum of waiting costs and capacity costs.

Queuing Models: Infinite-source

Many queuing models are available for a manager or analyst to choose from. The discussion here includes four of the most basic and most widely used models. The purpose is to provide an exposure to a range of models rather than an extensive coverage of the field. All assume a Poisson arrival rate. Moreover, the models pertain to a system operating under steady-state conditions; that is, they assume the average arrival and service rates are stable. The four models described are

1. Single server, exponential service time.
2. Single server, constant service time.
3. Multiple servers, exponential service time.
4. Multiple priority service, exponential service time.

Note that the terms "server" and "channel" mean the same thing. To facilitate your use of waiting line models, Table 4.5 provides a list of the symbols used for the infinite-source models.

Infinite-source symbols

Symbol	Represents
λ	Customer arrival rate
μ	Service rate per server
L_a	The average number of customers waiting for service
L_s	The average number of customers in the system (waiting and/or being served)
r	The average number of customers being served
ρ	The system utilization
W_q	The average time customers wait in line
W_s	The average time customer's spend in the system (waiting in line and service time)
$^1/_\mu$	Service time
P_o	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

Basic Relationships

There are certain basic relationships that hold for all infinite-source models. Knowledge of these can be very helpful in deriving desired performance measures, given a few key values. Here are the basic relationships:

Note: The arrival and service rates, represented by λ and μ , must be in the same units (e.g., customers per hour, customers per minute).

(I) System utilization: This reflects the ratio of demand (as measured by the arrival rate) to supply or capacity (as measured by the product of the number of servers, M, and the service rate, μ).

$$\rho = \frac{\lambda}{M \times \mu}$$

(II) The average number of customers being served:

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

For nearly all queuing systems, there is a relationship between the average time a unit spends in the system or queue and the average number of units in the system or queue. According to Little's law, for a stable system, the average number of customers in line or in the system is equal to the average customer arrival rate multiplied by the average time in line or the system. That is,

$$L_S = \lambda Ws, \qquad \text{and} \qquad L_q = \lambda W_q$$

The implications of these are important in analysis of waiting lines. The relationships are independent of any probability distribution and require no assumptions about which customers arrive or are serviced, or the order in which they are served. It also means that knowledge of any two of the three variables can be used to obtain the third variable. For example, knowing the arrival rate and the average number in line, one can solve for the average waiting time.

Figure 4.5.6: Basic Relationships

	Line	+	**Service**	=	**System**
Customers →	000	→	⧇	→	
Average number waiting:	L_q	+		=	L_s
Average time waiting:		+		=	W_s

(III) The average number of customers

(A) Waiting in line or queue for service: L_q [Model dependent. Obtain using a table or formula.]

(B) Waiting In the system (line plus being served): $L_s = L_q + r$

(IV) The average time customers are

(A) Waiting in line or queue: $W_q = \frac{L_q}{\lambda}$

(B) Waiting in the system: $W_s = W_q + \frac{1}{\mu} = \frac{L_s}{\lambda}$

All infinite-source models require that system utilization be less than 1.0; the models apply only to underloaded systems.

The average number waiting in line, L_q, is a key value because it is a determinant of some of the other measures of system performance, such as the average number in the system, the average time in line, and the average time in the system. Hence, L_q will usually be one of the first values you will want to determine in problem solving.

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.

a. What are the arrival and service rates?

b. Compute the average number of customers being served at any time.

c. 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.

d. Determine the system utilization for M = 1, 2, and 3 servers.

Solution:

a. 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/ μ. Its reciprocal is $\mu = 20$ customers per hour = Service Rate.

b. Average no. of customers being served at any time.

$$r = \frac{\lambda}{\mu} = \frac{16}{20} = 0.80 \text{ customer.}$$

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	$P_o = 1 - (\frac{\lambda}{\mu})$
Probability of *n* units in the system	$P_n = P_o(\frac{\lambda}{\mu})^n$
Probability of less than *n* units in the system	$P_{<n} = 1 - (\frac{\lambda}{\mu})^n$

c. Given: $L_q = 3.2$ customers

$L_s = L_q + r = 3.2 + 0.80 = 4.0$ customers

Average time customers wait in line

$$= W_q + \frac{L_q}{\lambda} = \frac{3.2}{16} = 0.20 \text{ hour, or } 0.20 \text{ hour} \times 60 \text{ minutes/hour} = 12 \text{ minutes}$$

W_s = Average time customers wait in system = $W_q + \frac{1}{\mu}$

Waiting time in line plus service

$$0.20 + \frac{1}{20} \text{ hour, or 15 minutes}$$

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 Mμ increases, the system utilization for a given arrival rate decreases.

Single server, exponential service time, M/M/1

The simplest model involves a system that has one server (or a single crew). The queue discipline is first-come, first-served, and it is assumed that the customer arrival rate can be approximate by a Poisson distribution and service time by a negative exponential distribution. There is no limit on length of queue.

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:

a. System utilization.

b. Percentage of time the server (agent) will be idle.

c. The expected number of customers waiting to be served.

d. 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.

Solution:

Arrival Rate = λ = 15 customers per hour

Service Rate = $\mu = \frac{1}{\text{Service Time}} = \frac{1 \text{ customer}}{3 \text{ minutes}} \times 60$ minutes per hour = 20 customers per hour

a. System Utilisation = $\rho = \frac{\lambda}{M\mu} = \frac{\lambda}{1(20)} = 0.75$

b. Percentage of time the server will be idle = 1 – r = 1– 0.75 = 0.25, or 25 percent

c. Expected no. of customers waiting to be served = $L_q = \frac{\lambda}{\mu(\mu - \lambda)} = \frac{225}{20(20-15)} = \frac{225}{(20 \times 5)} = \frac{225}{100} = 2.25$ customers

d. Average time customers will spend in the system = $W_S = \frac{L_q}{\lambda} + \frac{1}{\mu} = \frac{2.25}{15} + \frac{1}{20} = 0.20$ 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 $P_4 = P_0 = \left(\frac{\lambda}{\mu}\right)^4 = 0.25\left(\frac{15}{20}\right)^4 = 0.079$

Single Server, Constant Service Time, M/D/1

As noted previously, waiting lines are a consequence of random, highly variable arrival and service rates. If a system can reduce or eliminate the variability of either or both, it can shorten waiting lines noticeably. A case in point is a system with constant service time. The effect of a constant service time is to cut in half the average number of customers waiting in line:

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

The average time customers spend waiting in line is also cut in half. Similar improvements can be realized by smoothing arrival times (e.g., by use of appointments).

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

a. The average number of cars in line.

b. The average time cars spend in line and service.

Solution:

Arrive Rate = λ = 8 cars per hour

Service Rate = μ = 1 per 5 minutes, or 12 per hour

Av. no. of cars waiting in line = $L_q = \dfrac{\lambda^2}{2\mu(\mu - \lambda)} = \dfrac{8^2}{2(12)(12-8)} = 0.667$ car

Av. time cars spend in line and service = $W_S = \dfrac{L_q}{\lambda} + \dfrac{1}{\mu} = \dfrac{0.667}{8} + \dfrac{1}{12} = 0.167$ 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.

Solution:

The usual notations are given:

Arrival Rate = λ = 20 customers / hour and service rate = μ = 24 customers / hour

Average no. of customers in the system = $L_q = \dfrac{\lambda}{\mu(\mu - \lambda)} = \dfrac{20}{(24-20)} = \dfrac{20}{5} =$ 5 customers

Average time a customer spends in the system = $W_S = \dfrac{L_S}{\lambda} = \dfrac{5}{20} = \dfrac{1}{4} = 0.25$ hour = 15 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 ₹1.50 per hour and the hourly cost of a machinist away from his work is ₹ 4.

Calculate:

(i) The average number of machinists being served or waiting to be served at any given time.

(ii) The average time a machinist spends waiting for service.

(iii) The total cost of operating the system for an eight – hour day.

(iv) The cost of the system if there were two attendants working together as a team, each paid ₹ 1.50 per hour and each able to service on average 2 per hour.

Solution:

Arrival rate = λ = 2 per hour

Service rate = μ = 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 = ₹ 4 × 2 = ₹8.00 per hour

Attendant cost = 1.50 per hour

9.50 per hour

Cost of 8- hour day = 8 hrs × ₹9.50 = ₹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 λ = 2 per hour

m = 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 = $W_S = \frac{1}{(\mu - \lambda)} = \frac{1}{(4-2)} = \frac{1}{2}$ hour

Machinists cost = ½ hr × ₹4 =	₹ 2.00
Attendant cost (@ 1.50 per attendant × 2 attendants	₹ 3.00
Total Cost	₹ 5.00

Cost per 8 – hour day = ₹5 × 8 hrs. = ₹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:

(i) average queue length,

(ii) average length of non-empty queues,

(iii) average number of workers in system including the worker being attended

(iv) mean waiting time of an arrival,

(v) average waiting time of an arrival who waits.

Solution:

Here, Arrival Rate = $\lambda = \frac{60}{60}$ per second = 1 per minute

Service Rate = $\mu = \frac{60}{60}$ 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

$$W_n = \frac{1}{\mu - \lambda} = \frac{1}{(1.5 - 1)} = 2 \text{ minutes}$$

Simulation and Line Balancing

4.8

Simulation

The techniques of LPP, Transportation, and Assignment are used for optimization of various types of problem faced in business situations. However, all the business situations can not be solved with the above techniques only. There may be some complex situations, where numbers of assumptions are also necessary. It may be quite often possible to simulate the given system and study the behavior.

To simulate means to imitate. In general, simulation involves developing a model of real phenomenon and then performing experiments on the model evolved. It is to be noted that it is a descriptive and not optimizing technique. In simulation, a given system is copied and the variables and constants associated with it are manipulated in that artificial environment to examine the behavior of the system. For ex: aerodynamic testing, scaled down models of airplanes and placing them in work tunnels etc.

Thus, also in a complex situation of business a given system is taken and simulated for obtaining the required results.

It consists of four phases:

1. Definition of the problem and statement of objectives.
2. Construction of an appropriate model
3. Experimentation with the model constructed.
4. Evaluation of the results of simulation.

Monte Carlo Simulation:

Although simulation can be of many types, our discussion will focus on the probabilistic simulation using the Monte Carlo method. Also called computer simulation, it can be described as a numerical technique that involves modelling a stochastic system with objective of predicting the system's behaviours. The chance element is a very significant feature of Monte Carlo simulation and this approach can be used when the given process has a random, or chance, component.

In using the Monte Carlo method, a given problem is solved by simulating the original data with random number generators. Basically, its use requires two things, first, as mentioned earlier, we must have a model, that represents an image of the reality of the situation. Here the model refers to the probability distribution of the variable in question. What is significant here is that the variable may not be known to explicitly follow any of the theoretical distribution like Poisson, Normal and so on. The distribution may be obtained by direct observation or from past records. To illustrate, suppose, that a bakery keeps a record of the sale of the number of cakes of a certain type and the information relating to sales of 200 days is as below –

Demand (No of cakes):	5	6	7	8	9	10	11	12	**Total**
(No of days) :	4	10	16	50	62	38	12	8	**200**

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	

Solution:

Table - I

Random No. Range Table for demand

Demand per week	Frequency (f)	Probability (p = f ÷ ∑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
	∑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*

Simulated Values for next 10 weeks		
Weeks	**Random Nos.**	**Demand**
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 = $\frac{120}{10}$ = 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 ₹ 60 and is sold for ₹ 80. Since some of the tax laws change year after year, any copies unsold while the edition is not current must be sold for ₹ 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

Solution:

Random No. Range Table			
Demand	**Probability**	**Cumulative Probability**	**Random No. Range**
15	.05	.05	00-04
16	.08	.13	5-12

Random No. Range Table			
Demand	**Probability**	**Cumulative Probability**	**Random No. Range**
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

Calculation of demand and profit for next 20 years					
Year	Random Numbers	Expected demand	No. of books unsold if stock is		
			16*	17*	18*
18	08	16	-	1	2
19	92	20	-	-	-
20	73	18	-	-	-
Total			**2**	**7**	**18**

*Lookiong 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 (₹)	Average Profit/Year (Profit ÷ 20)
15	15 × 20 = 300	₹ 6000	₹ 300
16	16 × 20 – 2 = 318	₹ 6300 (318 × 20) – 2 × 30	₹ 315
17	(17 × 20) – 7 = 333	₹ 6450 (333 × 20) -7 × 30	₹ 322.5
18	(18 × 20) – 18	₹ 6300 (342 × 20) – 18 × 30	₹ 315

* Net Profit = No. of books sold × ₹ 20# – No. of books unsold × ₹ 30**

Selling price/book = ₹ 80, Cost/book = ₹ 60

Profit /book = 80 – 60 = ₹ 20

Selling price of any unsold book = ₹ 30

**Loss incurred/unsold book = ₹ 60 – ₹ 30 = ₹ 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 (₹)	Probability	Weekly Payments (₹)	Probability
3000	0.20	4000	0.30
5000	0.30	6000	0.40

Weekly Receipts (₹)	Probability	Weekly Payments (₹)	Probability
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 ₹ 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.

Solution:

Range of random numbers							
Receipt (₹)	Probability	Cumulative probability	Range	Payments (₹)	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 (₹)	Random No. for payment	Expected Payment (₹)	Week end Balance (₹)
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

Simulation of Data for a period of 12 weeks					
Week	**Random No. for receipt**	**Expected Receipt (₹)**	**Random No. for payment**	**Expected Payment (₹)**	**Week end Balance (₹)**
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 = ₹ (3,000)

Highest balance = ₹ 7,000

Average balance during the quarter = 45,000/12 = ₹ 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.

Solution:

Simulation of data of an Automobile Production line			
Production/day	**Probability**	**Cumulative Probability**	**Random No. Range**
95	0.03	0.03	00-02

Simulation of data of an Automobile Production line			
Production/day	**Probability**	**Cumulative Probability**	**Random No. Range**
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 ₹ 10 per order. The store also incurs a carrying cost of ₹ 0.50 per book per day. The inventory carrying cost in 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.

A. Order 5 books when the inventory at the beginning of the day plus order outstanding is less than 8 books.

B. 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**

Solution:

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	Quanity for which Order Placed
1	89	3	8	-	5	-
2	34	2	5	6	9	-
3	70	3	9	-	6	0

Day	Random No.	Demand	Opening Stock	Ordered Quantity receipt	Closing Stock	Quanity for which Order Placed
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	₹ 40
Carrying cost 0.5 × 39	₹ 19.50
Total Cost	₹ 59.50

Option B

Day	R No.	Demand	Opening Stock	Ordered Quantity receipt	Closing Stock	Quanity 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	₹ 20.0
Carrying cost 0.5 × 45	₹ 22.50
Total Cost	₹ 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 following12 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.

Solution:

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 = $\dfrac{\text{Total idle time}}{\text{Total Operating}}$ = 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 ₹ 20 per kg. and sells at ₹ 30 per kg. Any commodity remains at the end of the day, has no sales value. Moreover the loss on unsatisfied demand is ₹ 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.

Solution:

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 (a)	Supply (b)	Demand (c)	*Sales Revenue (d)	Cost (II) (e) = (b) × ₹20/kg	Loss due to unsatisfied demand (III) (f) = [(c)–(b)]× ₹8/kg	Profit (₹) (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 – handing 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	

Solution:

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	(10 + 0.30) = 0.40
12	15	0.25	0.65

Demand (tons/day)	Frequency (days)	Probability P(X)	Cumulative probability
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 ¼ 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

(a) Formulate a cumulative distribution in percentage terms.

(b) Graphs the frequency and cumulative distributions.

(c) 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?

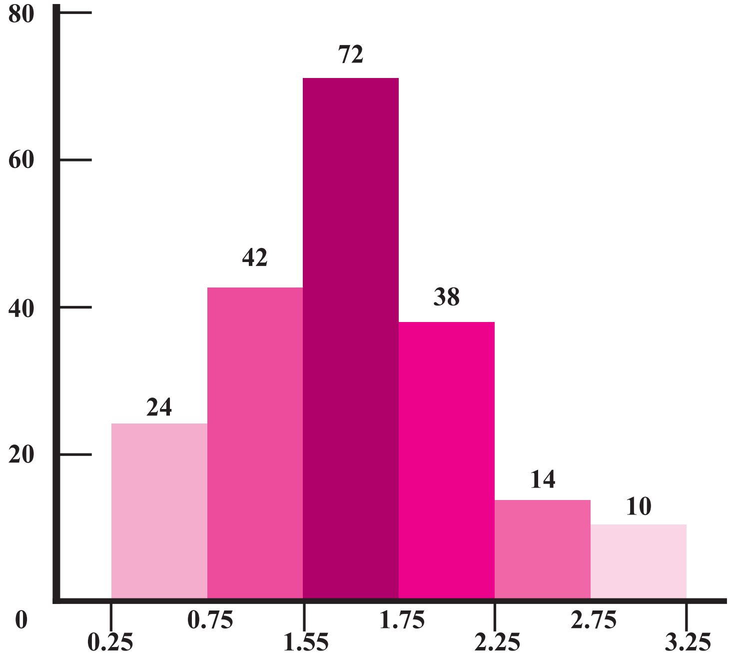
(d) What proportion of the times exceed 2.0 minutes?

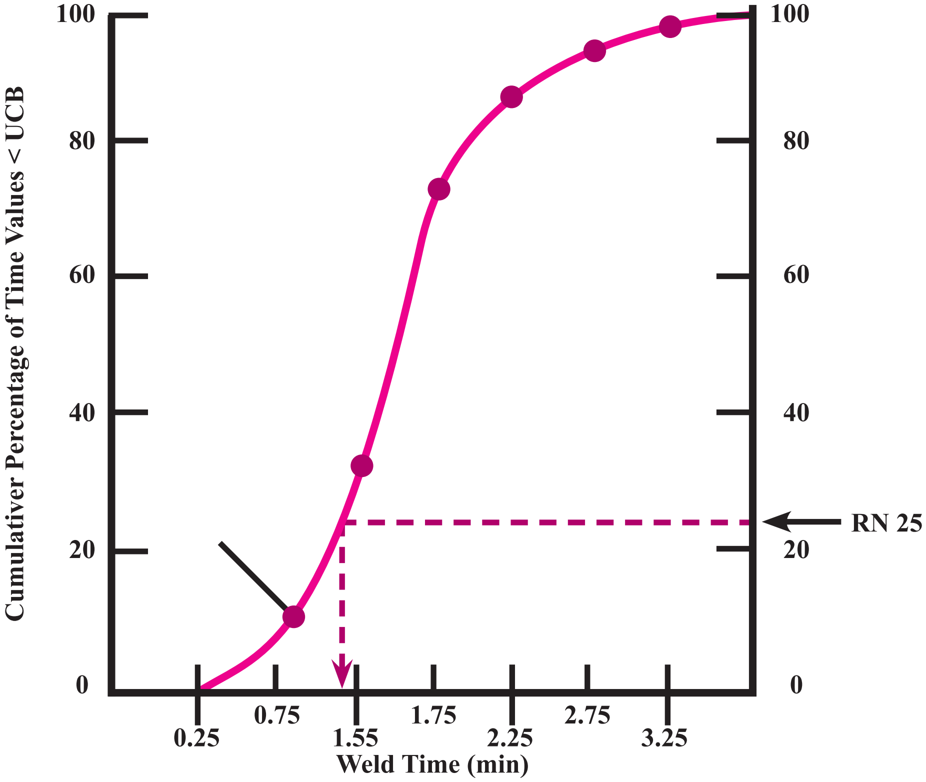
Solution:

(a) 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

(b) 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).


80
60
40
20
0
72
42
38
24
14
10
0.25
0.75
1.55
1.75
2.25
2.75
3.25


Cumulativer Percentage of Time Values < UCB
100
80
60
40
20
0
100
80
60
40
20
0
RN 25
0.25
0.75
1.55
1.75
2.25
2.75
3.25
Weld Time (min)

(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 activitiesIn 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?

Solution:

(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	1
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:

$$\text{Average inventory} = \frac{\text{Total waiting time}}{\text{Total run time}}$$

$$= \frac{\text{1.0 assembly minute}}{\text{3.5 minutes}}$$

$$= \text{0.29 assembly}$$

(c) Average output per hour:

$$\text{Units/hr} = \frac{\text{6 unit}}{\text{3.5 minutes}}\left(\frac{\text{60 min}}{\text{hr}}\right) = \text{102.9 units/hr}$$

$$= \text{102.9 units/hr.}$$

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.

Solution:

Computation of Random Interval for Processing Time

Process time Minutes	A1			A2		
	P_i	$\sum P_i$	Range	P_i	$\sum P_i$	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

	Random No.	Process Time	Random No.	Process Time	Total
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 Minutes

A2 = 167/15 = 11.13 Minutes

For product = 349/15 = 23.27 Minutes

Expected process time for the product = 23.27 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 ₹)	Probability	Sales Revenue (₹)	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

Solution:

Cost (₹)	Probability	Cumulative Probability	Random Range	Sales Revenue (₹)	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 (₹)	Random No. for Sales	Sales Revenue (₹)	Monthly Net Revenue (₹)
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

Month	Random No. for Cost	Cost (₹)	Random No. for Sales	Sales Revenue (₹)	Monthly Net Revenue (₹)
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 = ₹ 1750.

Line Balancing

Line balancing is arranging a production line so that there is an even flow of production from one work station to the next, i.e. so that there are no delays at any work station that will leave the next work station with idle time.

Line balancing is also defined as "the apportionment of sequential work activities into work stations in order to gain a high utilization of labour and equipment and therefore minimize idle time." Balancing may be achieved by rearrangement of the work stations or by adding machines and / or workers at some of the stations so that all operations take about the same amount of time.

Line Balancing Procedure in Assembly Layouts

Step 1 : Determine what tasks must be performed to complete one unit of a finished product and the sequence in which the tasks must be performed. Draw the precedence diagram.

Step 2 : Estimate the task time (amount of time it takes a worker or a worker/machine combination to perform each task).

Step 3 : Determine the cycle time (the amount of time that would elapse between products coming off the end of the assembly line if the desired hourly production rate is met.)

Step 4 : Assign each task to a worker and balance the assembly line. This process results in determining the scope of each worker's job or which tasks that he or she will perform.

Steps Involved in Combining of the Tasks into Worker's Jobs

1. Starting at the beginning of the precedence diagram, combine tasks into a work station in the order of the sequence of tasks so that the combined task times approach but do not exceed the cycle time or multiples of the cycle time.
2. When tasks are combined into a workstation, the number of multiples of the cycle time is the number of workers required at the work station, all performing the same job.

Analysis of Line Balancing Problems

The procedure involves the following steps

1. Determine the no. of work stations and time available at each work station.
2. Group the individual tasks into amounts of work at each work station.

3. Evaluate the efficiency of grouping

When the available work time at any station exceeds that which can be done by one worker, additional workers must be added at that work station.

The key to efficient line balancing is to group activities or tasks in such a way that the work times at the work station are at or slightly less than the cycle time or a multiple of cycle time if more than one worker is required in any workstation.

Determination of cycle time (CT) : When the amount of output units required per period (period may be hour, shift, day or week etc.) is specified and the available time per period is given (i.e., the number of working hours per shift, number of shifts per day, number of working days per week etc.) then,

$$\text{Cycle time (CT)} = \frac{\text{Available time per period}}{\text{Output units required per period}}$$

Cycle time is the time interval at which completed products leave the production line.

Determination of the Ideal or Theoretical Minimum Number of Workers Required in the Line

$$\begin{array}{c}\text{Ideal or theoretical minimum}\\ \text{no. of workers required in the}\\ \text{assy. line / production line}\end{array} = \frac{\begin{array}{c}\text{Total operation}\\ \text{or task time}\end{array} \times \begin{array}{c}\text{Output units}\\ \text{required per period}\end{array}}{\text{Available time per period per worker}}$$

$$N = \sum t \times \left(\frac{1}{CT}\right) = \frac{\sum t}{CT}$$

Balancing Efficiency : An efficient line balancing will minimize the amount of idle time. The balance efficiency can be calculated as:

$$\text{(i)}\quad E_{ffB} = \frac{\text{Output of task time}}{\text{Input by workstation times}} = \frac{\sum t}{CT \times N}$$

Where, $\sum t$ = Sum of the actual worker times or task times to complete one unit

CT = Cycle time ;

N = No. workers or work stations

$$\text{(ii)}\quad E_{ffB} = \frac{\text{Theoretical minimum number of workers}}{\text{Actual number of workers}}$$

The grouping of tasks is done with the aid of a precedence diagram. The precedence diagram is divided into work zones or stations and the appropriate activities are granted under each workstation until the cycle time is as fully utilized as possible.

Terminology Used in Line Balancing

(i) **Tasks :** Element of work or activity

(ii) **Task precedence :** Indicates the sequence in which tasks must be performed. Except the beginning task, all other tasks have preceding tasks.

(iii) Task times : The amount of time required for an automatic machine or a well trained worker to perform a task.

(iv) Cycle time : The interval of time between two successive products coming off the end of a production line or assembly line.

(v) Productive time per hour : The duration (in minutes) a work station or machine is working in each-hour. The productive time per hour is lesser than the actual available time due to lunch break, breakdown, personal time for the worker, start-ups and shutdowns.

(vi) Work station : Physical location where a particular set of tasks is performed. Workstation could be either a machine or equipment operated by a worker or an automatic machine or a machine operated by a robot.

(vii) Work centre : A physical location where two or more identical workstations are located in order to provide the needed production capacity.

(viii) Theoretical minimum number of workstations : The least number of work stations that can provide the required production calculated by :

$$N_t = \frac{\text{Sum of all task time}\left(\sum t\right)}{\text{Cycle Time (CT)}}$$

$$\text{Cycle time} = \frac{\text{Available time}}{\text{Output required}}$$

(ix) Actual number of workstations: The total number of workstations required on the entire production line, calculated as the next higher integer value of the number of workstations working.

(x) Utilisation : The percentage of time that a production line is working. This is calculated as

$$\text{Utilisation or Balance efficiency} = \frac{\text{Minimum number of workstations}}{\text{Actual number of workstations}} \times 100 = \frac{\sum t}{CT \times N} \times 100$$

Line Balancing Procedure

Steps :

1. Calculate the cycle time and determine the theoretical minimum number of workstations

$$N_t = \frac{\text{Sum of all task time}\left(\sum t\right)}{\text{Cycle Time (CT)}}$$

$$\text{Cycle time} = \frac{\text{Available time}}{\text{Output required}}$$

2. Compute the actual number of workstation (N) required by rounding up the theoretical number of workstations to the next higher integer value.
3. Assign the tasks to the workstations beginning with station 1. Tasks are assigned to work stations moving from left to right through the precedence diagram.
4. Before assigning each task to a workstation, use the following criteria to determine which tasks are eligibly to be assigned to a workstation
   (a) All preceding tasks in the sequence have been assigned already.

(b) The task time does not exceed the time remaining at the workstation.

If no tasks are eligible to be assigned to a particular workstation, move to the next workstation.

5. After each task assignment, determine the time remaining at the current work station by subtracting the sum of times for tasks already assigned to the work station from the cycle time.

6. When there is a tie between two tasks (parallel tasks) to be assigned, use one- of these rules :

   (a) Assign the, task with the longest task time

   (b) Assign the task with greatest number of followers.

   If there is still a tie, choose one task arbitrarily,

7. Continue assignment of tasks until all tasks have been assigned to workstations.

8. Calculate the idle time (or balance delay), percent idle time and efficiency of balancing the line.

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

Solution:

(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 desending 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.

Solution :

(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 respecive slack values.

(b) Calculation of Critical ratio :

$$\text{Critical Ratio} = \frac{\text{Due Date – Date Now}}{\text{Lead Time Remaining}} = \frac{\text{DD – DN}}{\text{LTR}} = \frac{\text{Available time till due date}}{\text{Operation time still needed to complete the job}}$$

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

Solution:

(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 lime 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 lime. 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.

Lean Operations

4.9

Lean operation has its roots in the Toyota Automobile Co., of Japan, where waste was to be avoided at all costs:

(i) the waste in time caused by having to repair faulty products

(ii) the waste of investment in keeping high inventories and

(iii) the waste of having idle workers.

The elements of lean production are:

(i) To consider the organisation in terms of supply chain of value streams that extends from suppliers of raw materials, through transformation to the final customer.

(ii) To organise workers in teams and to have every one in the organisation conscious of his or her work.

(iii) To produce products of perfect quality and to have continuous quality improvement as a goal.

(iv) To organise the operation by product or cellular manufacturing, rather than using a functional or process lay-out.

(v) To operate the facility in a just-in-time mode.

Just-In-Time (JIT)

4.10

Objectives of JIT manufacturing : The specific goal of JIT manufacturing is to provide the right quality level at the right place. Customer demand always determines what is right. JIT tries to build only what internal and external customers want and when they want it. The more focussed objectives of JIT are:

(i) Produce only the products (goods or services) that customers want.

(ii) Produce products only as quickly as customers want to use them.

(iii) Produce products with perfect quality.

(iv) Produce in the minimum possible lead times.

(v) Produce products with features that customers want and no others.

(vi) Produce with no waste of labour, materials or equipment, designate a purpose for every movement to leave zero idle inventory.

(vii) Produce with methods that reinforce the occupational development of workers.

Overview of JIT manufacturing

JIT manufacturing includes many activities :

(i) Inventory reduction : JIT is a system for reducing inventory levels at all stages of production viz. raw materials, work-in-progress and finished goods.

(ii) Quality improvement : JIT provides a procedure for improving quality both within the firm and outside the firm.

(iii) Lead time reduction : With JIT, lead time components such as set-up and move times are significantly reduced.

(iv) Vendor control/Performance improvement : JIT gives the buying organisation greater power in buyer-supplier relationship. The firm moves from a situation where multiple suppliers are used to a situation where only one or two suppliers are used for supplying most of the parts. With fewer suppliers, the buying organisation has more power because it is making larger purchases from each vendor. Also, the buying organisation can now impose higher requirements on each supplier in terms of delivery and quality.

(v) Continuous Improvement : In the JIT system, existing problems are corrected and new problems identified in a never-ending approach to operations management.

(vi) Total Preventive Maintenance : JIT emphasises preventive maintenance to reduce the risk of equipment break-downs which may cause production hold ups and increase in manufacturing cycle time due to delays.

(vii) Strategic Gain : JIT provides the firm's management with a means of developing, implementing and maintaining a sustainable competitive advantage in the market place.

Productivity Management and Quality Management

5

This Module Includes

Productivity Management and Quality Management

SLOB Mapped against the Module

To develop detailed understanding about frameworks and tools for measuring and managing productivity of resources as well as quality control of outputs.

Module Learning Objectives:

After studying this module, the students will be able to:

- Identify the reasons for failure of quality management in various field
- Describe the importance of quality standards in management.
- Understand TQM

Measurement Techniques of Productivity Index

5.1

Productivity implies development of an attitude of mind and a constant urge to find better, cheaper, quicker, easier and safe ways of doing a job, which could be either manufacturing an article or providing a service. Since the beginning of the industrial era, the manufacturers or producers have been facing the problem of how to use the available resources and factors of production to the best of their ability and capacity so as to get the maximum output with the minimum cost of production. Industrial revolution, social, technological and scientific developments, changes in economic systems are the various efforts made in this direction and the process of development and changes is still on. New machines, methods and technology are being invented and used in the industrial field to minimise the wastage of men, materials and machines. It is all to increase the productivity.

Productivity is the quality or state of being productive. It is some relationship of outputs to inputs. It is a concept that guides the management of a production system, and measures its success. It is the quality that indicates how well labour, capital, materials and energy are utilised. Productivity improvement is sought everywhere because it supports a higher standard of living, helps control inflation, and contributes towards a stronger national economy.

Productivity is an indicator reflecting the changes in the performance of the enterprise and having some sort of input-output comparison relating to various activities of an organisation. It also facilitates the management to control and plan the future operations of the enterprise.

Productivity is the talk of the day and it is generally regarded as efficiency in industrial production to be measured by some relationship between outputs and inputs. The increase in productivity is looked upon as the key to prosperity at all levels. In its modern sense, it refers to the relationship between the result and the means employed or to be more specific between the product and the factors used for obtaining it. It is the quantitative relationship between what we produce and the resources which we use to obtain it. It can also be termed as the ratio of what is produced to what is required to produce it. The higher is the ratio, the greater is the productivity. Thus, it seeks to measure the economic soundness of the use of the means of production. It means productivity can be considered higher if the same amount of production is obtained with lesser inputs or it will be lower if the same quantity of production is obtained with larger quantity of inputs. It is higher when there is maximum production with the least usage of resources.

A productivity index is a device of numerically expressing the ratio between outputs and the inputs of the resources. These indices are prepared by comparing the volume of output of goods with the labour employed on that job or the profits of the firm with the capital employed. If the comparison shows an upward trend in indices, it is a sign of improved or better productivity and vice-versa.

The productivity is a measure of how much input is required to achieve a given output.

Symbolically:

$P = \frac{O}{I}$ where P = Productivity;

O = Output,

I = Input.

The output may be measured in terms of the units of goods produced or the value of goods and services produced. The input, on the other hand, can be referred to as the combination of different factors, i.e., raw materials, machinery, worker's time, power, efforts and imagination of entrepreneur and the managers. A unit of input, therefore, can be expressed as one worker, or one hour of labour time or one tonne of raw materials, or one kw of electricity and so on. Thus, it is very clear from the above description that the productivity can be calculated or measured for each one of the factors comprising of the input or of all the factors together. The productivity of labour, for example, can be found out by ascertaining the ratio between the quantity of goods produced and the number of workers or man-hours employed on the production of such output.

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

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 particulars '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.
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.
   (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.
   (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.
   (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.
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.
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.

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.
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.
7. **Other Uses:**
   (i) Higher productivity increases the profits and reserve funds of the industry that can be used for expansion and modernisation.
   (ii) 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) 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.

Measurement of Productivity: The productivity or the performance of various input and output factors can be measured in many ways. These measures are mainly based on the following two criteria:

(i) **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.

(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.

Productivity measurement implies the use of standards set for each input factor in terms of output. In circumstances where standards are not in use, productivity can be measured only when the output is converted into 'units or work' which is defined as the amount of work that can be performed by one unit of input. Thus productivity can be measured by dividing the output by the performance of each input factor taken together.

Some of the well-known indices of productivity are given below:

(A) **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

(B) **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

(C) **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 turn-over. But 'added value' is a more useful approach for measuring productivity. 'Added value' means output - inputs.

The most common financial ratio of productivity is—

Productivity = Added Value / Labour Costs

Productivity = Added Value / Conversion Costs

The first ratio gives the financial productivity of labour force and the second ratio gives the financial productivity of all the resources of the company put together.

(D) **Other Useful Measures:** There are many other useful productivity ratios to measure the productivity of various input factors. These are:

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

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

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

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

A combined measure of productivity can be taken as

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

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.

Tools of productivity or how to increase productivity:

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.

1. **Human Aspects:** Under this, cooperation of workers is sought in the following ways:
   (i) More workers participation in management or in decision making through joint consultation.
   (ii) Improving communication services.
   (iii) 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.
   (iv) 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.
2. **Supply of Inputs:**
   (i) Improvement in the nature and quality of raw materials and their supplies to the work.
   (ii) Proper provision of plant, equipment and their maintenance.
   (iii) Introduction of more and more machines and equipment in place of physical work.
   (iv) Fuller utilisation of manpower and efficiency or capacity of plant and equipment employed.
3. **Technological Aspects:**

Certain methodological and technological developments are also necessary to improve the productivity of the concern.

These are;

(i) Work, time and motion studies to determine better ways and means of doing a job.

(ii) Implementing various simplification, specialisation and standardisation programmes.

(iii) Applying control techniques comprising of production, planning and control, cost control and quality control techniques.

(iv) Improving layout of plants, shops and machine tools, and material handling and internal transportation system.

(v) Improving inspection techniques so as to minimise the wastage and defective work.

Factors affecting industrial productivity:

Productivity is defined to be some ratio between output and input. Thus all factors which affect output and inputs will also affect the measure of productivity.

The following factors affect the productivity.

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. The principal factors in technological development affecting productivity are:

   (a) **The Size of the Plant:** The size of the plant and the capacity utilisation has direct bearing on productivity. Production below or above the optimum level will be uneconomical and will tend towards lower level of productivity.

   (b) **Research and Development:** Investment in research and development may yield better method of work and better design and quality of products.

   (c) **Plant and Job Layout:** The 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.

   (d) **Machine and Equipment Design:** Whether the design of machinery and equipment is modern and in keeping with the limitations and capacities of the workers, will also determine the production efficiency and level of productivity.

   (e) **Production Processes:** Advanced production processes involving the use of modern integrated and automatic machinery and semi-processed materials have been known to help in raising levels of productivity.

   (f) **Power, Raw Materials etc.** Improved quality of raw materials and increased use of power have a favourable effect on productivity.

   (g) **Scientific Management Techniques:** Scientific management techniques such as better planning of work, simplification of methods, time and motion study, emphasis for reduced wastage and spoilage have positive effects on productivity.

   It will be realised that technological development requires a great amount of funds and general economic and technical environment in the country. Thus capital plays an important role in increasing the productivity through implementing technological development. It should also be recognised that such developments influence the job performance of employees. With better machines, tools and processes, it should be considered that both ability and willingness to work should be increased.

2. **Individual Factors**: Individual factors such as knowledge, skill and attitude also affect the productivity of industry. Knowledge is acquired through training, education and interest on the part of learner.

Skill is affected by aptitude (one's capacity to learn a particular kind of work), personality (emotional maturity, balance of mind etc.) as also by education, experience, training etc. Increased knowledge, skill and aptitude certainly increase the productivity and a person deficient in these personal attributes is less productive than an average man.

The attitude (willingness of employee to work for the organisation) of employees towards the work and the organisation, affect their productivity to a great extent. Knowledge and skill without willingness are futile. The urge to work is a complex phenomenon governed by several factors such as formal and informal organisation, leadership, need, satisfaction, influence of trade unions etc. These factors motivate the workers to work better and with enthusiasm.

3. **Organisation Factors***:* Organisation factors include various steps taken by the organisation towards maintaining better industrial relations such as delegation and decentralisation of authority, participative management (workers' participation in management), organisational efficiency, proper, personnel policies relating to selection, placement, promotion, wage, salary levels, incentives, merit rating, job evaluation, training and provision for two-way communication, supervision, etc. These factors also influence motivation. Likewise the existence of groups with higher productivity as their goal is likely to contribute to the organisational objectives. These facts were brought out by Hawthorne experiments in U.S.A. A properly-motivated worker will certainly contribute to the industrial productivity.
4. **Work Environment***:* The importance of proper work environment and physical conditions on the job has been emphasised by industrial psychologists and human engineers. Better work environment ensures the greatest ease at work through better ventilation and lighting arrangement, improved safety devices, reduction in noise, introduction of suitable rest-pause etc.
5. **Other factors***:* There are several other factors that affect productivity. These are:
   (a) **Natural Factors***:* Physical, geographical and climatic conditions influence the productivity to a large extent. Abundance of natural resources affects the productivity and similarly climate affects the efficiency of workers to a great extent.

   (b) **Managerial Factors***:* The industrial productivity is influenced very much through managerial ability and leadership. The managerial ability of utilising the available resources to the maximum, organising capacity, foresightedness, decision-making ability and entrepreneurship are certain factors that contribute to productivity.

   (c) **Government Policy***:* Government policies towards industry also contribute to the industrial productivity. Taxation policy, financial and administrative policy, tariff policy and protection policy affect the productivity to a large extent.

Thus, the above factors are responsible for the increased productivity.

Production and Productivity:

Production and productivity are not synonymous. Production refers to the volume, value or quantity of goods and services produced during a given period by a worker, plant, firm or economy. It is the sum total of results achieved by the various factors used together. Productivity, on the other hand, is not concerned with the volume of production. It is the ratio of output and input factors of an enterprise. It shows the efficiency of production or the efficiency level of input factors. In other words, productivity is relative to the resources used in turning out a certain amount of physical output, while production is used, more or less, in absolute sense. The distinction between these two terms becomes more clear when we find that increase in production does not necessarily mean the increase in productivity. If increase in production is attributed to the increase in the inputs of production in the same proportion, the production will have increased but productivity may have declined or may remain constant because the ratio of output and inputs has shown a decline or has not shown any improvement.

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?

Solution:

Monthly productivity per worker = $\frac{200}{10}$ = 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?

Solution:

Productivity = $\frac{\text{Actual production}}{\text{Standard production}}$

Standard production of hose complings per shift = $\frac{8 \times 60}{15}$ = 32 pcs.

Productivity of industry A = $\frac{30}{32} = \frac{15}{16}$ 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 × 6 = 180 nos. (Assuming the industry to work for one shift per day)

Production per week of industry B = 20 × 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

(i) If plant is operated at 75% efficiency, and the operator is working at 100% efficiency, what is the output per month?

(ii) If machine productivity is increased by 10% over the existing level, what will be the output per month?

(iii) If operator efficiency is reduced by 20% over the existing level, what will be the output per month?

Solution:

(a) Hours worked per day = 8

Working days per month = 25

Hours worked per month = 25 × 8 = 200 hrs.

Machine time = 22 minutes

Operator time = 8 minutes

Total time per unit = 30 minutes = ½ 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 × $\frac{75}{100}$ = 300 units.

(b) If machine productivity is increased by 10% i.e. Machine time = 22 × $\frac{100}{(100+10)}$ = 20 minutes.

Then, total time = 20 + 8 = 28 minutes

Monthly production = $\frac{400 \times 30}{28} \times \frac{75}{100}$ = 321 units.

(c) If operator efficiency reduced by 20% i.e.

Operator time = 8 × $\frac{(100+20)}{100}$ = 8 × 1.2 = 9.6 minutes.

Total 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:—

(a) Percent absentism

(b) Efficiency of utilisation of labour

(c) Productive efficiency of labour

(d) Overall productivity of labour in terms of units produced per man per month.

Solution:

No. of days per month = 25

Daily working hrs. = 8

No. of operators = 15

No. of Man days per month = 15 × 25 = 375 Man days.

Total working hrs. per month = 375 × 8 = 3,000

Hours lost in absentism in a month = 30 × 8 = 240

(a) Percent absentism $= \frac{240 \text{hrs.} \times 100}{3000 \text{hrs}} = 8\%$

(b) 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) Standard time required to produce 240units = 240 × 8 = 1920 labour-hours.

In November, man hours lost = 30 × 8 = 240

idle time (in hours) = 276

Total loss of time = 516 hours.

Productive hours available in November = 3000

Less, Total loss of time = (516)

Actual labour-hours = 2484 hours

Efficiency of labour $= \frac{\text{Std. Labour hrs.}}{\text{Actual Labour hrs.}} = \frac{1920 \times 100}{2484} = 77.3\%$

(d) 15 men produces 300 units,

Std. labour productivity = 300/15 = 20 units.

In November, overall productivity = 240/15 = 16 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	:	₹ 4 per hour

(iii) What is the net labour productivity achieved by the operator during the day?

Solution:

Total standard minutes worked during the day = 30 × 15 = 450, working time = 8 – 2 = 6 hours = 360 minutes. Performance = (450 × 100) /360 = 125% i.e incentive is payable on 25% which is above 100%

(i) Incentive bonus = 0.25 × 6 × 4 = ₹ 6 for six hours on measured work

(ii) Guaranteed wage for 8 hours = 8 × 4 = ₹ 32; Total earnings for the days

= ₹ (6 + 32) = ₹ 38

(iii) Net labour productivity = Output in units / Net man hours = 15 / 6 = 2.5 sets per hour.

Five Key Aspects of Productivity

5.2

Productivity

Productivity is commonly defined as a ratio between the output volume and the volume of inputs. In other words, it measures how efficiently production inputsare being used in an economy to produce a given level of output. Productivity is considered a key source of economic growth and competitiveness and, as such, is basic statistical information for many international comparisons and country performance assessments. For example, productivity data are used to investigate the impact of product and labour market regulations on economic performance. Productivity growth constitutes an important element for modelling the productive capacity of economies. It also allows analysts to determine capacity utilisation, which in turn allows one to gauge the position of economies in the business cycle and to forecast economic growth.

It is quite easy to say that productivity is output divided by input. But the term 'output' is ambiguous since there is no simple way of totalling the products and services. Again, when we consider input, we come across diverse factors. In order to produce anything, we need people, capital, land, facilities, machine tools, mineral deposits, energy resources, ingenuity, activity, climate, electrical power, organisation, rational price and a host of other factors.So, productivity can be more correctly stated as the relationship between achieving a result and the time it takes to accomplish it. Hence productivity = results/time.If a carpenter can complete a job in 5 hours and another completes the same job in 10 hours, the former's productivity is double the latter.

$$\textbf{Productivity} = \frac{\textbf{Output in a Period of Time}}{\textbf{Input in the Same Period of Time}}$$

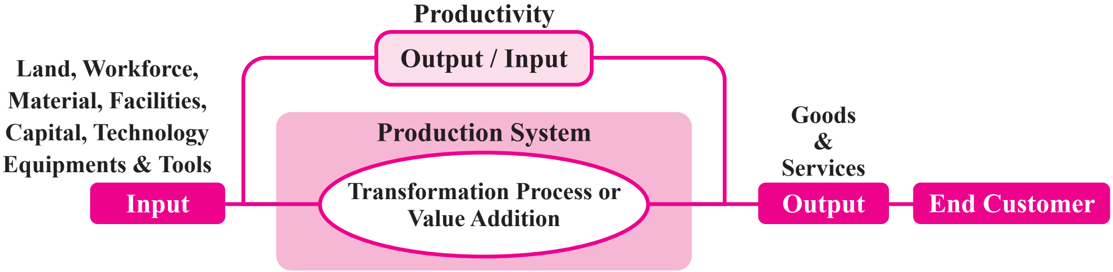


Figure 5.1: System Concept of productivity

- Employee productivity can be defined as the amount of work (or output) produced by an employee in a specific period of time. As a manager, it's important to understand how long it takes your teammates to complete specific tasks, and if there are any roadblocks or distractions along the way that you could help them overcome."We often assume that productivity means getting more things done each day. Wrong. Productivity is getting important things done consistently," says James Clear. He further added "And no matter what you are working on, there are only a few things that are truly important. Being productive is about maintaining a steady, average speed on a few things, not maximum speed on everything."Productivity in the workplace will often translate into good customer service, healthier work relationships, and motivated employees. Employee productivity can be measured in three ways: Measure goals, Measure quality of work, and measure the amount of work completed; and some of the ways to increase employee productivity in the workplace are – Improve Workplace conditions, Allow flexible schedules, Set clear deadlines and expectations, Encourage self-care and time off, Optimize meetings, Coach employees on their priorities, Learn time management skills, and Boost morale by celebrating accomplishments.

- Material productivity in manufacturing units is a vital factor in ensuring a high level of effectiveness and efficiency.Materials is one of the basic inputs which constitute 50 to 70 percent of the total value of the output of selected companies. Therefore, to improve the performance of the selected organisations, material productivity will have to be improved. For calculating the material productivity ratio, material output (Net sales) is divided by the material input; the ratio reveals the output received in constant prices per rupees of material input. Suppose the base year material productivity ratio is 100,material index below 100 will mean low productivity and above 100 will mean improvement in productivity in comparison with the productivity of the base year.

- Land, labour and capital are the three basic inputs of the production process. But they do not make contribution to total output separately or independently. They produce goods and services only when brought together in the presence of an organizing authority or catalyst. This catalyst is, of course, management, and the three factors of production are the resources or inputs at the disposal of management.The competence and attitudes of managers have an important bearing on productivity. In many organisations, productivity is low despite latest technology and trained manpower. This is due to inefficient and indifferent management. Competent and dedicated managers can obtain extraordinary results from ordinary people. Job performance of employees depends on their ability and willingness to work. Management is the catalyst to create both. Advanced technology requires knowledgable workers who in turn work productively under professionally qualified managers. No ideology can win a greater output with less effort. It is only through sound management that optimum utilization of human and technical resources can be secured. The Manager is the dynamic, life-giving element in every business. Without his leadership, the resources of production remain resources and never become production. In competitive economy, above all, the quality and performance of the managers determine the success of a business, indeed they determine its survival' [P. F. Drucker: The Practice of Management.]

- Apart from these, some other factors also have a great impact on productivity. This includes:

Technological Factors

- Product design
- Plant layout
- Size and capacity of the plant
- Location of plant
- Timely supply of raw material
- Repairs and maintenance
- Material handling system
- Research and development
- Inventory control

Natural Factors

It is quite obvious that there are some factors that are not under the control of anyone. These are natural factors. The physical, geographical, geological, and climatic conditions fall in this category. These factors highly influence industries that carry out extraction activity.

Social Factors

We live in a society, and we have to follow its culture, traditions, customs, rules, and norms. Also, it poses a significant influence on productivity. However, the social factors, differ from place to place. This means what is considered wrong in India, might not be considered wrong in other countries like Japan or USA and vice versa.

Political Factors

To increase productivity, law and order, peace, and stability of the government are a must. Industrial policy, tariff policy, and taxation also have an influence on the firm's productivity.

Economic Factors

There are certain factors that also have an impact on productivity such as:

Market size, Banking and credit facilities and Transport and communication system

- Every organisation strives to create and sustain a climate of perpetual interest and passion among its personnel in order to improve results through the efficient use of facilities and resources. Productivity improvement techniques assure larger revenues, which can be used to instal cutting-edge technology and improve the overall performance of the business. Individual productivity development solutions include methods for managing time and increasing job efficiency. An organisation may undertake a number of key steps toward improving productivity.
    (a) Develop productivity measures for all operations; measurement is the first step in managing and controlling an organisation.
    (b) Look at the system as a whole in deciding which operations are most critical; it is over-all productivity that is important.
    (c) Develop methods for achieving productivity improvement, such as soliciting ideas from workers (perhaps organizing teams of workers, engineers, and managers), studying how other firms have increased productivity, andre-examining the way work is done.
    (d) Establish reasonable goals for improvement.
    (e) Make it clear that management supports and encourages productivity improvement. Consider incentives to reward workers for contributions.
    (f) Measure improvements and publicize them.

Some of the key techniques for managers to improve productivity at workplaces are as follows:

Time Your Time, Initiate Regular Breaks, Self-Imposed Deadlines, Quit the Habit of Multitasking, Encourage the "2-Minute Rule", Avoid Unnecessary Meetings, Use the Unexpected 'Bonus' Time, Be Proactive and Not Reactive.

TQM Basic Tools and Certification

5.3

Total Quality Management

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

Basic Concepts in TQM

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

Essentials of TQM Focus

1. Customer satisfaction
2. Leadership
3. Quality policy
4. Organisation structure
5. Employee involvement
6. Quality costs
7. Supplier selection and development
8. Recognition and reward.

Underlying Principles in TQM

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

Scope of TQM

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

TQM is Japanese approach to quality. The term TQM refers to a quest-for quality in an organisation. TQM is a process that underlines three philosophies. One is never-ending push to improve, which is referred to as continuous improvement; the second is the involvement of every employee in the organisation and the third is the goal for customer satisfaction, which means meeting or exceeding customer expectations. It often focuses on benchmarking world-class standards, product and service design and purchasing. In addition, TQM involves a number of other elements such as:

- 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 and
- Inclusion of suppliers as a part of quality improvement programme.

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.

TQM seeks to breakdown communication barriers among employees and also between the organisation and its external stakeholders, in order to increase cross-functional integration and provide new avenues for co-operation to improve quality. It would be incorrect to think of TQM merely a collection of techniques. Rather, TQM reflects a whole new attitude toward quality. It is about the culture of an organisation. To truly reap the benefits of TQM, the culture of an organisations must change. In other words, TQM organisation strives to develop co-operative relationships with its suppliers and distributors so that continuous improvement of quality becomes their goals too. Ford, Motorola, and GM have taken steps to develop long-term relationships with their suppliers and distributors.

ISO Standard Basics

5.4

Quality Certification

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.

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.

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.

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.

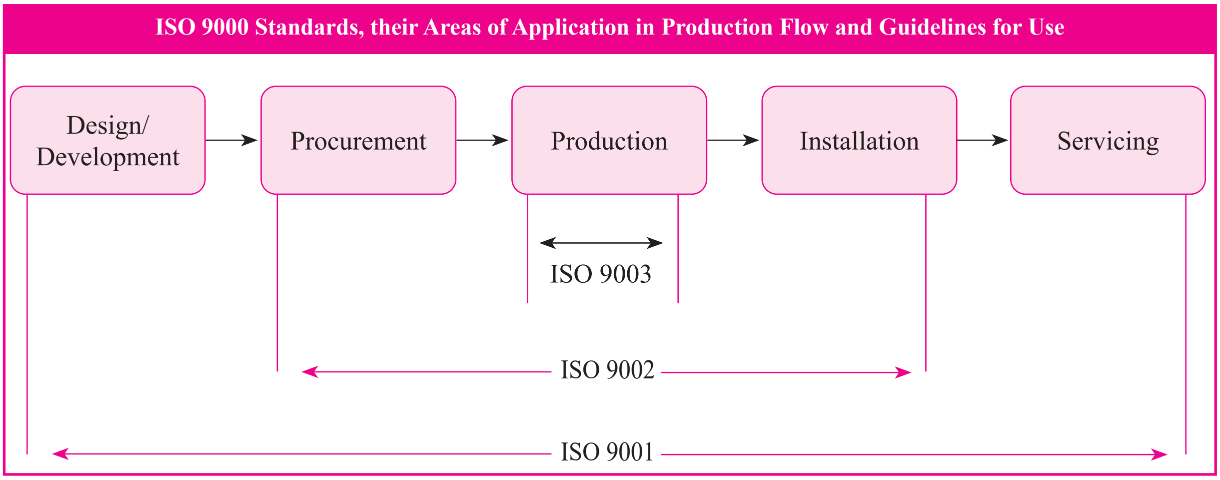


Figure 5.2: Production flow and Guidelines for use

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

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

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

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

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

Solution:

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.

Solution:

Normal time per unit = Observed time / unit × Rating factor = 5 × (120/100) = 6minutes

Allowances = 30% of normal time = (30 × 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 × 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. Activity Element	1	2	3	4	Performance Rating
(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.

Solution:

Average time for Activity Element A = $\frac{0.15+0.25+0.17}{3}$ = 0.19 min.

Average time for Activity Element B = $\frac{1.56+1.80+1.75}{3}$ = 1.703 min.

Average time for Activity Element C = $\frac{0.20+0.10+0.15}{3}$ = 0.15 min.

Computation of Normal Time

Activity Element	Average time (Mins)	Performance Rating (%)	Normal Time (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

So Normal Time for the job of packaging = 2.101 Mins

Standard Time = $\frac{\text{Normal Time}}{1-(\text{Allowance Factor}/100)} = \frac{2.101}{1-\frac{10}{100}}$ = 2.334 Mins.

Standard Production in a shift of 8 hours = $\frac{8\times 60}{2.334}$ = 205.66 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

Solution:

(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 Mannual 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 Efficency of Labour.

Solution:

Percentage of working time = $\frac{2500 - 400}{2500} \times 100$ = 84%

Actual working time in a study of 100 hours = 84 hours = 84 × 60 = 5040 mins.

Production — 6000 articles

Time required to produce an article = $\frac{5040}{6000}$ = 0.84 mins

Of this Manual time = $0.84 \times \frac{2}{3}$ ($\because$ Ratio of Manual to Machine activity elements = 2:1)

= 0.56 mins

Machine time = 0.84 × $\frac{1}{3}$ = 0.28 min.

Normal Time of man = Time of man as per study × Rating Factor / 100

$$= 0.56 \times \frac{115}{100} = 0.644 \text{ min.}$$

Normal Time of machine = 0.28 min.

Allowances for man = 12% of Normal time of Man = 0.12 × 0.644 = 0.077 min

Standard Time for Man to produce an article = Normal Time of Man + Allowances

= 0.644 + 0.077 = 0.721 min.

Standard Time for machine = 0.28 min.

Standard Time to produce an article = 0.28 + 0.721 = 1.001 mins.

Standard time required to produce 42000 articles = 42000 × 1.001 = 42042 mins. = 700.7 hours.

No. of days/month - 25, Daily working hours - 8, No. of workers - 5

Total available working hours/month = 5 × 25 × 8 = 1000

Actual working hours/month = 1000 × 0.93 [Since Absentism = 7%]

= 930

$$\text{Efficiency of utilisation of Labour} = \frac{\text{Standard time to produce 42000 article}}{\text{Total available hours}} \times 100$$

$$= \frac{700.7}{1000} \times 100 = 70.07\%$$

$$\text{Productive efficiency of Labour} = \frac{\text{Standard time to produce 42000 article}}{\text{Actual working hours}} \times 100$$

$$= \frac{700.7}{930} \times 100 = 75.34\%$$

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?

Solution:

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.

Solution:

Productivity =Actual production/Standard production

Standard production of tobacco plant is = 8 × 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 × 7 = 280 Packets (if it works for 7 days with one shift)

And, expected productivity of plant in Z = 55 × 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

(a) If plant is working at 65% efficiency, what is the expected output permonth?

(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?

Solution:

Working hours per month = 22 × 8 = 176 hrs.

No. of units that can be produced/month by the operator = 176 × 60/38= 277.89 approx 278.

a. 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 × 0.65 = 180.62 Units.

b. If the plant efficiency increases by 20% new output will be

New machine time is 28 × 100/120 = 23.33 minutes, and then the total time = 10 + 23.33 = 33.33 min

New monthly production = 277.89 × (38/33.33) × 0.65 = 205.93 Units

c. If the operator's efficiency is reduced by 30% then new production will be

New Operator's time = 10 × (130/100) = 13 min

So new total time = 13 + 28 = 41 minutes.

Now new monthly production = 277.89 × (38/41) × 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.

Solution:

No of mandays per month = 20 × 24 = 480 Man days

Total working hr per month = 480 × 8 = 3840.

Hr lost in absenteeism in a month = 28 × 8 = 224

1. Efficiency of utilisation of manpower = (250 × 8 / 3840) × 100 = 52.08%
2. Absenteeism = (224 hr/3840hr) ×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 (₹)
Q1	1600	800	1000000
Q2	1500	750	1024000
Q3	1700	775	1300000
Q4	2000	900	1200000

Solution:

Quarter	No of Employees	Working Hours	Man Hours	Business Achieved (₹)	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 × Working Hours = 1600 × 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%.

Solution:

Normal time per unit = Observed time / unit × Rating factor = 7 × (110/100) = 7.7 minutes

Now, Allowances = 25% of normal time = (25 × 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 = (8×60)/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.

Solution:

(a) Product 1 → Processing time needed toproduce demand quantity (hrs.) = Annual Demand × Processing time (Standard time in hr) = 425 × 4 = 1700 hrs

Product 2 → Processing time needed to produce demand quantity (hrs.) = 429 × 5 = 2145 hrs

Product 3 → Processing time needed to produce demand quantity (hrs.) = 546 × 5.5 = 3003 hrs.

Hence total time needed= 6848hrs.

(b) Annual production capacity for a single machine = 8 × 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.

Solution:

Percentage of working time = ((3000-500)/3000) × 100 = 83.33%

Actual working time in a study of 150 hrs = 150 × 0.8333 × 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 × (3/5) = 0.643 mins and machine time is 1.0714 × (2/5) = 0.43 mins.

Normal time of labour = time of labour as per study × Rating Factor/100 = 0.643 × 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 × 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 × 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 × 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%)

Project Management, Monitoring and Control

6

This Module Includes

Project Management, Monitoring and Control

SLOB Mapped against the Module

To gain knowledge on project planning, managing and control to ensure optimum utilization of time and resources.

Module Learning Objectives:

After studying this module, the students will be able to:

- Describe project management objectives
- Understand powerful coordinating tool for planning, scheduling and controlling of projects
- Effective utilization of resources and minimization of effective resources
- Diagram networks of project activities
- Estimate the completion time of a project
- Effect of delay on activity.

Project Planning

6.1

Planning begins with well-defined objectives. The project team may be drawn from several organizational departments, e.g., engineering, production, marketing, and accounting. Project definition involves identifying the controllable and uncontrollable variables involved, and establishing project boundaries. Performance criteria should relate to the project objectives, which are often evaluated in terms of time, cost, and resource utilisation.

Project planning is part of project management, which relates to the use of schedules such as Gantt charts to plan and subsequently report progress within the project environment. **Project management** is the discipline of organizing and managing resources (e.g. people) in such a way that the project is completed within defined scope, quality, time and cost constraints. A project is a temporary and one-time endeavour undertaken to create a unique product or service, which brings about beneficial change or added value. This property of being a temporary and one-time undertaking contrasts with processes, or operations, which are permanent or semi-permanent ongoing functional work to create the same product or service over and over again. The management of these two systems is often very different and requires varying technical skills and philosophy, hence requiring the development of project managements.

The first challenge of project management is to make sure that a project is delivered within defined constraints. The second, more ambitious challenge is the optimized allocation and integration of inputs needed to meet predefined objectives. A project is a carefully defined set of activities that use resources (money, people, materials, energy, space, provisions, communication, etc.) to meet the predefined objectives.

Initially, the project scope is defined and the appropriate methods for completing the project are determined. Following this step, the durations for the various tasks necessary to complete the work are listed and grouped into a work breakdown structure. The logical dependencies between tasks are defined using an activity network diagram that enables identification of the critical path. Float or slack time in the schedule can be calculated using project management software. Then the necessary resources can be estimated and costs for each activity can be allocated to each resource, giving the total project cost. At this stage, the project plan may be optimized to achieve the appropriate balance between resource usage and project duration to comply with the project objectives. Once established and agreed, the plan becomes what is known as the baseline. Progress will be measured against the baseline throughout the life of the project. Analysing progress compared to the baseline is known as earned value management.

Gantt Chart: Gantt Chart is a principal tool used in scheduling and also in some methods of loading. This chart was originated by the American engineer Henry L. Gantt and consists of a simple rectangular grid, divided by series of parallel horizontal and verticular lines. The vertical lines always divide the horizontal scale units of time. The time units can be in years, months, weeks, days, hours, minutes or even seconds according to the work for which it is prepared. In this chart, the time which an activity takes in completing the task is represented by the horizontal line. The length of the line is drawn in proportion to the duration of time. Generally, the time in the chart should flow from left to right and activities be listed from top to bottom. The progress of the work may be shown by a bar or a line within the uprights of the activity symbol and its length should represent the amount of work completed. Horizontal lines divide the chart into sections which can represent various work tasks (work schedule) or work centres (load schedule). When it shows only work tasks-products, orders, or operations to be completed, it is known as Work Schedule. When it shows the same task opposite the work centres at which they are produced-factories, departments, workshops, machine tools or men it is known as Load Chart.

The units scheduled or loaded on these charts are always the same because these work tasks are known as having a known standard time. The work tasks can be represented on the chart by numbers or symbols. The symbols used on the chart may vary from company to company.

Network Analysis: Routing is the first step in production planning. In small projects, routing is very simple. Sequence of operations is almost decided and the operations can be performed one after the other in a given sequence. But in large project, this is rather a difficult problem. There may be more than one route to complete a job. The function of production manager is to find out the path which takes the least time in completing the project.

In a big project, many activities are performed simultaneously. There are many activities which can be started only at the completion of other activities. In such cases, a thorough study is required to collect the complete details about the project and then to find out a new, better and quicker way to get the work done in a decent way. In such cases, the first step is to draw some suitable diagram showing various activities and their positions in the project. It should also explain the time to be taken in completing the route from one operation to the other. It also defines the way in which the delay in any activity can affect the entire project in terms of both money and time. Such a diagram is called network diagram. A network is a picture of a project, a map of requirements tracing the work from a departure points to the final completion objective. It can be a collection of all the minute details involved or only a gross outline of general functions.

Important characteristics in a Network Analysis: The following are some important points to remember in a network analysis:

(i) The objective is to finish within the specified time otherwise there is a penalty.

(ii) Various activities are to be completed in an order; however, a number of activities are performed simultaneously while there are many other activities, which can be started only when some other activities are completed.

(iii) The cost of any activity is proportional to its time of completion.

(iv) There can be hurdles in the process and the resources to be allocated may be limited. A network graph consists of a number of points or nodes, each of which is connected to one or more of the other nodes by routes or edges. It is a set of operations and activities describing the time orientation of a composite project.

Important Concept of Network drawing:

A Network can be considered as a means of graphically depicting all the operations involved in a Project. When a Network is constructed then it is essential to maintain the relationship between various Activities of the Project.

Some of the key concepts of Network drawing can start with defining some of the key terminology of Network. These are —

Activity — All projects may be viewed as a number of operations which when completed will cause the completion of the project. Each of these operations is termed as an **Activity** of the project which require expenditure of time and resources for accomplishment.

In a Network diagram, an Activity is depicted by a single arrow (⟶). This is not scaled and as such it's length has no bearing on the time the Activity takes for its completion. In other words the length of Activity arrow is drawn conveniently so that the clarification of relationship of activities is proper. It does not depict the importance of time. The head of the arrow shows the direction of flow of the Activity. An Activity can not begin until the preceeding one/ones is/are not completed.

Predecessor Activity means the Activity that must be completed prior to the start of an Activity.

Successor Activity can not be started until are or more of the other activities are completed but immediately succeed them.

Concurrent Activities means the Activities which can occur simultaneously.

Event — An **Event** represents a specific accomplishment in the project and takes place at a particular instant of time and does not, therefore consume time or resources. It can be considered as a time oriented reference point that signifies the end of ane activity and start of another. Events are represented by circles (○) in a Network diagram, Events are also known as Nodes.

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

Start Event is also called Tail Event & Finish Event is called Head Event of the Activity.

Merge Event is that event where more than one Activity ends. In the diagram below 3 and 4 are the Merge Events.

Burst Event is that Event from where more than one Activity starts. In the diagram below, 2 and 1 are the Burst Events.

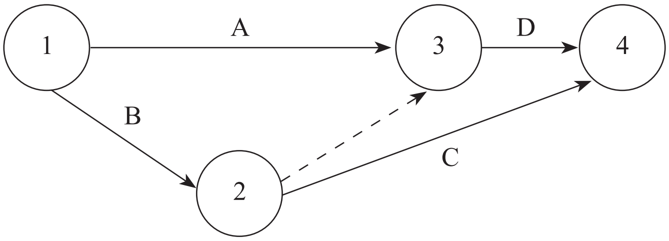
Merge and Brust Events are those Events where more than one Activity ends and from where more than one Activityh starts. In other words these are the combination of both Merge and Brust Events.

Dummy Activity — Activities occuring simultaneously, is a very common feature in a project. Also it can so happen that two Activities are having same Start and End Events. To resolve such situations, Dummy Activities are introduced. Hence as a rule there is only one Activity between two Events. With the use of Dummy Activity, other activities can be identified by unique end events. Dummy Activities consume no time or resource. In Network diagrams these are represented by dashed arrows (- - - ➔) and is inserted in the Network to clarify activity pattern in the following situations

(a) to make activities with common start and end Events distinguishable

(b) to identify and maintain the proper precedence relationship between activities that are not connected by events.

For the situation where A & B are concurrent activities, C is dependent on B and D is dependent on both A & B we have no other option but to introduce a Dummy Activity (Shown in the diagram) to clearly represent the precedence relationship of the Activities.



Procedure for drawing a network diagram: The procedure for drawing a network diagram may be explained below.

There are three basic questions and the network depends on them.

These questions are:

- Which operation must be completed before each given operation can be started?
- Which activities can be carried out in parallel?
- Which operation immediately succeeds other given activities?

The common practice is simply to work backward through the list of operations, generating the immediate predecessors for each operation.

Slack and float:

Slack - Slack signifies the freedom for rescheduling or to start the job. It can be calculated by the difference between EFT and LFT for any job. A job for which the slack time is zero is known as critical job. The critical path can be located by all those activities or events for which slack time is either zero or float time is the least. The abbreviations EFT and LFT given in the above line have the following explanation.

EFT (Earliest Finish Time) - this is the sum of the earliest start time plus the time of duration for any event.

LFT (Latest Finish Time) - It is calculated from the LFT of the head event. For its calculation total project time is required. The total project time is the shortest possible time required in completing the project.

Floats - Floats in the network analysis represent the difference between the maximum time available to finish the activity and the time required to complete it. There are so many activities where the maximum time available to finish the activity is more than the total time required to complete it. This difference is known as floats.

Floats may be total, free, and independent:

Total Float: Total float is the maximum amount by which duration time of an activity can be increased without increasing the total duration time of the project. Total float can be calculated as follows:

(i) First, the difference between Earliest Start Time (EST) of tail event and Latest Finish Time (LFT) of head event for the activity shall be calculated.

(ii) Then, subtract the duration time of the activity from the value obtained in (i) above to get the required float for the activity.

The total float can be helpful in drawing the following conclusions:

(a) If total float value is negative, it denotes that the resources for completing the activity are not adequate and the activity, therefore, cannot finish in time. So, extra resources or say critical path needs crashing in order to reduce the negative float.

(b) If the total float value is zero, it means the resources are just sufficient to complete the activity without any delay.

(c) If the total float value is positive, it points out that total resources are in excess of the amount required or the resources should be reallocated to avoid the delay otherwise the activity will be delayed by so much time.

Free Float: It is that fraction from total float of an activity which can be used for rescheduling the activity without affecting the succeeding activity. If both tail and head events are given their earliest times, i.e., EST and EFT the Free Float can be calculated by deducting head slack from total float, i.e.,

Free Float = Total float - Slack time of the head event.

Independent Float: It is the time by which the start of an activity can be rescheduled without affecting the earliest start time of any immediately following activities assuming that the preceding activity has finished at its latest finish time. It may be calculated as

Independent Float = Free Float – Tail Slack

or, Independent Float = Free Float -Slack Time of tail event. The basic difference between slack and float time is that a slack is used with reference to events whereas float is used with reference to activity.

Use of Float Information in Decision Making: The float information can be used in decision-making in the following ways:

(i) Total float can affect both the previous and the subsequent activities.

(ii) Total float can be used without affecting the subsequent activities.

(iii) Independent float can be used in allocating the resources elsewhere and increasing the time of some non-critical activities.

(iv) Negative float signifies reduction in target time to finish the work in time.

Critical Path Method (CPM): The critical path analysis is an important tool in production planning and scheduling.Gnatt charts are also one of the tools of scheduling but they have one disadvantage for which they are found to be unsuitable. The problem with Gnatt Chart is that the sequence of operations of a project or the earliest possible date for the completion of the project as a whole cannot be ascertained. This problem is overcome by this method of Critical Path Analysis.

CPM is used for scheduling special projects where the relationship between the different parts of projects is more complicated than that of a simple chain of task to be completed one after the other. This method (CPM) can be used at one extreme for the very simple job and at other extreme for the most complicated tasks.

A CPM is a route between two or more operations which minimises (or maximises) some measures of performance. This can also be defined as the sequence of activities which will require greatest normal time to accomplish. It means that the sequence of activities which require longest duration are singled out. It is called at critical path because any delay in performing the activities on this path may cause delay in the whole project. So, such critical activities should be taken up first.

One of the purposes of critical path analysis is to find the sequence of activities with the largest sum of duration times, and thus find the minimum time necessary to complete the project. The path of the Network with the critical series of activities is known as the **'Critical Path'**.

Under CPM, the project is analysed into different operations or activities and their relationship are determined and shown on the network diagram. So, first of all a network diagram is drawn. After this the required time or some other measure of performance is posted above and to the left of each operation circle. These times are then combined to develop a schedule which minimises or maximises the measure of performance for each operation. Thus CPM marks critical activities in a project and concentrates on them.

Thus CPM technique is a very useful analysis in production planning of a very large project.

PERT (Programme Evaluation and Review Technique):

There are so many modem techniques developed recently for the planning and control of large projects in various industries especially in defence, chemical and construction industries. Perhaps, the PERT is the best known of such techniques.

PERT is a time-event network analysis technique designed to watch how the parts of a programme fit together during the passage of time and events. This technique was developed by the special project office of the U.S.

Navy in 1958. It involves the application of network theory to scheduling, problems. In PERT we assume that the expected time of any operation can never be determined exactly.

Major Features of PERT or Procedure or Requirement for PERT:

The following are the main features of PERT:

(i) All individual tasks should be shown in a network. Events are shown by circles. Each circle represents an event—a subsidiary plan whose completion can be measured at a given time.

(ii) Each arrow represents an activity —the time - consuming elements of a programme, the effort that must be made between events.

(iii) Activity time is the elapsed time required to accomplish an event. In the original PERT, three-time values are used as follows:

- t_1 (Optimistic time): It is the best estimate of time if everything goes exceptionally well.
- t_2 (Most likely time): It is an estimated time what the project engineer believes necessary to do the job or it is the time which most often is required if the activity is repeated a number of times.
- t_3 (Pessimistic time): It is also an estimate of time of an activity under adverse conditions. It is the longest time and rather is more difficult to ascertain.

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

$t = \frac{t_1 + 4t_2 + t_3}{6}$ and the variance of t is given by: $V(t) = \left(\frac{t_3 - t_1}{6}\right)^2$

(iv) The next step is to compute the critical path and the slack time.

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

Difference in PERT and CPM - Although these techniques (PERT and CPM) use the same principles and are based on network analysis yet they are different in the following respects from each other:

(i) PERT is appropriate where time estimates are uncertain in the duration of activities as measured by optimistic time, most likely time, and pessimistic time, whereas CPM (Critical Path Method) is good when time estimates are found with certainty. CPM assumes that the duration of every activity is constant and therefore does not deal with uncertainty in time.

(ii) PERT is concerned with events which are the beginning or ending points of operation while CPM is concerned with activities

(iii) PERT is suitable for non-repetitive projects while CPM is designed for repetitive projects.

(iv) PERT can be analysed statistically whereas CPM not.

(v) PERT is not concerned with the relationship between time and cost, whereas CPM establishes a relationship between time and cost and cost is proportionate to time.

Project Life Cycle

6.2

What is project Management?

A project is defined as a sequence of activities undertaken for getting a set of tasks done to achieve the desired business goals successfully. Project Management centres on planning and managing everything involved in delivering a Project.

What is a project?

A project is defined as a one-time activity with a series of tasks that produces a specific outcome to achieve organizational goals.

Projects are a set of interdependent tasks that have a common goal. No matter what the project is, each project is broken down into objectives and what needs to be done to achieve them, ensuring that the project stays on track and is completed as per plan.

The primary constraints of a project are:

- Time – the schedule for the project to reach completion
- Cost – the budget allocated for the project to meet its objectives and complete it on time
- Scope – the specific deliverables of the project
- Quality – the standard of the outcome of the project

Phases of Project Management Life Cycle

1. Project Initiation.

It provides an overview of the project, along with the strategies required to attain desired results. It is the phase where the feasibility and business value of the project are determined.

The Project Charter is considered to be the most important document of any project as it comprises:

- Business vision and mission
- Project goals and benefits
- List of stakeholders
- Scope of the Project
- Project deliverables
- Risks associated with the project
- Project budget and resources

2. Planning phase:

- Create a Statement of Work document to flesh out the details of project deliverables
- Develop a Work Breakdown Structure
- Create a project plan, assign team members (and other resources) to the various tasks and build a detailed project timeline
- Identify the Project Team roles and other resources for the project. At this stage, the Project Manager – working with a project staffing function – will most likely identify specific people for some of the key roles needed for the success of the project.
- Create a risk mitigation plan to identify potential risks and develop a strategy to minimize them
- Incorporate an effective change management plan for necessary changes in the project and to avoid bottlenecks
- Create a communication plan to schedule interactions with relevant stakeholders

3. Project Quality Management:

- The main principle of project quality management is to ensure the project will meet or exceed stakeholder's needs and expectations.
- Project Quality management consists of four main processes:
  - Quality Definition
  - Quality Assurance
  - Quality Control
  - Quality Improvements.
    - Quality Definition:

      Quality management implies the ability to anticipate situations and prepare actions that will help bring the desired outcomes. The goal is the prevention of defects through the creation of actions that will ensure that the project team understands what is defined as quality.
    - Quality Assurance:

      Quality Assurance is a process to provide confirmation based on evidence to ensure to the donor, beneficiaries, organization management and other stakeholders that product meet needs, expectations, and other requirements. It assures the existence and effectiveness of process and procedures tools, and safeguards are in place to make sure that the expected levels of quality will be reached to produce quality outputs.
    - Quality Control

      Quality control is the use of techniques and activities that compare actual quality performance with goals and define appropriate action in response to a shortfall.
    - Quality Improvements:

      Quality improvement refers to the application of methods and tools to close the gap between current and expected levels of quality by understanding and addressing system deficiencies and strengths to improve, or in some cases, re-design project processes.

4. Execution Phase

This stage is where the bulk of the project happens. Deliverables are built to make sure the project is meeting requirements. This is where most of the time, money, and people are pulled into the project.

This phase happens in tandem with the execution phase. As the project moves forward, the project manager must make sure all moving parts are seamlessly headed in the right direction. If adjustments to the project plan need to be made due to unforeseen circumstances or a change in direction, they may happen here.

During the controlling and monitoring phase, project managers may have to do any of the following:

- Manage resources
- Monitor project performance
- Risk management
- Perform status meetings and reports
- Update project schedule
- Modify project plans.

5. Project Closure:

The closing phase is a critical step in the project management life cycle. It signals the official end of the project and provides a period for reflection, wrap-up, and organization of materials.

Project managers can:

- Take inventory of all deliverables
- Tie up any loose ends
- Hand the project off to the client or the team that will be managing the project's day-to-day operations
- Perform a post-mortem to discuss and document any learnings from the project
- Organize all project documents in a centralized location
- Communicate the success of the project to stakeholders and executives
- Celebrate project completion and acknowledge team members

Gantt Charts

6.3

Gantt chart is a graphical representation of a series of activities drawn to a time scale. Horizontal axis (X-axis) represents time and vertical axis (Y-axis) shows the activities to be performed. The Gantt chart shows activities to specific jobs at individual/work centers by horizontal bars. Also known as a 'bar chart' because of its graphic presentation of the information, the position and the length of the horizontal bar indicate the start and completion date of the activity.

Strengths of Gantt Charts

Gantt charts are preferred for various reasons, which are as follows:

- Very simple to understand by everyone e.g. foreman, engineers, managers, and top management.
- Provide useful information in a format that is simple to develop and interpret.
- It is a good tool for planning as well as monitoring the progress of the work. It helps schedulers to evaluate the progress of a project at various levels.
- Helps in loading the work center in relation to the available capacity.
- It provides the user with a quick, visual indication of the actual status of each order and its anticipated or planned status.
- The scheduler could easily incorporate changes in timing, machine loads, and current status.
- Some common changes make Gantt charts fairly flexible to apply. It indicates the need for reassessing the resources incase the load at one work station becomes too much. Workforce could be temporarily adjusted to meet the high demand of the heavily loaded workstation by shifting the manpower from a relatively less loaded work center. Even multi-purpose equipments are shifted from less loaded work centers to heavily loaded work centers.
- Gantt charts suit the requirements of a wide range of media from ruled paper to mechanical devices and computer systems.

Limitations

- It does not convey the variability of the task duration, equipment performance (including breakdowns), and human potential, any one of which could influence the accuracy of loading the work centers.
- It does not clearly indicate the details regarding progress of activities.
- It does not give a clear indication of the interrelationship between separate activities.
- The chart is static and has to be updated periodically to account for new job arrivals and revised time estimates for existing jobs.

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.

Solution:

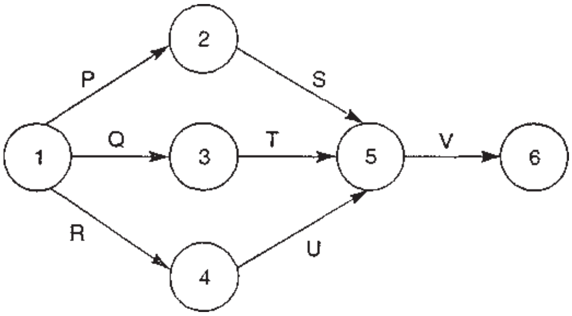


Illustration 2

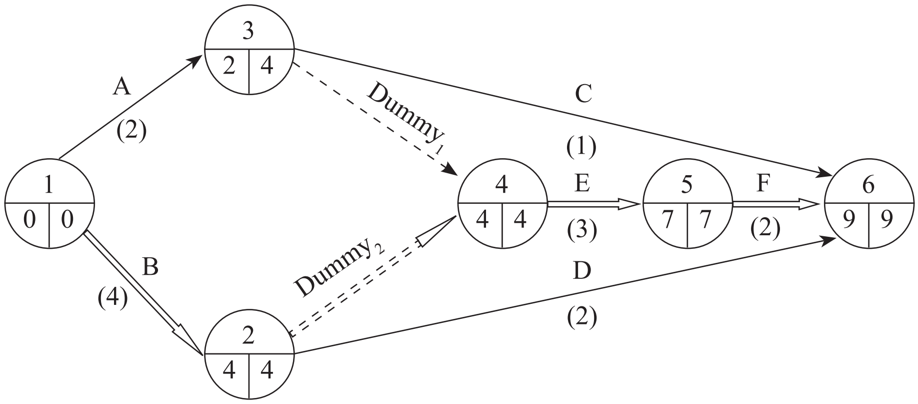
Project with the following data is to be implemented. Draw the network and find the critical path.

Activity	Predecessor	Duration (days)	Cost (₹ Day)
A	-	2	50
B	-	4	50
C	A	1	40
D	B	2	100
E	A,B	3	100
F	E	2	60

1. What is the minimum duration of the project?
2. Draw a Gantt chart for early start schedule.
3. Determine the peak requirement of money and the day on which it occurs in the above schedule.

Solution:

(1)



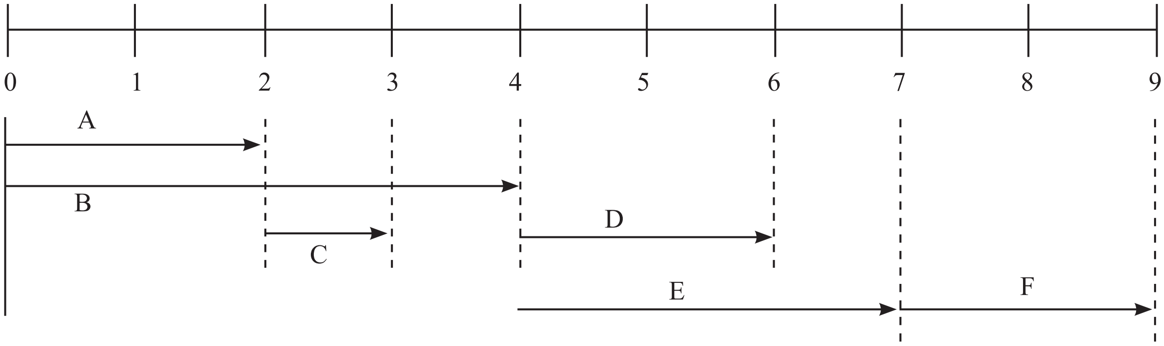
Critical Path B – Dummy$_2$ – E – F

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	2	3	8	9	6	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 occurance 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 (₹ 50 for A + ₹ 50 for B) per day i.e. ₹ 100 per day
- (ii) B & C — Either on day 3 or on day 4 of the project and it will require (₹ 50 for B + ₹ 40 for C) per day i.e. ₹ 90 per day
- (iii) C, D & E — During day no. 5 or day no. 6 and cost is ₹ (40 + 100 + 100) = ₹ 240 per day
- (iv) C, D & F — During day no. 8 or day no. 9 and cost is ₹ (40 + 100 + 60) = ₹ 200 per day
- (v) D & E — During day nos. 5 & 6 or 6 & 7. Cost is ₹ (100 + 100) = ₹ 200 per day
- (vi) D & F — During day nos. 8 & 9. Cost = ₹ (100 + 60) = ₹ 160 per day
- (vii) C & E — Either on day no. 5 or 6 or 7. Cost to be incurred = ₹ (40 + 100) = ₹ 140 per day

From above we can say that C can occur by using either of the options (ii), (iii), (iv) & (vii). As cost fo option (ii) is least one should decide fo it at a cost of ₹ 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 ₹ 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 @ ₹ 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 @₹ 90 per day

(c) E being Critical Activities must have to start at it's earliest time (i.e. 4) and occur @ ₹ 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 @ ₹ 160 per day.

Hence peak requirement of money is ₹ 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.

Solution:

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)

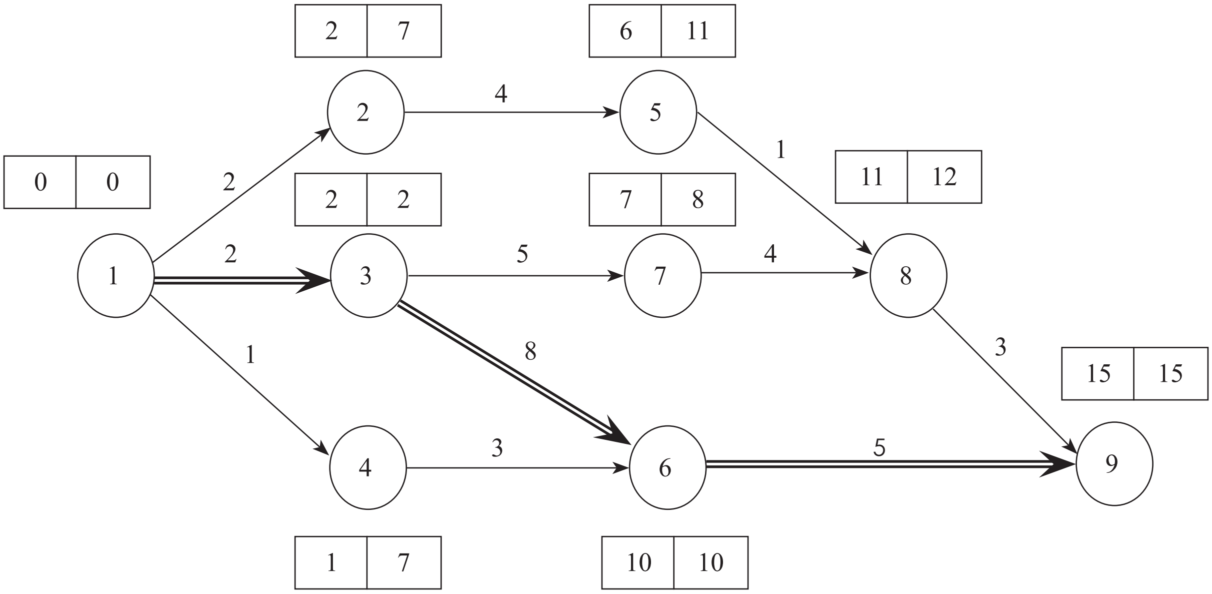


Table: Activity Relationship

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

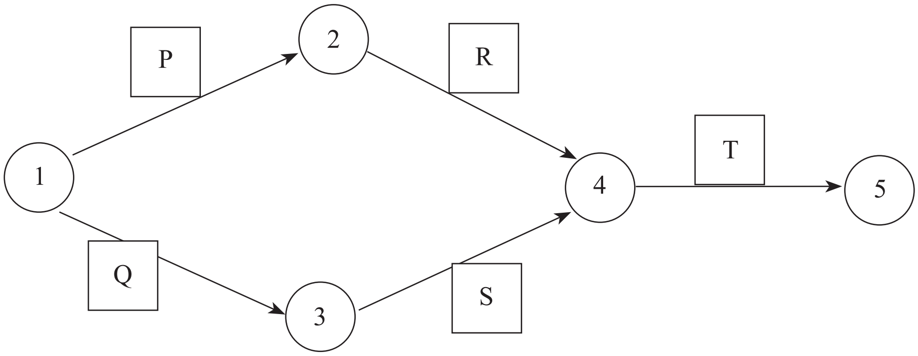
Illustration 4

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.

Solution:



PERT and CPM

6.4

Network Analysis

Network analysis is the general name given to certain specific techniques which can be used for planning, management and control of project. It often acts as a network management tool for breaking down projects into components or individual activities and recording the result on a flow chart or network diagram. These results generally reveal information that is used to determine duration, resource limitations and cost estimates associated with the project.

It offers insight into what is occurring at each critical point of the network. Project management and efficient resource allocation are two critical aspects of the production and operations managers' responsibilities. Since a project is non-repetitive and temporal in nature, the mode of management differs from the usual job shop or other related types of scheduling.

Network analysis enables us to take a systematic quantitative structural approach to the problem of managing a project through to successful completion. Also, since it has a graphical representation, it can be easily understood and used by those with a less technical background.

Network is a graphical representation of all the Activities and Events arranged in a logical and sequential order. Network analysis plays an important role in project management. A project is a combination of interrelated activities all of which must be executed in a certain order for its completion. Activity is the actual performance of the job. This consumes resources (Time, human resources, money, and material. An event refers to start or completion of a job. This does not consume any resources.

Applications:

- Construction of a Residential complex,
- Commercial complex,
- Petro-chemical complex
- Ship building, Aircraft Manufacturing
- Satellite mission development
- Installation of a pipe line project etc.

The procedure of drawing a network is:

1. **Specify the Individual Activities:** From the work breakdown structure, a listing can be made of all the activities in the project. This listing can be used as the basis for adding sequence and duration information in later steps.
2. **Determine the Sequence of the Activities:** Some activities are dependent on the completion of others. A listing of the immediate predecessors of each activity is useful for constructing the CPM network diagram.

3. **Draw the Network Diagram:** Once the activities and their sequencing have been defined, the CPM diagram can be drawn. CPM originally was developed as an activity on node (AON) network, but some project planners prefer to specify the activities on the arcs.
4. **Estimate Activity Completion Time:** The time required to complete each activity can be estimated using past experience or the estimates of knowledgeable persons. CPM is a deterministic model that does not take into account variation in the completion time, so only one number is used for an activity's time estimate.
5. **Identify the Critical Path:** The critical path is the longest-duration path through the network. The significance of the critical path is that the activities that lie on it cannot be delayed without delaying the project. Because of its impact on the entire project, critical path analysis is an important aspect of project planning.

The critical path can be identified by determining the four parameters for each activity. The four parameters are Earliest Start, Earliest Finish, Latest Finish and Latest Start.

Rules for drawing the network diagrams.

In a network diagram, arrows represent the activities and circles represent the events.

- The tail of an arrow represents the start of an activity and the head represent the completion of the activity.
- The event numbered 1 denotes the start of the project and is called initial event.
- Event carrying the highest number in the network denotes the completion of the project and is called terminal event.
- Each defined activity is represented by one and only arrow in the network.
- Determine which operation must be completed immediately before other can start.
- Determine which other operation must follow the other given operation.
- The network should be developed on the basis of logical, analytical and technical dependencies between various activities of the project.

The basic network construction – Terminology used.

Network representation: There are two types of systems –

AOA system (Activity on Arrow system)	AON system (Activity on Node system)
In this activities are represented by an arrows.	In this method activities are represented in the circles.

A project consists of tasks with definite starting and ultimate ending points and hence a project manager is saddled with the responsibilities of getting job done on schedule within allowable cost and time constraint specified by the management. Typically all projects can be broken into:

Separate activities – where each activity has an associated completion time (time from the start of the activity to its finish).

Precedence relationships – which govern order in which we may perform the activities.

The main problem is to bring all these activities together in a coherent fashion to complete the project at a required time.

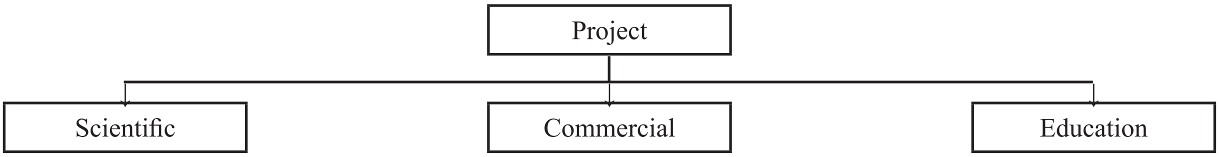
Apart from the traditional method of adding activity durations, these exist two different techniques for network analysis namely the PERT – Program Evaluation and Review Technique and CPM – Critical Path Management.

PERT has the ability to cope with uncertainty in activity completion times while CPM emphasized on the trade-off between cost of the project and its overall completion time.

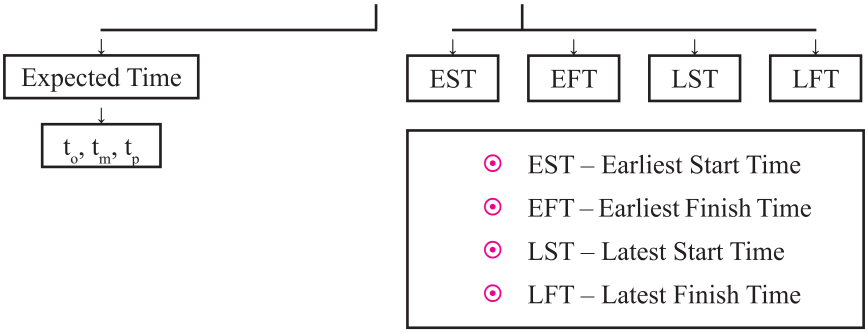
The CPM has the advantage of decreasing completion times by probably spending more money.

PERT-CPM

- CPM – Critical Path Method
- PERT – Program Evaluation Review Techniques



- Any project is composed of related activities.
- Activities are composed of related events.
- Each activity is divided into three parts:
  I. Independent Activity
  II. Dependent Activity
  III. Dummy Activity
- For completion of each activity except dummy, time is required.
- Time taken for completion of the activity divided into two parts:
  I. Deterministic time
  II. Probabilistic time
- Probabilistic time is divided into three parts:
  I. Optimistic time(t_o)
  II. Most likely time(t_m)
  III. Pessimistic time(t_p)
  where t_e = expected time = $(t_o + 4 \times t_m + t_p)/6$
  Variance = $((t_p - t_o)/6)^2$
- For calculation of expected time & Variance we apply Beta Distribution.
- Time calculated based on <u>activities</u> as well as <u>events</u>.



- EST – Earliest Start Time
- EFT – Earliest Finish Time
- LST – Latest Start Time
- LFT – Latest Finish Time

- EST and EFT are forward process.
  - First we calculate EST then EFT.
- Where EFT = EST + d_{ij} ; d_{ij} = duration (expected time) for i-j activity
- LST and LFT are backward process.
  - First we calculate LFT then LST

    Where LST = LFT – d_{ij}
- **Steps to be followed for solving PERT/CPM problem:**
  - Step 1: Draw the network diagram.

↓

Diagrammatic presentation of the project which composed of:

- Dependent activity
- Independent activity
- Dummy activity

- Step 2: Calculate te(expected time/duration) for each activity from the problem given.
- Step 3: Calculate EST, EFT, LFT & LST for the problem.
- Step 4: Calculate Total Float (TF)

  Where, TF = LFT – EFT, for checking the Critical Path.
  - Critical Path is the path which contains maximum activity with maximum duration.
- Step 5: After calculating Critical Path, calculate Critical Path Duration (CPD) and Variance for each activities.
- Step 6: At last we calculate total time (approx.) taken for the completion of the project using Normal Distribution.

Activities:

Let,

A – Independent Activity

B – Independent activity

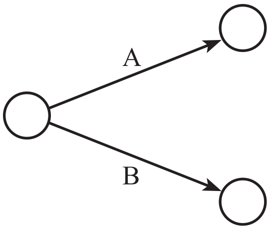
C – Dependent activity (Dependent on A and B)

D – Dependent Activity (dependent on C)

- For independent activity starting point must be same.
- The dependent activity C will start after the completion of A and B.
- The dependent activity D will start after the completion of C.

Let's take a look at the Network Diagram of the above processes.

Network Diagram:



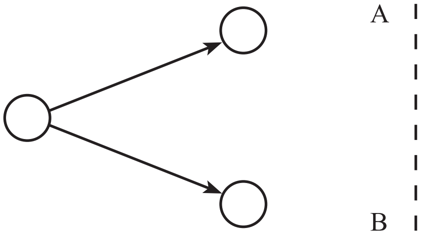
For Network diagram:

○ - Starting or Finishing point

→ - Activity along with its direction

⇢ - Dummy activity

- As A and B are independent activities of the process so their starting point is also same but since they are different activities their directions are different.
- Now from where the activity C will be starting – from the end of A or from the end of B? This remains a question to complete the Network Diagram. Here we need to add a Dummy Activity after the end of A & B.



- Now the Dummy Activity is added but the direction is still not clear so that we can start C.
- The duration of the activity or the Time taken by the independent activities will decide the direction the Dummy activity to maintain the sequence of the project and go further in the process.

Let the time taken for each activity be:

Activity	Time Taken(max)
A – Independent Activity	3
B – Independent activity	4
C – Dependent activity (Dependent on A and B)	5
D – Dependent Activity (dependent on C)	6

For A – 3 days is needed at max.

B – 4 days is needed at max.

- Then the direction of the dummy activity (in this case) will be from A to B since A will finish before B anyhow.

For a Dummy Activity:

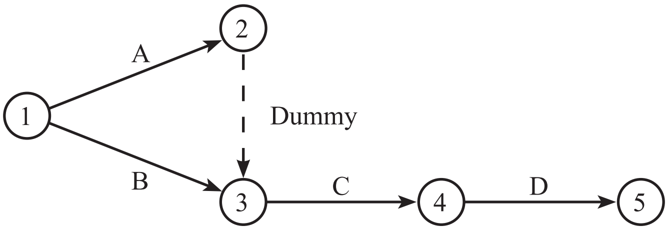
- The starting point of the dummy activity will be the end point of the activity which ends first.
- If both the independent activities finish at the same point then the direction can be in any way.

- Dummy Activity is required to maintain the sequence of the project. Therefore, it has no time to complete.

i.e. For the dummy activity the time taken is 0 units always.

- Now we can complete the Network Diagram as below.

- For understanding the Network Diagram we need some numbering techniques:
  - Assigning numbers to starting and finishing points in a particular order.



- After the numbers are added it becomes easier to denote the activities according the path they follow.
  - A (1-2) – A starts at 1 and finishes at 2
  - B (1-3) – B starts at 1 and finishes at 3
  - Dummy (2-3) – Dummy starts at 2 and finishes at 3
  - C (3-4) – C starts at 3 and finishes at 4
  - D (4-5) – D starts at 4 and finishes at 5
- There is a Source and a Destination for every project. In our case Source is 1 and Destination is 5.
- Every project aims at starting from the Source and reach the Destination through a certain path.
- In our case, we have the Network Diagram above with the path defined from 1 to 5 as follows:
  - Path I: 1 – 2 – 3 – 4 – 5
  - Path II: 1 – 3 – 4 – 5
- Calculating the path duration of each path :
  - Path I : 3 days(1 – 2) + 0 days(2 – 3) + 5 days(3 – 4) + 6 days(4 – 5) = 14 days
  - Path II : 4 days(1 – 3) + 5 days(3 – 4) + 6 days(4 – 5) = 15 days
- Path II takes maximum time to reach the destination from source or to complete the project. Therefore it is the Critical Path.
  - Critical Path (CP) –> 1 – 3 – 4 – 5
  - Critical Path Duration (CPD) = 15 days
  - Critical Path Activities (CPA) –> B(1 – 3), C(3 – 4), D(4 – 5)
- Critical Path contains the major activities of the project thus the activities are called Critical Path Activities.
  - Table showing the calculation of EST, EFT, LST, LFT and TF:

Activities	Time(d_{ij})	EST	EFT (= EST + dij)	LST (= LFT - dij)	LFT	TF (= LFT – EFT)
A (1-2)	3	0	3	1	4	1
B (1-3)	4	0	4	0	4	0*
Dummy (2-3)	0	3	3	4	4	1
C (3-4)	5	4	9	4	9	0*
D (4-5)	6	9	15	9	15	0*

- To calculate the above values, here are the few things to be remembered:
  - In case of EST, if the starting point is same then EST will be same.
  - In case of LFT, if the finishing point is same then the LFT will be same.
  - For independent activities, EST = 0.
  - For the last activity LFT = EFT.
- **Calculation behind the above table created:**
  - **EST and EFT are Forward Processes** i.e. we start from the first activity and end at the last activity. And we go for EST first then EFT is calculated.
    - Since A and B are independent activities, their EST = 0.
    - The Dummy activity can only start after the completion of A. So the EST of the Dummy activity will be the Time taken to complete A i.e. 3
    - C can start after the completion of B. So the EST of C will the time taken to complete B i.e. 4
    - D can start only after the completion of C. So the EST of D will the time taken to complete C plus the time taken to start C i.e. 4(to start C) + 5(to complete C) = 9.
    - EST is filled. Now we get the EFT by adding the time/duration (dij) of each activity to EST. EFT completed.
  - **LST and LFT are Backward Processes** i.e. we start from the last activity and move towards the first activity. And we go for LFT first and then LST is calculated.
    - For the last activity LFT = EFT i.e. for D, LFT = 15
    - For C, we don't need to consider the time for D but we need to consider every other activity. Thus LFT of C will be the LFT of D minus the Time taken to complete D. i.e. 15(LFT of D) – 6(Time taken for D) = 9
    - For Dummy activity, we don't need to consider the time for C & D but we need to consider every other activity. Thus LFT of Dummy will be the LFT of D minus the Time taken to complete C & D. i.e. 15(LFT of D) – 6(Time taken for D) – 5(Time taken for C) = 4
    - For B, it needs to finish before the start of C. So it's LFT = EST of C i.e. 4.
      - Also for B, we don't need to consider the time for Dummy, C & D but we need to consider A. Thus LFT of B will be the LFT of D minus the Time taken to complete Dummy, C & D. i.e. 15(LFT of D) – 0(Time for Dummy) - 6(Time taken for D) – 5(Time taken for C) = 4.
      - If we think it otherwise, the LFT of Dummy is 4. And B needs to finish either on 4th day or before (from the start of the project), it can't take more time than that. But it itself needs 4 days to complete the activity. Thus LFT will be 4 only.
    - For A, It is an independent activity but it needs to complete before start of C. B doesn't count in case of A because both follows separate path. From the last activity till Dummy the LFT stays at 4 which means A can complete the activity at 4th day as well even if its time required is 3 days, and also Dummy doesn't have any stipulated time to complete. A should only be bothered about the start of C.
      - Also for A, we don't need to consider the time for Dummy, C & D from the critical path duration. Thus LFT of A will be the LFT of D minus the Time taken to complete Dummy, C & D. i.e. 15(LFT of D) – 0(Time for Dummy) - 6(Time taken for D) – 5(Time taken for C) = 4.

- ▶ LFT is filled now. Then calculate the LST by subtracting each value by the time/duration (d_{ij}) of each activity. LST is also filled.
- TF is calculated as TF = LFT – EFT. The table is complete now.
- The zeroes in the TF column are assigned a * to indicate the Critical Path Activities.

⊙ If the TF of an activity is zero, then they are called the Critical Path Activities. This is the other way of finding the CPAs where the results stays same as before when we found it through the network diagram.

Illustration 5

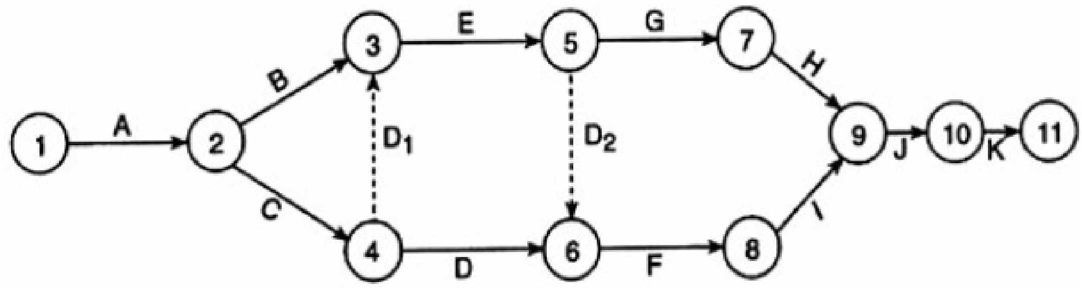
XYZ Auto-manufacturing company has to prepare a design of its latest model of motorcycle. The various activities to be performed to prepare design are as follows:

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.

Solution:

The network diagram will be as follows:



Where D_1 and D_2 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 (₹)	Time (days)	Cost (₹)
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 ₹ 100.

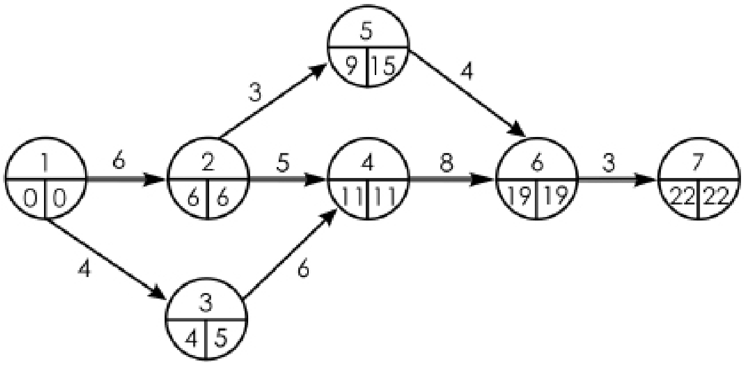
(i) Draw the network and identify the critical path.

(ii) What are the normal project duration and associated cost?

(iii) Crash the relevant activities systematically and determine the optimum project completion time and cost.

Solution:

(i) 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:

Total cost = Direct normal cost + Indirect cost for 22 days.

= 4,700 + 100 × 22 = ₹ 6,900.

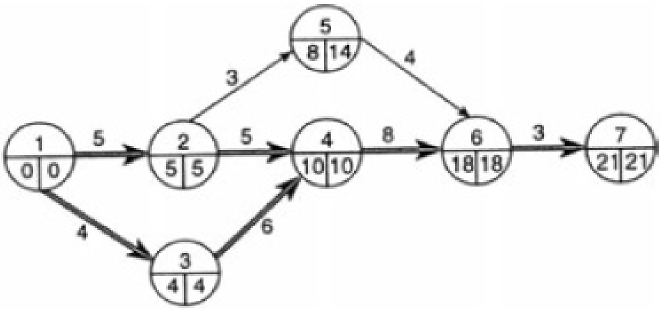
(iii) For critical activities, cost - slope is given below:

Critical activity	Cost-slope* (₹/day)
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	$\frac{800 - 450}{3 - 2} = 350$

$$^{*}\text{Cost slope} = \frac{\text{Crash Cost} - \text{Normal Cost}}{\text{Normal Time} - \text{Crash Time}}$$

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.

Duration = 21 days, and cost = 4700 + 1 × 200 + 100 × 21 = ₹ 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 ₹ 350.

Crash activity 4 — 6 by 4 days at the cost of ₹ 550 per day.

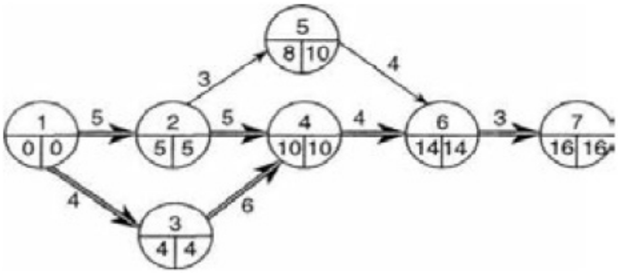
Crash activities 1—2 and 1 — 3 by 1 day each at a cost of ₹ (200 + 700) = ₹ 900.

Crash activities 2 — 4 and 3 — 4 by 2 days each at a cost of ₹ (500 + 550) = ₹ 1050/day.

Thus, we shall first crash activities 6 — 7 by 1 day and then activity 4 — 6 by 4 days.

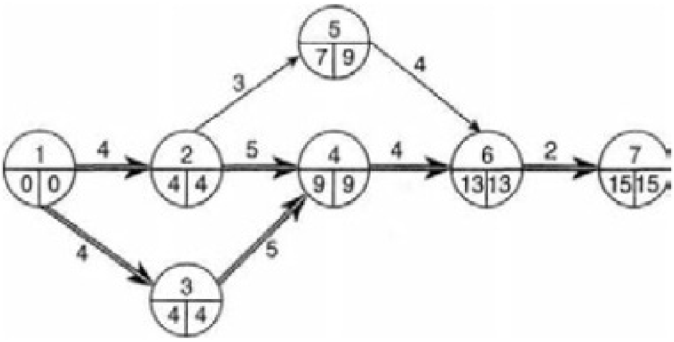
On crashing activity 6 — 7 by 1 day, cost = 4900 + 350 × 1 + 100 × 20 = ₹ 7250, and duration = 20 days. Next we crash 4—6 by 4 days.

Cost = 5250 + 550 × 4 + 100 × 16 = ₹ 9050. Duration = 16 days.



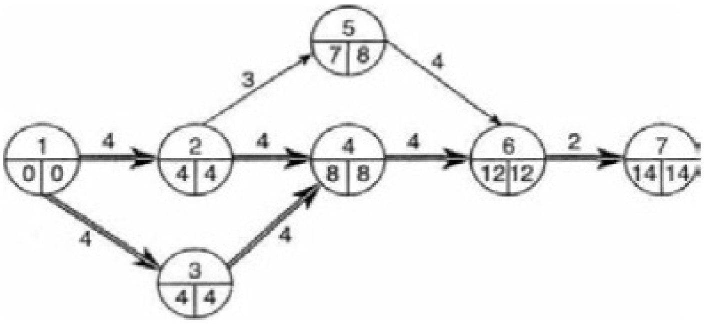
Next we crash activities 1—2 and 3—4 by 1 day each.

Cost = 7450 + 200 × 1 + 550 × 1 + 100 × 15 = ₹ 9700.



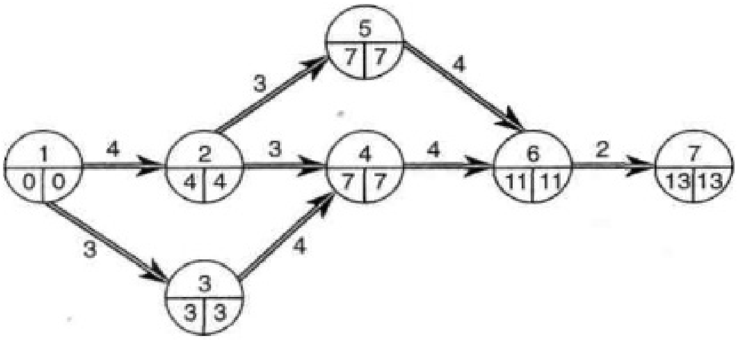
Next we crash activities 2 ⟶ 4 and 3 ⟶ 4 by 1 day each.

Cost = 8200 + 500 × 1 + 550 × 1 + 100 × 14 = ₹ 10,650. Duration = 14 days.



We crash activities 1—3 and 2—4 by 1 day each.

Cost = 9250 + 700 × 1 + 500 × 1 + 100 × 13 = ₹ 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

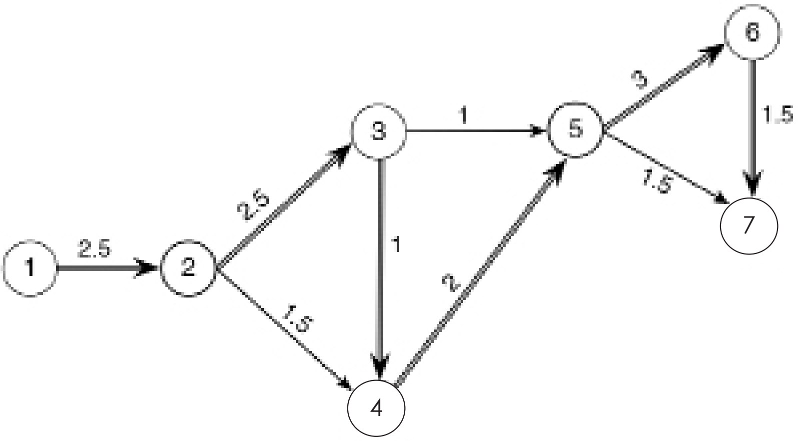
Also, no further crashing is possible. Hence minimum duration of the project =13 days with cost ₹ 11,750

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		

Solution:



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:

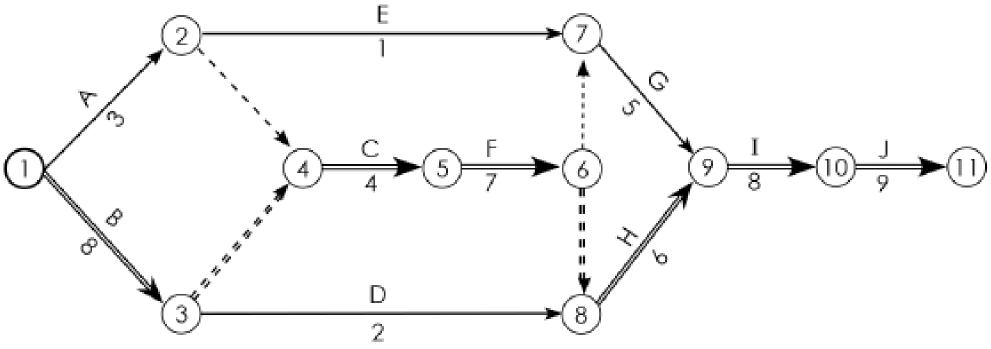
Activity	A	B	C	D	E	F	G	H	I	J
Time	3	8	4	2	1	7	5	6	8	9
Predecessors	—	—	AB	B	A	C	EF	DF	GH	I

- 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:

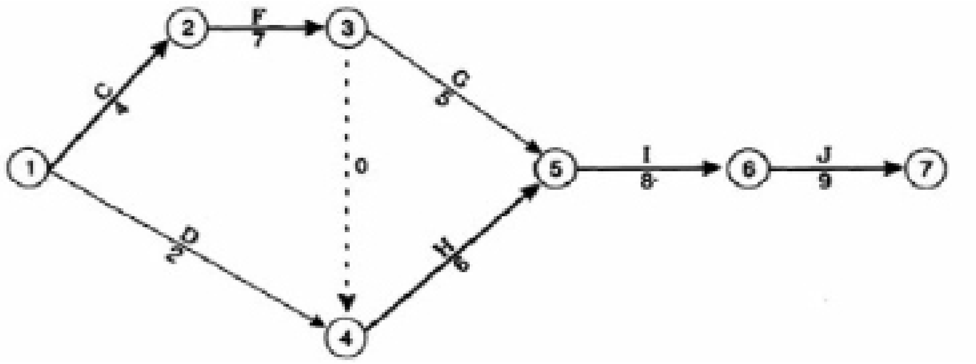
Activities completed: A, B, E. Other activities have not started as yet.

- 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?

Solution:



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

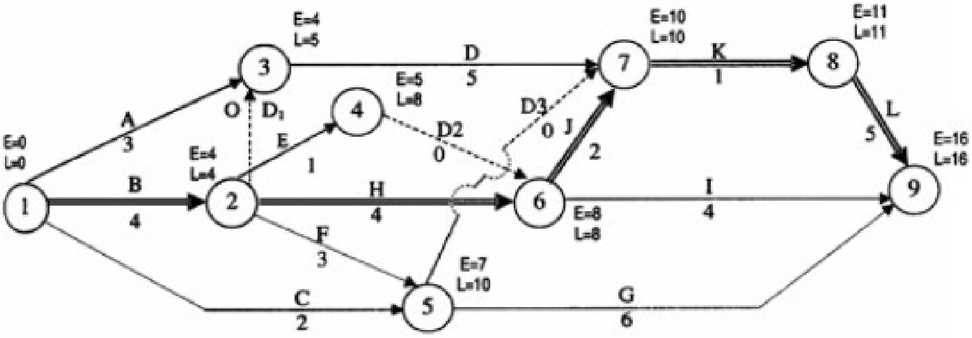
Given is the following information regarding a project:

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.

Solution:

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	$\boxed{\mathbf{0}}$	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	$\boxed{\mathbf{0}}$	0	0
I	4	8	12	12	16	4	4 – 0= 4	4 – 0= 4
J	2	8	8	10	10	$\boxed{\mathbf{0}}$	0	0
D3	0	7	10	7	10	3	3 – 0 = 3	3 – 3 = 0
K	1	10	10	11	11	$\boxed{\mathbf{0}}$	0	0
L	5	11	11	16	16	$\boxed{\mathbf{0}}$	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:

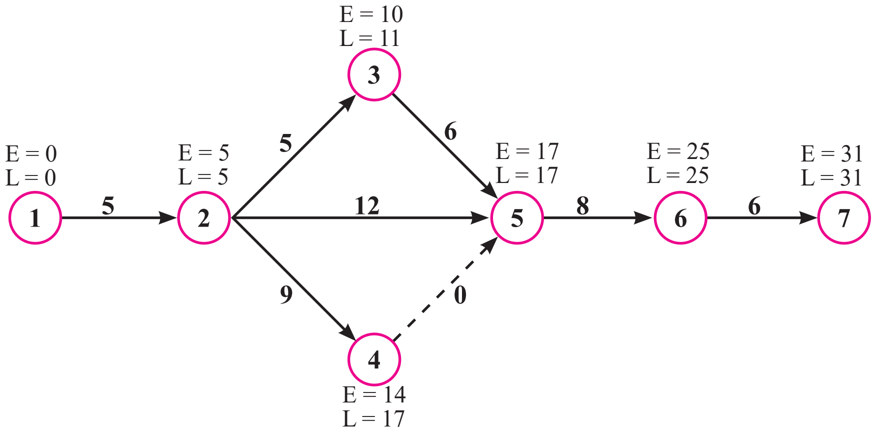
Activity	Normal time (Hrs.)	Normal cost (₹)	Crash time (Hrs.)	Crash cost (₹)
1-2	5	200	4	300
2-3	5	30	5	30
2-4	9	320	7	480
2-5	12	620	10	710
3-5	6	150	5	200
4-5	0	0	0	0
5-6	8	220	6	310
6-7	6	300	5	370

Overhead cost is ₹ 50 per hour.

Required:

Draw network diagram and identify the critical path.

Solution:



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.

Solution:

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.]

Solution:

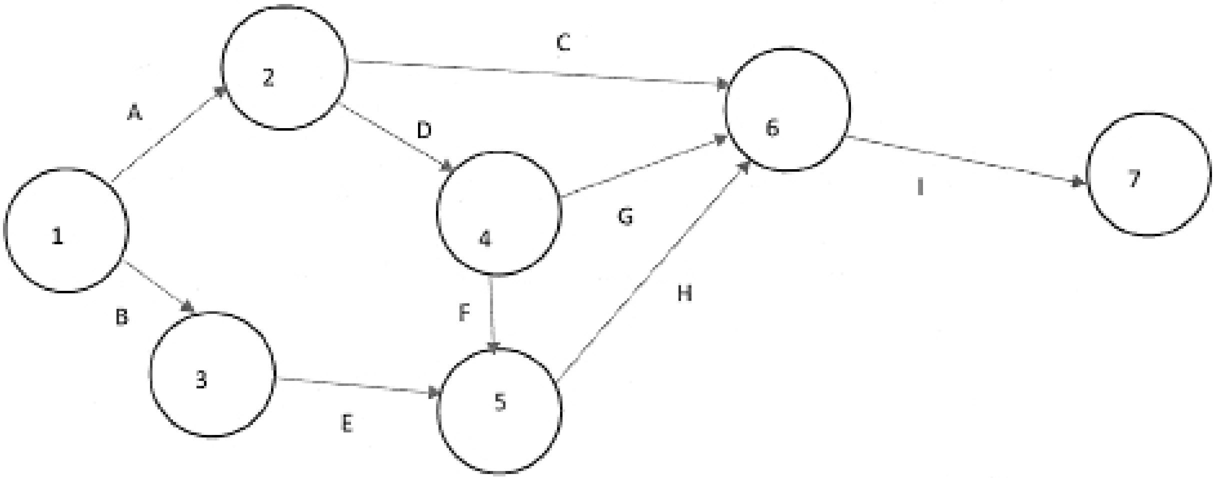


Illustration 13

Construct the network diagram from the data given below and find

(a) total duration of the project

(b) Critical Path

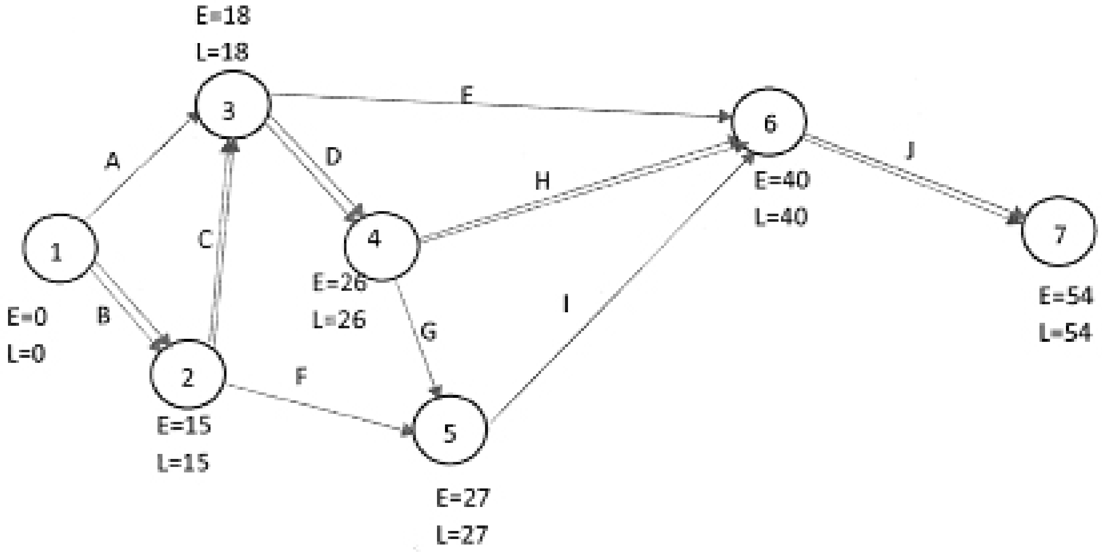
(c) EST, EFT, LST, LFT.

(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

Solution:

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 - ES-Tij = LFTij - EFTij)
A(1-3)	15	0	15	3	18	15
B (1-2)	15	0	15	0	15	0
C(2-3)	3	15	18	15	18	0
D (3-4)	5	18	23	18	23	0
E (3-6)	8	18	26	29	37	11
F(2-5)	12	15	27	10	22	5
G (4-5)	1	23	24	21	22	2
H (4-6)	14	23	37	23	37	0
1 (5-6)	3	27	30	34	37	7
J (6-7)	14	37	51	37	51	0



Critical Path 1-2-3-4-6-7

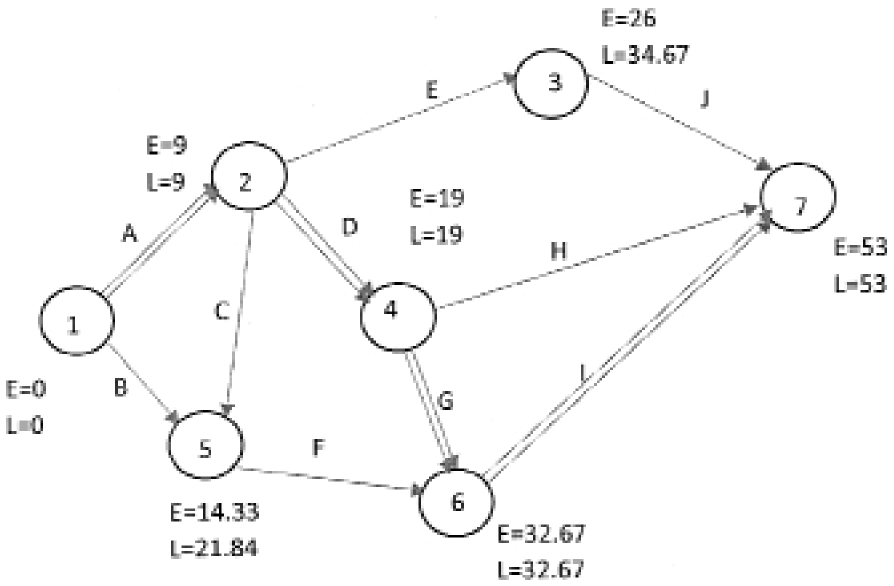
Critical Activity: B -C -D -H-J.

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

Solution:



Activity	Optimistic time (to)	Most likely Time (tm)	Pessimistic time (tp)	$a^2= (tp-to/6)^2$	te = to+4tm+tp/6
1-**2**	6	9	12	1.00	9.0
1-5	4	7	8	0.44	6.7

Activity	Optimistic time (to)	Most likely Time (tm)	Pessimistic time (tp)	$a^2 = (tp-to/6)^2$	te = to+4tm+tp/6
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		2	3	4
questionnaire				
B.Sample design		6	10	20
C.Testing of		2	4	6
questionnaire				
and refinements				
D.Recruiting				
interviewers	B	2	3	10
E.Training of	D,A	1	1	1
interviewers				
F.Allocation of	B	4	5	6
interviewers				
to territories				

Task	Duration(days)			
	Precedence	Optimistic	Most(likely)	Pessimistic
G.Conducting	C,E,F	5	12	25
interviews				
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

Solution:

t_e = Expected time

A = Optimistic time;

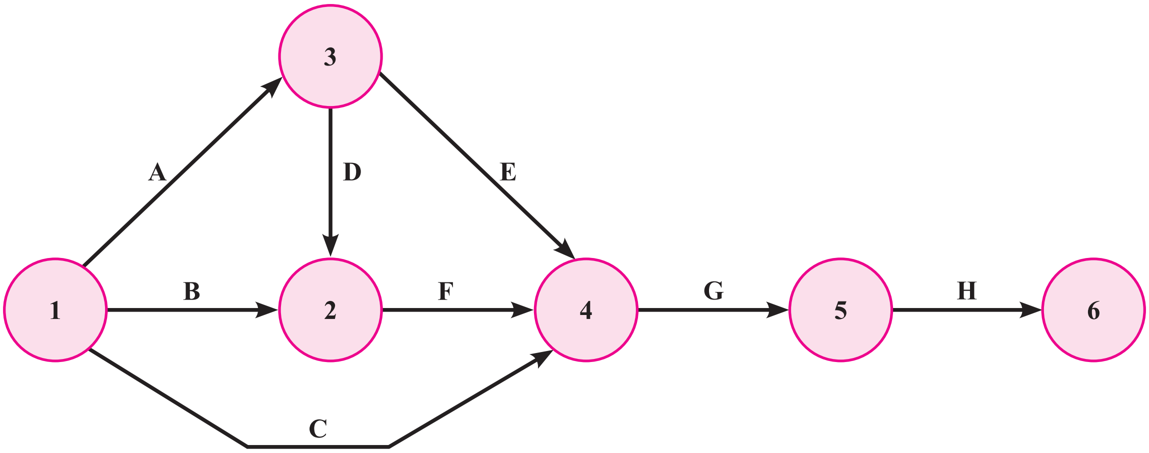
M = Most likely time;

B = Pessimistic time

Activity	A	M	B	Te	Variance
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

$$t_e = (A + 4M + B)/6$$

$$\text{Variance}(t) = [(B - A)/6]^2$$



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

$$\mathbf{CSD_1} = \sqrt{\frac{49}{9}+\frac{16}{9}+0+\frac{100}{9}+\frac{49}{9}} = 14.9/3 = 4.966 \text{ (Approx.)}$$

$$\mathbf{CSD_2} = \sqrt{\frac{49}{9}+\frac{1}{9}+\frac{100}{9}+\frac{49}{9}} = 14.1/3 = 4.7 \text{ (Approx.)}$$

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-μ)/σ<= ((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<=n)

P((T-μ)/σ<= (n-μ)/σ) = P(Z<= 3)

P(Z<= (n-40)/4.7) = P(Z<= 3)

n = 4.7 × 3 + 40

n = 54 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

(a) Draw the network.

(b) Calculate expected time for each activity and variance for each activity.

(c) Calculates EST, EFT, LST, LFT, TF

(d) Identify critical path.

(e) Find the no of day by which approximately 90% of the project will be completed

Solution:

t_e = Expected time

A = Optimistic time;

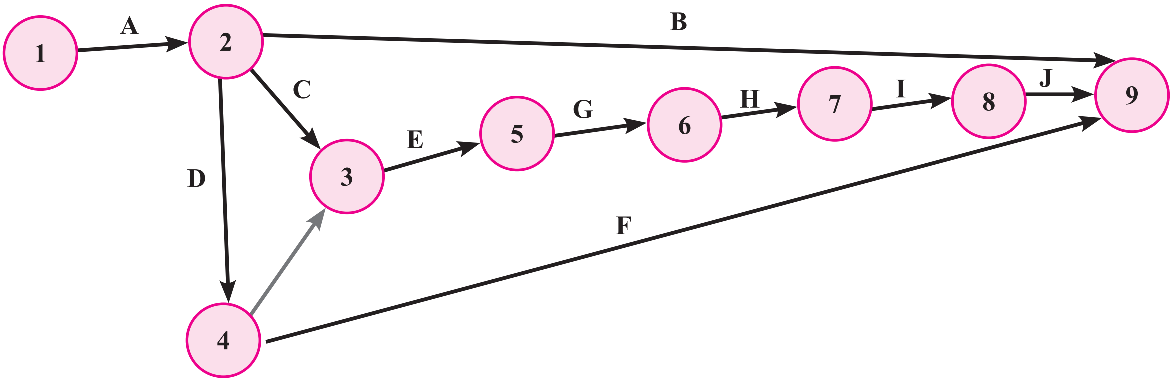
M = Most likely time;

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

Activity	A	M	B	t_e	Variance (t)	EST	EFT	LST	LFT	TF
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

$$\textbf{CSD} = \sqrt{\frac{1}{9}+\frac{4}{9}+4+\frac{4}{9}+\frac{25}{9}+\frac{4}{9}+\frac{25}{9}} = 3.31$$

Let n be the no. of days by which 90% of the project will be completed.

P[T<= n] = 0.90

P[(T-43)/3.31<=(n-43)/3.31} = 0.90 = 1.28

(n-43)/3.31 = 1.28

n = (1.28 × 3.31) + 43

n = 47.23 = 48 days

STANDARD NORMAL DISTRIBUTION: Table Values Represent AREA to the LEFT of the Z score.

Z	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
0.0	.50000	.50399	.50798	.51197	.51595	.51994	.52392	.52790	.53188	.53586
0.1	.53983	.54380	.54776	.55172	.55567	.55962	.56356	.56749	.57142	.57535
0.2	.57926	.58317	.58706	.59095	.59483	.59871	.60257	.60642	.61026	.61409
0.3	.61791	.62172	.62552	.62930	.63307	.63683	.64058	.64431	.64803	.65173
0.4	.65542	.65910	.66276	.66640	.67003	.67364	.67724	.68082	.68439	.68793
0.5	.69146	.69497	.69847	.70194	.70540	.70884	.71226	.71566	.71904	.72240
0.6	.72575	.72907	.73237	.73565	.73891	.74215	.74537	.74857	.75175	.75490
0.7	.75804	.76115	.76424	.76730	.77035	.77337	.77637	.77935	.78230	.78524
0.8	.78814	.79103	.79389	.79673	.79955	.80234	.80511	.80785	.81057	.81327
0.9	.81594	.81859	.82121	.82381	.82639	.82894	.83147	.83398	.83646	.83891
1.0	.84134	.84375	.84614	.84849	.85083	.85314	.85543	.85769	.85993	.86214
1.1	.86433	.86650	.86864	.87076	.87286	.87493	.87698	.87900	.88100	.88298
1.2	.88493	.88686	.88877	.89065	.89251	.89435	.89617	.89796	.89973	.90147
1.3	.90320	.90490	.90658	.90824	.90988	.91149	.91309	.91466	.91621	.91774
1.4	.91924	.92073	.92220	.92364	.92507	.92647	.92785	.92922	.93056	.93189
1.5	.93319	.93448	.93574	.93699	.93822	.93943	.94062	.94179	.94295	.94408
1.6	.94520	.94630	.94738	.94845	.94950	.95053	.95154	.95254	.95352	.95449
1.7	.95543	.95637	.95728	.95818	.95907	.95994	.96080	.96164	.96246	.96327
1.8	.96407	.96485	.96562	.96638	.96712	.96784	.96856	.96926	.96995	.97062
1.9	.97128	.97193	.97257	.97320	.97381	.97441	.97500	.97558	.97615	.97670
2.0	.97725	.97778	.97831	.97882	.97932	.97982	.98030	.98077	.98124	.98169
2.1	.98214	.98257	.98300	.98341	.98382	.98422	.98461	.98500	.98537	.98574
2.2	.98610	.98645	.98679	.98713	.98745	.98778	.98809	.98840	.98870	.98899
2.3	.98928	.98956	.98983	.99010	.99036	.99061	.99086	.99111	.99134	.99158
2.4	.99180	.99202	.99224	.99245	.99266	.99286	.99305	.99324	.99343	.99361
2.5	.99379	.99396	.99413	.99430	.99446	.99461	.99477	.99492	.99506	.99520
2.6	.99534	.99547	.99560	.99573	.99585	.99598	.99609	.99621	.99632	.99643
2.7	.99653	.99664	.99674	.99683	.99693	.99702	.99711	.99720	.99728	.99736
2.8	.99744	.99752	.99760	.99767	.99774	.99781	.99788	.99795	.99801	.99807
2.9	.99813	.99819	.99825	.99831	.99836	.99841	.99846	.99851	.99856	.99861
3.0	.99865	.99869	.99874	.99878	.99882	.99886	.99889	.99893	.99896	.99900
3.1	.99903	.99906	.99910	.99913	.99916	.99918	.99921	.99924	.99926	.99929
3.2	.99931	.99934	.99936	.99938	.99940	.99942	.99944	.99946	.99948	.99950
3.3	.99952	.99953	.99955	.99957	.99958	.99960	.99961	.99962	.99964	.99965
3.4	.99966	.99968	.99969	.99970	.99971	.99972	.99973	.99974	.99975	.99976
3.5	.99977	.99978	.99978	.99979	.99980	.99981	.99981	.99982	.99983	.99983
3.6	.99984	.99985	.99985	.99986	.99986	.99987	.99987	.99988	.99988	.99989
3.7	.99989	.99990	.99990	.99990	.99991	.99991	.99992	.99992	.99992	.99992
3.8	.99993	.99993	.99993	.99994	.99994	.99994	.99994	.99995	.99995	.99995
3.9	.99995	.99995	.99996	.99996	.99996	.99996	.99996	.99996	.99997	.99997

Basics of MS Project

6.5

Microsoft Project

Microsoft Project is a project management software program developed and sold by Microsoft, designed to assist a project manager in developing a schedule, assigning resources to tasks, tracking progress, managing the budget, and analysing workloads.

Project creates budgets based on assignment work and resource rates. As resources are assigned to tasks and assignment work estimated, the program calculates the cost, equal to the work times the rate, which rolls up to the task level and then to any summary task, and finally to the project level.

Each resource can have its own calendar, which defines what days and shifts a resource is available. Microsoft Project is not suitable for solving problems of available materials (resources) constrained production. Additional software is necessary to manage a complex facility that produces physical goods.

Project Management

MS Project is feature rich, but project management techniques are required to drive a project effectively. A lot of project managers get confused between a schedule and a plan. MS Project can help you in creating a Schedule for the project even with the provided constraints. It cannot Plan for you. As a project manager you should be able to answer the following specific questions as part of the planning process to develop a schedule. MS Project cannot answer these for you.

- What tasks need to be performed to create the deliverables of the project and in what order? This relates to the scope of the project.
- What are the time constraints and deadlines if any, for different tasks and for the project as a whole? This relates to the schedule of the project.
- What kind of resources (man/machine/material) are needed to perform each task?
- How much will each task cost to accomplish? This would relate to the cost of the project.
- What kind of risk do we have associated with a particular schedule for the project? This might affect the scope, cost and time constraints of your project.

From the perspective of Project Management Methodology, a Plan and Schedule are not the same. A **plan** is a detailed action-oriented, experience and knowledge-based exercise which considers all elements of strategy, scope, cost, time, resources, quality and risk for the project.

Scheduling is the science of using mathematical calculations and logic to generate time effective sequence of task considering any resource and cost constraints. Schedule is part of the Plan. In Project Management Methodology, schedule would only mean listing of a project›s milestones, tasks/activities, and deliverables, with start and finish dates. The schedule is linked with resources, budgets and dependencies.

However, in this tutorial for MS Project (and in all available help for MS Project) the word 'Plan' is used as a 'Schedule' being created in MS Project. This is because of two reasons.

One, MS Project does more than just create a schedule it can establish dependencies among tasks, it can create constraints, it can resolve resource conflicts, and it can also help in reviewing cost and schedule performance over the duration of the project. So it does help in more than just creating a Schedule. Thus, it makes sense for Microsoft to market MS Project as a Plan Creator rather than over-simplifying it as just a Schedule Creator.

A project manager should also be able to answer other project-related questions as well. For example −

- Why this project needs to be run by the organization?
- What's the best way to communicate project details to the stakeholders?
- What is the risk management plan?
- How the vendors are going to be managed?
- How the project is tracked and monitored?
- How the quality is measured and qualified?

MS Project can help you −

- Visualize your project plan in standard defined formats.
- Schedule tasks and resources consistently and effectively.
- Track information about the work, duration, and resource requirements for your project.
- Generate reports to share in progress meetings

A blank project file can be daunting, especially if you're new to project management. But with a few clicks, you can tap the power of Project to convert your to-do list into a full-fledged project for you to manage and share with your team and stakeholders.

Here are a few starting points:

- Add tasks
- Outline tasks
- Link tasks
- Change your view
- Print your project

Add tasks

1. Click View > Gantt Chart.
2. Type a name in the first empty Task Name field at the bottom of the task list, and press Enter.

Want more? If adding tasks one at a time starts to take too long, you can also:

- Add multiple tasks at once.
- Cut and paste a list from another program.
- Import a tasks list from a SharePoint site.

Outline tasks

Indent and outdent tasks to show hierarchy — that is, to turn your task list into an outline of your project. An indented task becomes a subtask of the task above it, which becomes a summary task.

1. Click View > Gantt Chart.
2. In the Task Name column, click the task you want to indent.
3. Click Task > Indent Task . The task becomes a subtask.
4. Click Outdent Task to move the task back to the level of the task above it. It's no longer a subtask.

Want more? Use subtasks and summary tasks to show phases, easily navigate through a large project, and more.

Link tasks

You can link any two tasks in a project to show their relationship (also called a task dependency). Dependencies drive the project schedule — once you link the tasks, every change you make to one affects the other, which affects the next one, and so on.

1. Click **View** > **Gantt Chart**.
2. Hold down Ctrl and click the two tasks you want to link (in the **Task Name** column).
3. Click **Task** > **Link the Selected Tasks** .

Want more? Project supports four kinds of task links to show different relationships. Want to change the link type or remove the link completely?

Change your view

Project starts you off with the tried-and-true Gantt Chart, but you have dozens of other options for viewing your tasks and resources and how they're all connected. You can change any view to meet your specific needs.

1. Click the View tab.
2. In the Task Views group or Resource Views group, click the view that you want to use.
3. To see all the available views, click Gantt Chart > More Views, and then choose from the options in the More Views dialog box.

Want more? There's a lot more to learn here! Need some help choosing the right view of your project?

Print your project

Printing a view or report in Project is similar to printing in other Office programs:

Click **File** > **Print** > **Print**.

Want more? Getting *only* the specific project information you want to share with your stakeholders into your printout can involve some prep work before you hit the print button:

- Prepare a view for printing
- Prepare a report for printing

Show the critical path of your project in MS Project

Every task is important, but only some of them are critical. The critical path is a chain of linked tasks that directly affects the project finish date. If any task on the critical path is late, the whole project is late.

The critical path is a series of tasks (or sometimes only a single task) that controls the calculated start or finish date of the project. The tasks that make up the critical path are typically interrelated by task dependencies. There are likely to be many such networks of tasks throughout your project plan. When the last task in the critical path is complete, the project is also complete.

Show the critical path in the Gantt Chart view

The Gantt Chart view will likely be your most used view for showing the critical path.

1. Choose View > Gantt Chart.
2. Choose Format, and then select the Critical Tasks check box.

Tasks on the critical path now have red Gantt bars.

Show the critical path in other task views

You can see the critical path in any task view by highlighting it.

1. On the **View** tab, pick a view from the **Task Views** group.
2. Staying on the **View** tab, select **Critical** from the **Highlight** list.The critical path shows up in yellow.
3. To see *only* the tasks on the critical path, choose the **Filter** arrow, then pick **Critical**.

View the critical path in a master project

When you're managing a master project, whole subprojects can be on the critical path. You can see if this is true by telling Project to treat the subprojects like they are summary tasks.

1. Choose **File** > **Options**.
2. Choose **Schedule**, and then scroll down to the **Calculation options for this project** area.
3. Make sure the **Inserted projects are calculated like summary tasks** box is selected

Change what tasks show up on the critical path

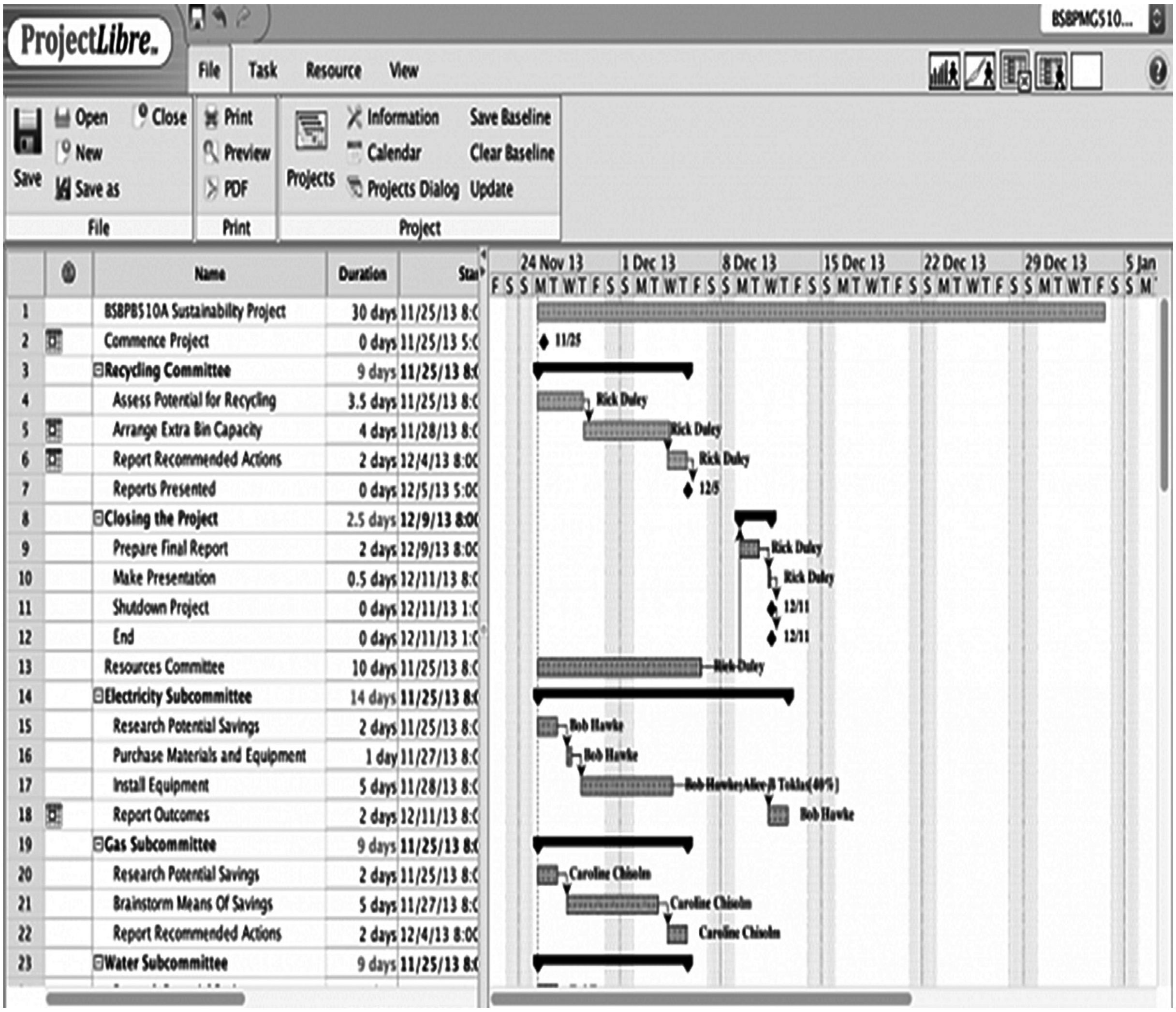
Typically, critical tasks have no slack. But you can tell Project to include tasks with one or more days of slack on the critical path so you can see potential problems coming from farther away.

1. Choose **File** > **Options**.
2. Choose **Advanced**, and then scroll down to the **Calculation options for this project** area.
3. Add a number to the **Tasks are critical if slack is less than or equal to** box.

Show multiple critical paths

You can set up your project schedule to display as many critical paths as you need to keep tabs on your project.

1. Choose **File** > **Options**.
2. Choose **Advanced**, scroll down to the bottom, and then select **Calculate multiple critical paths**.
3. Choose **View** > **Gantt Chart**.
4. Choose **Format**, and then select **Critical tasks**.

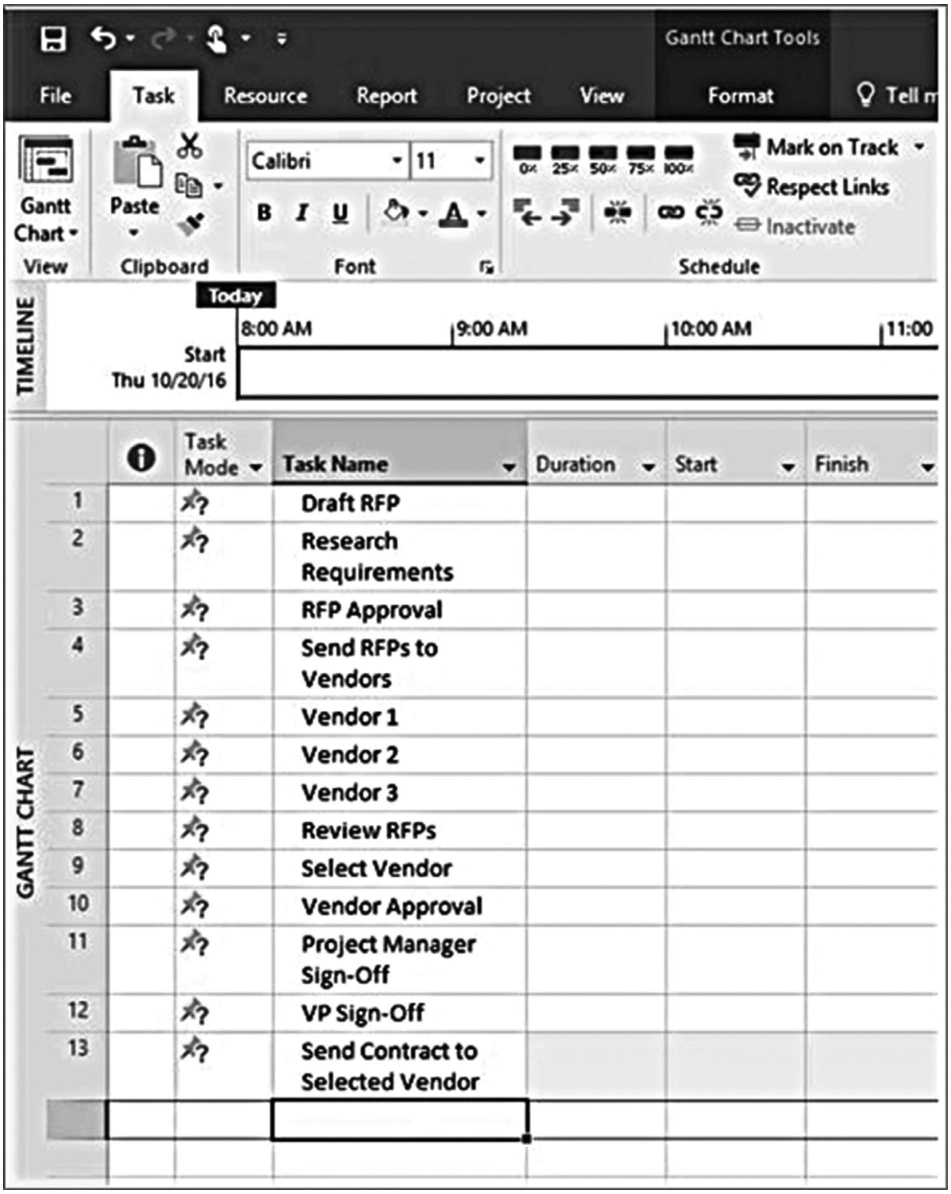


		Name	Duration	Sta
1		BSBPBS10A Sustainability Project	30 days	11/25/13 8:
2	▦	Commence Project	0 days	11/25/13 5:
3		⊟Recycling Committee	9 days	11/25/13 8:
4		Assess Potential for Recycling	3.5 days	11/25/13 8:
5	▦	Arrange Extra Bin Capacity	4 days	11/28/13 8:
6	▦	Report Recommended Actions	2 days	12/4/13 8:0
7		Reports Presented	0 days	12/5/13 5:0
8		⊟Closing the Project	2.5 days	12/9/13 8:0
9		Prepare Final Report	2 days	12/9/13 8:0
10		Make Presentation	0.5 days	12/11/13 8:
11		Shutdown Project	0 days	12/11/13 1:
12		End	0 days	12/11/13 1:
13		Resources Committee	10 days	11/25/13 8:
14		⊟Electricity Subcommittee	14 days	11/25/13 8:
15		Research Potential Savings	2 days	11/25/13 8:
16		Purchase Materials and Equipment	1 day	11/27/13 8:
17		Install Equipment	5 days	11/28/13 8:
18	▦	Report Outcomes	2 days	12/11/13 8:
19		⊟Gas Subcommittee	9 days	11/25/13 8:
20		Research Potential Savings	2 days	11/25/13 8:
21		Brainstorm Means Of Savings	5 days	11/27/13 8:
22		Report Recommended Actions	2 days	12/4/13 8:0
23		⊟Water Subcommittee	9 days	11/25/13 8:

Figure 6.1: MS Project - 1

How to Create a Timeline in Microsoft Project Tutorial:

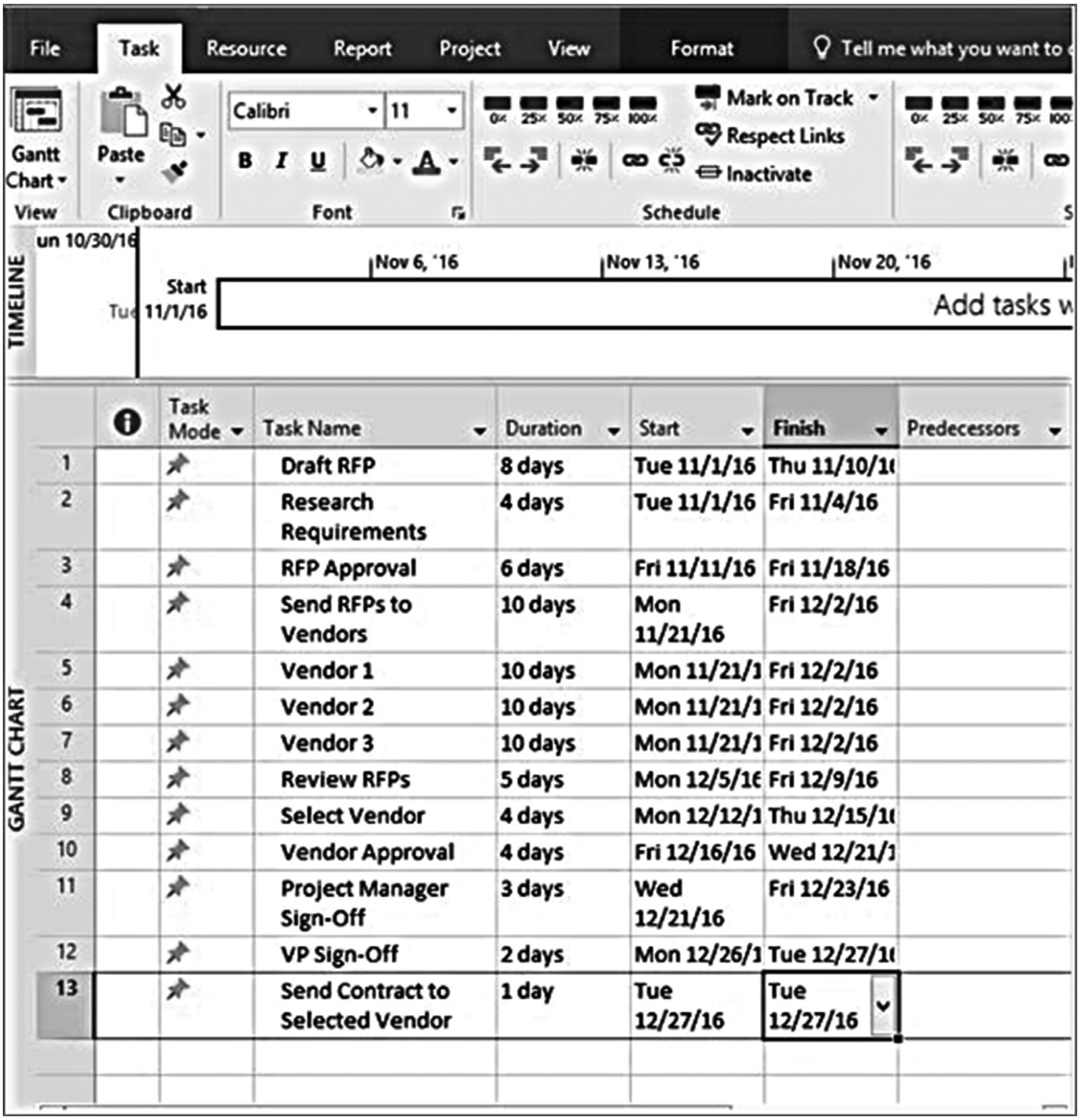
1. **Create a Task List** You'll need to build a list of required tasks. To get started, open Microsoft Project, click Blank Project, and type each task into a cell under Task Name.



	Task Mode	Task Name	Duration	Start	Finish
1		Draft RFP			
2		Research Requirements			
3		RFP Approval			
4		Send RFPs to Vendors			
5		Vendor 1			
6		Vendor 2			
7		Vendor 3			
8		Review RFPs			
9		Select Vendor			
10		Vendor Approval			
11		Project Manager Sign-Off			
12		VP Sign-Off			
13		Send Contract to Selected Vendor			

Figure 6.2: MS Project - 2

2. **Add Start and Finish Dates to Each Task** To enter start and end dates, click the Start cell that corresponds to the first task and enter a date (if you click the down arrow in the cell, a calendar will appear and you can use that to select a date). Then tab over to the Finish row and enter an end date. Microsoft will automatically enter the amount of time it will take to complete the task in the Duration row. You'll notice that as you add the dates, bar charts will be added to the timeline in the right-hand pane.



	ℹ	Task Mode	Task Name	Duration	Start	Finish	Predecessors
1		📌	Draft RFP	8 days	Tue 11/1/16	Thu 11/10/1	
2		📌	Research Requirements	4 days	Tue 11/1/16	Fri 11/4/16	
3		📌	RFP Approval	6 days	Fri 11/11/16	Fri 11/18/16	
4		📌	Send RFPs to Vendors	10 days	Mon 11/21/16	Fri 12/2/16	
5		📌	Vendor 1	10 days	Mon 11/21/1	Fri 12/2/16	
6		📌	Vendor 2	10 days	Mon 11/21/1	Fri 12/2/16	
7		📌	Vendor 3	10 days	Mon 11/21/1	Fri 12/2/16	
8		📌	Review RFPs	5 days	Mon 12/5/1	Fri 12/9/16	
9		📌	Select Vendor	4 days	Mon 12/12/1	Thu 12/15/1	
10		📌	Vendor Approval	4 days	Fri 12/16/16	Wed 12/21/1	
11		📌	Project Manager Sign-Off	3 days	Wed 12/21/16	Fri 12/23/16	
12		📌	VP Sign-Off	2 days	Mon 12/26/1	Tue 12/27/1	
13		📌	Send Contract to Selected Vendor	1 day	Tue 12/27/16	Tue 12/27/16	

Figure 6.3: MS Project - 3

3. **Add Tasks to the Timeline** To add tasks to the Timeline, click the View tab and click the *Timeline* bar that appears above the task list. Then right-click on a Task cell and choose Add to *Timeline* from the list and click it to add the task to the timeline.

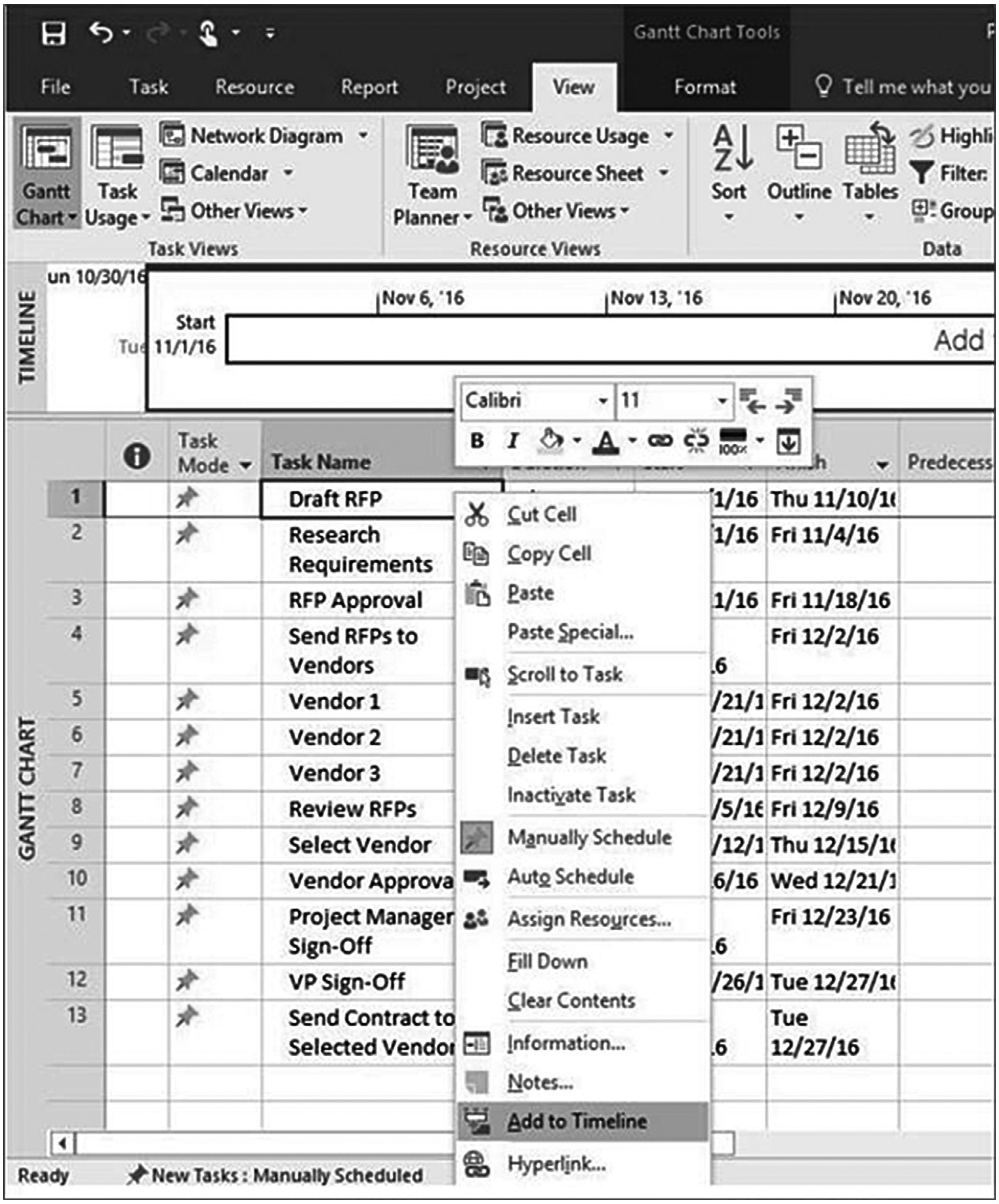
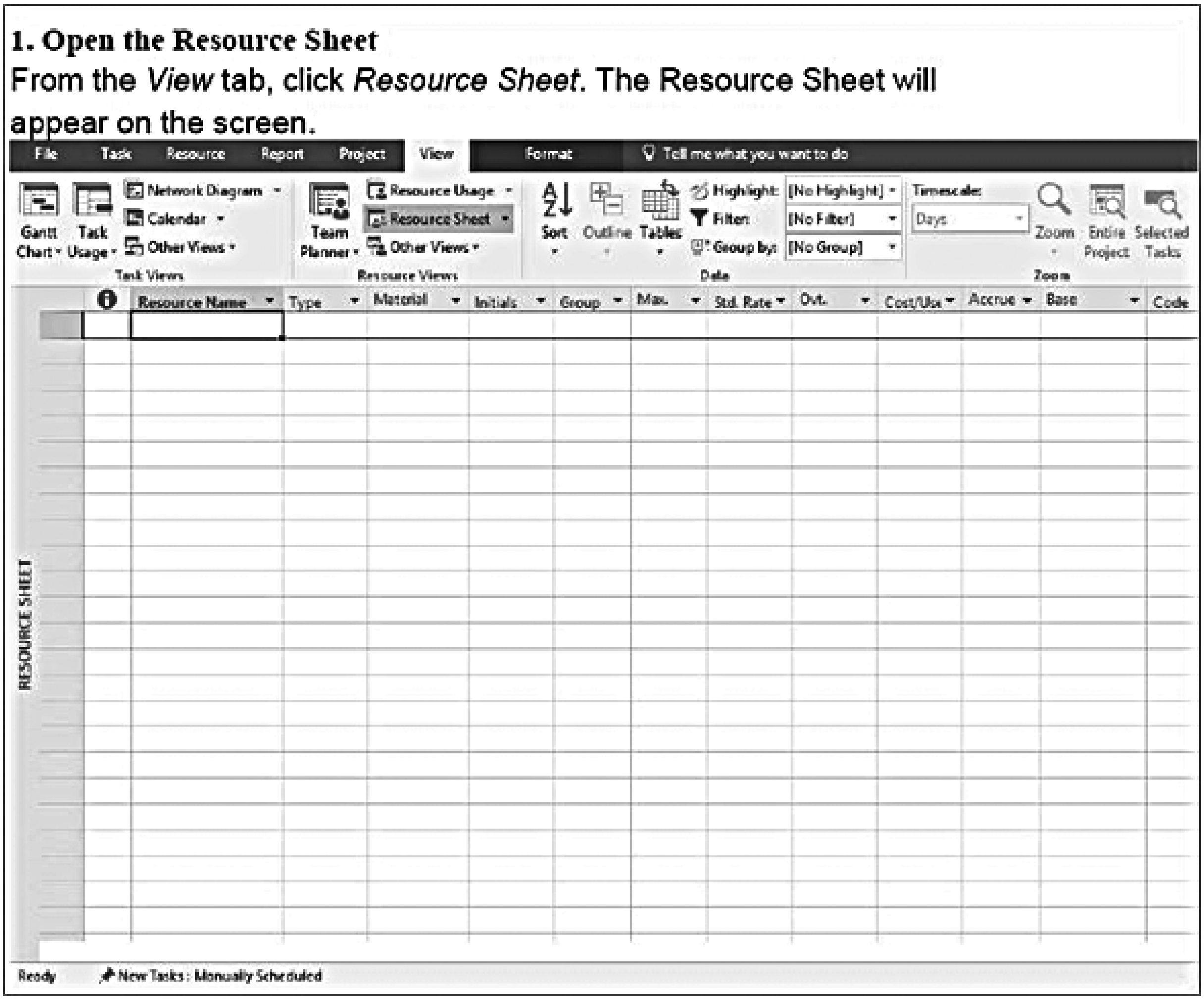


Figure 6.4: MS Project - 4

How to Set Up Resources in Microsoft Project

The term “resources” typically refers to people, but can also mean documentation or a certain type of work that will be needed to complete the project.

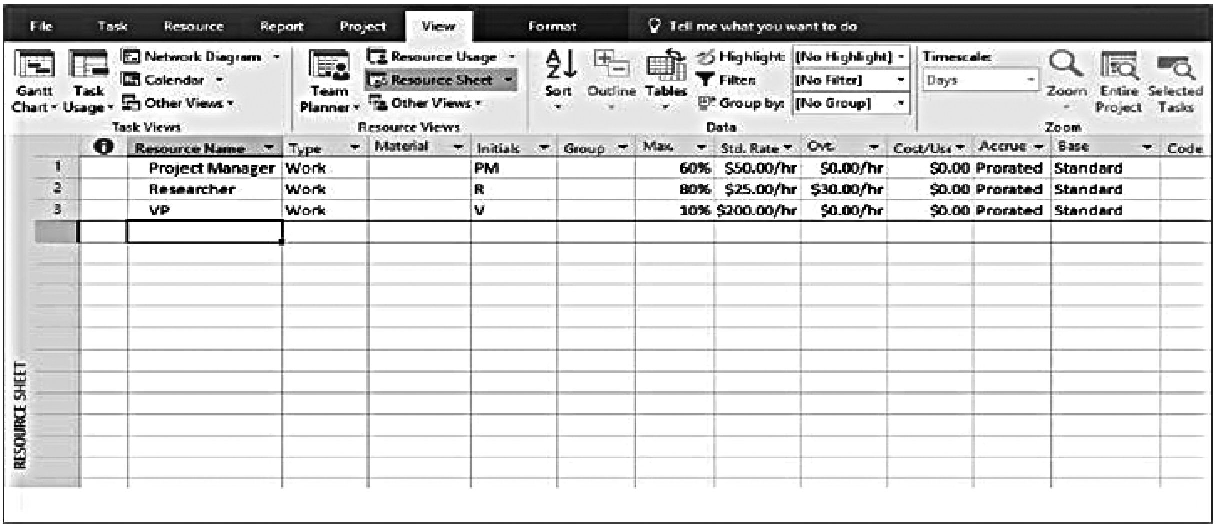


1. Open the Resource Sheet

From the *View* tab, click *Resource Sheet*. The Resource Sheet will appear on the screen.

Figure 6.5: MS Project - 5

3. **Add Resources** Type the name of the resource needed in the Resource Name field and complete the remainder of the information: Type, Material (if it's a material), Initials, Max (max amount of time), Standard Rate, Overtime, Cost/Use, Accrue, Base, and Code.



Highlight: [No Highlight]
Filter: [No Filter]
Group by: [No Group]
Timescale: Days

	ℹ	Resource Name	Type	Material	Initials	Group	Max.	Std. Rate	Ovt.	Cost/Use	Accrue	Base	Code
1		Project Manager	Work		PM		60%	$50.00/hr	$0.00/hr	$0.00	Prorated	Standard	
2		Researcher	Work		R		80%	$25.00/hr	$30.00/hr	$0.00	Prorated	Standard	
3		VP	Work		V		10%	$200.00/hr	$0.00/hr	$0.00	Prorated	Standard	

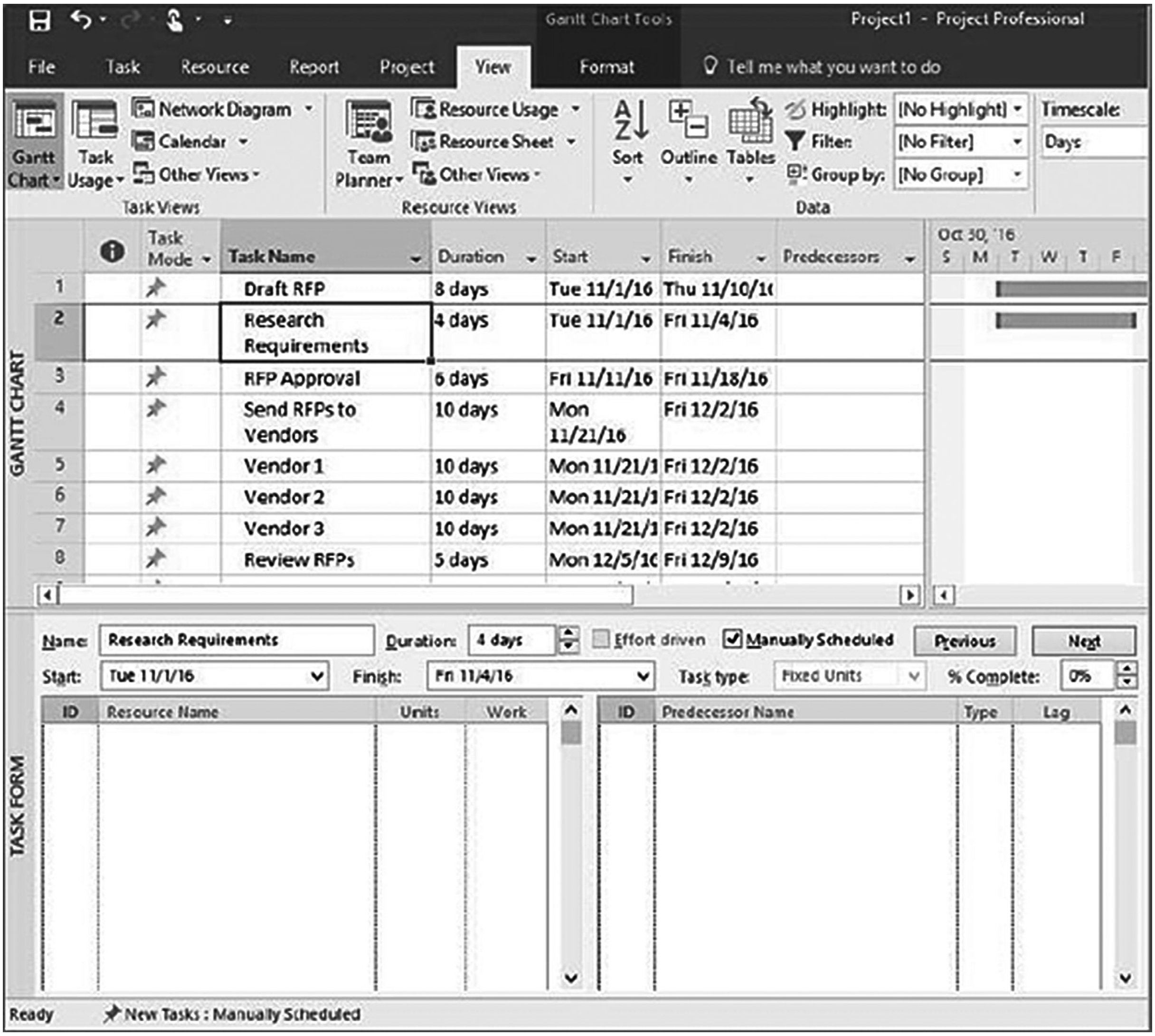
Figure 6.6: MS Project - 6

Once your resources are added to the project, you can easily view who is available to take on the task based on their workload, and manage how much time each team member will spend on tasks in the **Resource Management** view.

How to Assign Tasks in MS Project

Once you have a list of resources for your project, you'll want to assign tasks. This will help you better manage the project and get work done in a specific time period. One of the benefits of MS Project is that it can calculate how long it will take a person to complete the task based on their availability. If it's a particularly important part of the project that needs to be done quickly, you can assign multiple people to it and Microsoft Project will decrease the time it takes to complete the task based on how many resources are assigned. This also lets the people assigned to the project know how much time is required of them.

1. **Switch to the Gantt chart:** To assign tasks, you'll need to switch to the Gantt chart. Click the Gantt chart icon in top left corner of the window
2. **Open the Task Form** You should still be in the View tab. Click the Details box in the ribbon. The Task Form should appear on the lower half of the screen. If it doesn't appear, click the down arrow in the Details box and select Task Form.



Highlight: [No Highlight]
Filter: [No Filter]
Group by: [No Group]
Timescale: Days

	Task Mode	Task Name	Duration	Start	Finish	Predecessors
1		Draft RFP	8 days	Tue 11/1/16	Thu 11/10/1(	
2		Research Requirements	4 days	Tue 11/1/16	Fri 11/4/16	
3		RFP Approval	6 days	Fri 11/11/16	Fri 11/18/16	
4		Send RFPs to Vendors	10 days	Mon 11/21/16	Fri 12/2/16	
5		Vendor 1	10 days	Mon 11/21/1	Fri 12/2/16	
6		Vendor 2	10 days	Mon 11/21/1	Fri 12/2/16	
7		Vendor 3	10 days	Mon 11/21/1	Fri 12/2/16	
8		Review RFPs	5 days	Mon 12/5/1(	Fri 12/9/16	

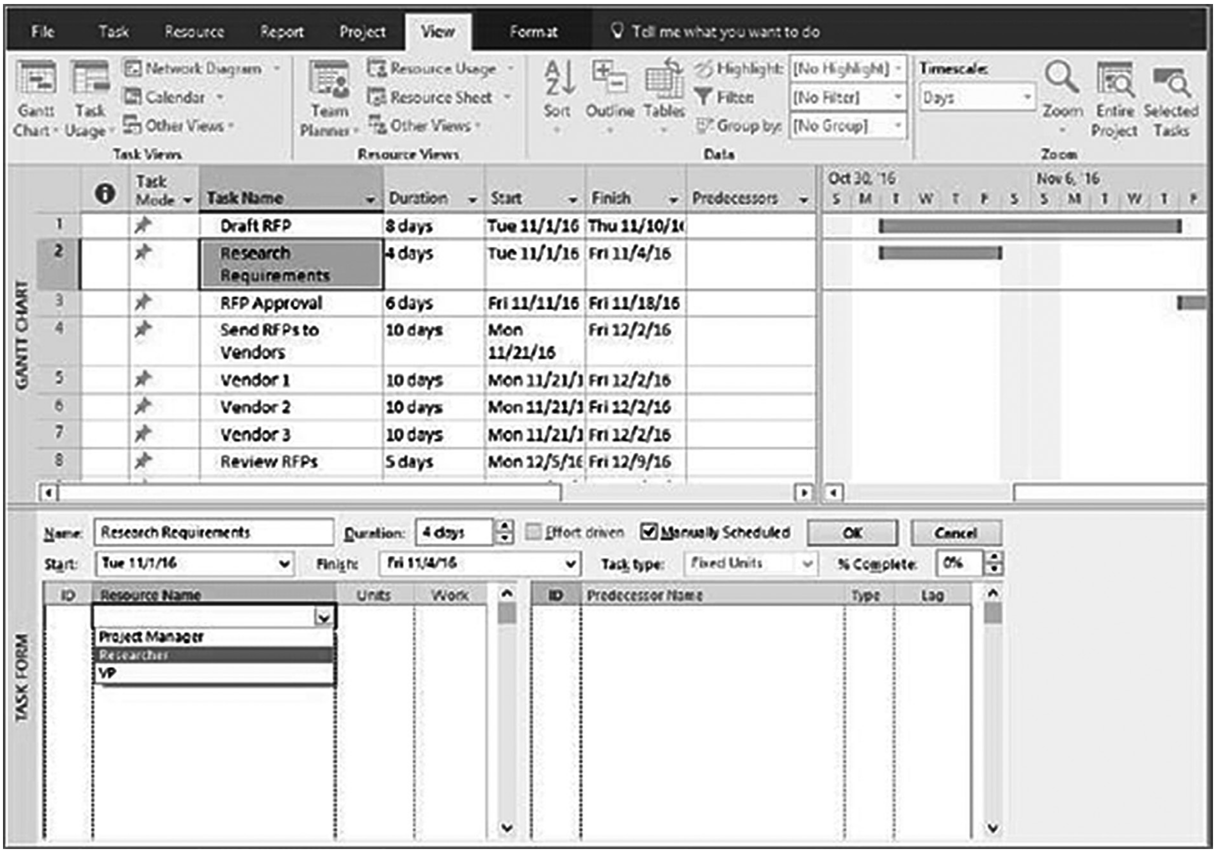
Name: Research Requirements
Duration: 4 days
☐ Effort driven
☑ Manually Scheduled
Start: Tue 11/1/16
Finish: Fri 11/4/16
Task type: Fixed Units
% Complete: 0%

ID	Resource Name	Units	Work

ID	Predecessor Name	Type	Lag

Figure 6.7: MS Project - 7

3. **Select a Task to Assign** Click a task in the Gantt chart view and it will appear in the Name section of the Task Form. Click the box under Resource Name and choose a resource from the drop-down menu. Then click OK.



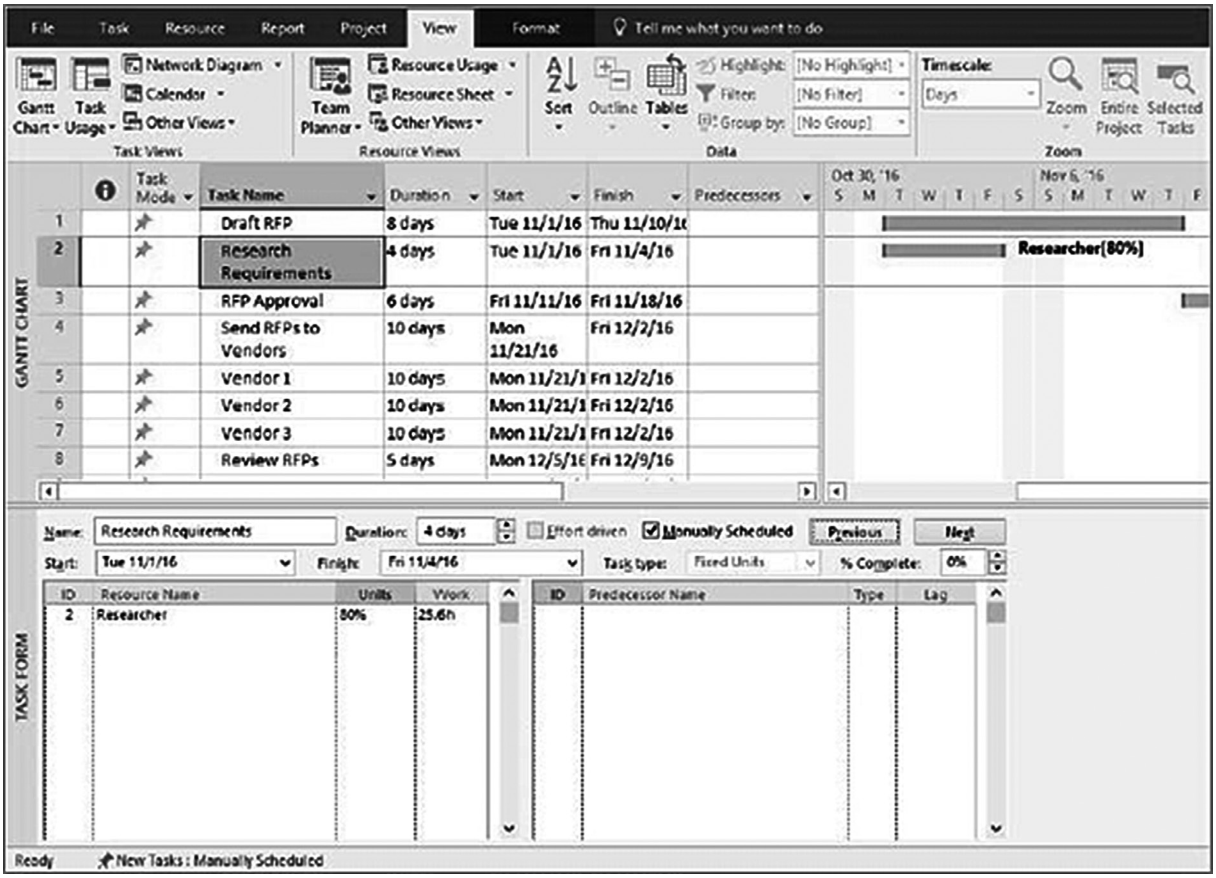
	Task Mode	Task Name	Duration	Start	Finish	Predecessors
1		Draft RFP	8 days	Tue 11/1/16	Thu 11/10/16	
2		Research Requirements	4 days	Tue 11/1/16	Fri 11/4/16	
3		RFP Approval	6 days	Fri 11/11/16	Fri 11/18/16	
4		Send RFPs to Vendors	10 days	Mon 11/21/16	Fri 12/2/16	
5		Vendor 1	10 days	Mon 11/21/1	Fri 12/2/16	
6		Vendor 2	10 days	Mon 11/21/1	Fri 12/2/16	
7		Vendor 3	10 days	Mon 11/21/1	Fri 12/2/16	
8		Review RFPs	5 days	Mon 12/5/16	Fri 12/9/16	

Name: Research Requirements
Duration: 4 days
Start: Tue 11/1/16
Finish: Fri 11/4/16
Task type: Fixed Units
% Complete: 0%

Project Manager
Researcher
VP

Figure 6.8: MS Project - 8

You can add another person to the same task by clicking the area under *Resource Name* and choosing the name you want. Click *OK*. As you assign tasks, the amount of time will be added to the Gantt chart.



	Task Mode	Task Name	Duration	Start	Finish	Predecessors
1		Draft RFP	8 days	Tue 11/1/16	Thu 11/10/1	
2		Research Requirements	4 days	Tue 11/1/16	Fri 11/4/16	
3		RFP Approval	6 days	Fri 11/11/16	Fri 11/18/16	
4		Send RFPs to Vendors	10 days	Mon 11/21/16	Fri 12/2/16	
5		Vendor 1	10 days	Mon 11/21/1	Fri 12/2/16	
6		Vendor 2	10 days	Mon 11/21/1	Fri 12/2/16	
7		Vendor 3	10 days	Mon 11/21/1	Fri 12/2/16	
8		Review RFPs	5 days	Mon 12/5/1	Fri 12/9/16	

Name: Research Requirements
Duration: 4 days
☐ Effort driven
☑ Manually Scheduled
Start: Tue 11/1/16
Finish: Fri 11/4/16
Task type: Fixed Units
% Complete: 0%

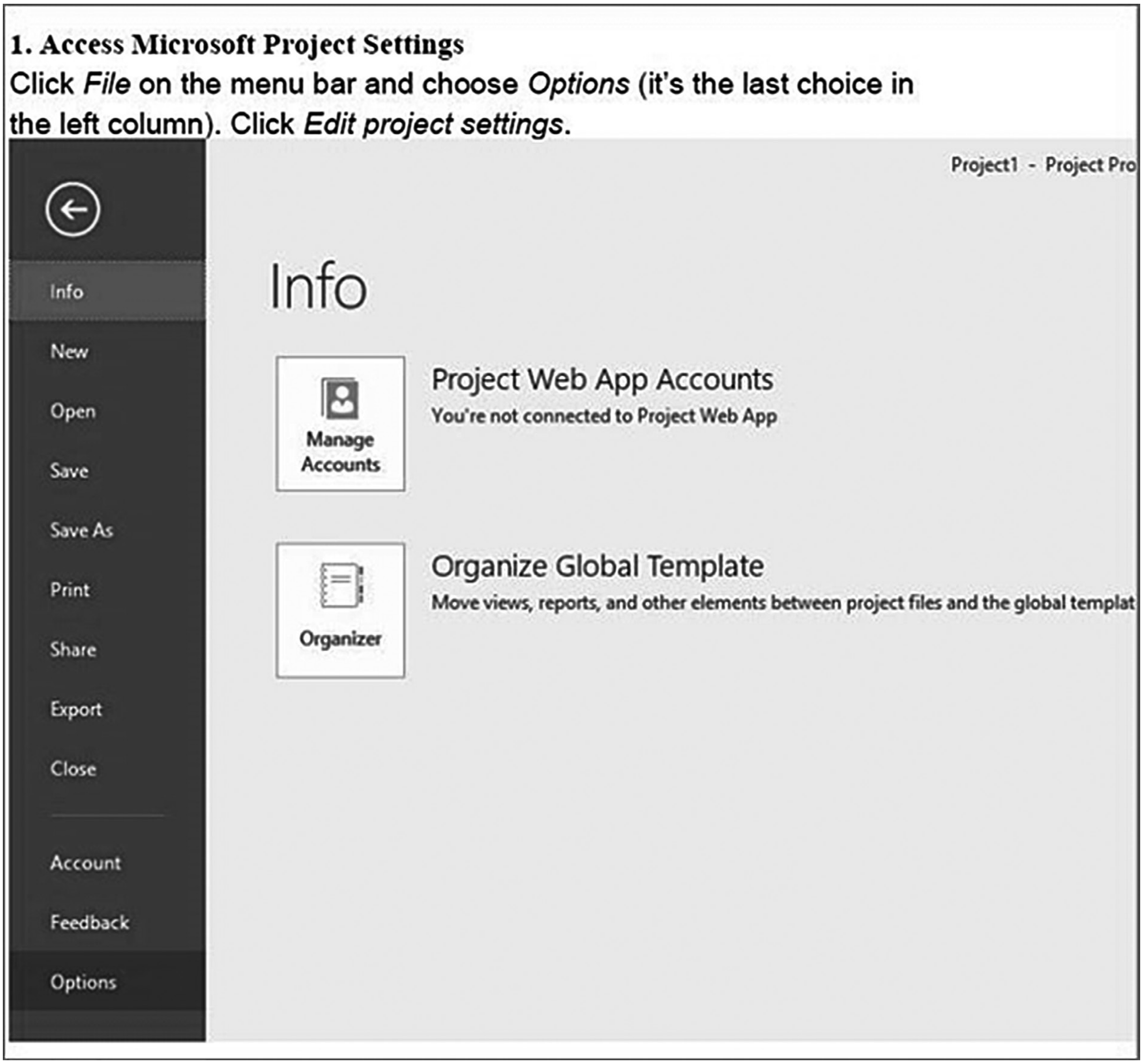
ID	Resource Name	Units	Work
2	Researcher	80%	25.6h

ID	Predecessor Name	Type	Lag

Figure 6.9: MS Project - 9

How to Schedule Tasks Automatically or Manually:

With Microsoft Project 2016 you can schedule tasks manually or automatically. When you opt to manually schedule tasks it's up to you schedule all new tasks and track them to ensure they are being completed on time. If you choose Automatic scheduling, Project will schedule tasks based on dependencies, calendars, and constraints among other things. The default option when creating tasks is to schedule them manually, here it is mentioned how to change the setting to automatic.



1. Access Microsoft Project Settings

Click *File* on the menu bar and choose *Options* (it's the last choice in the left column). Click *Edit project settings*.

Project Web App Accounts

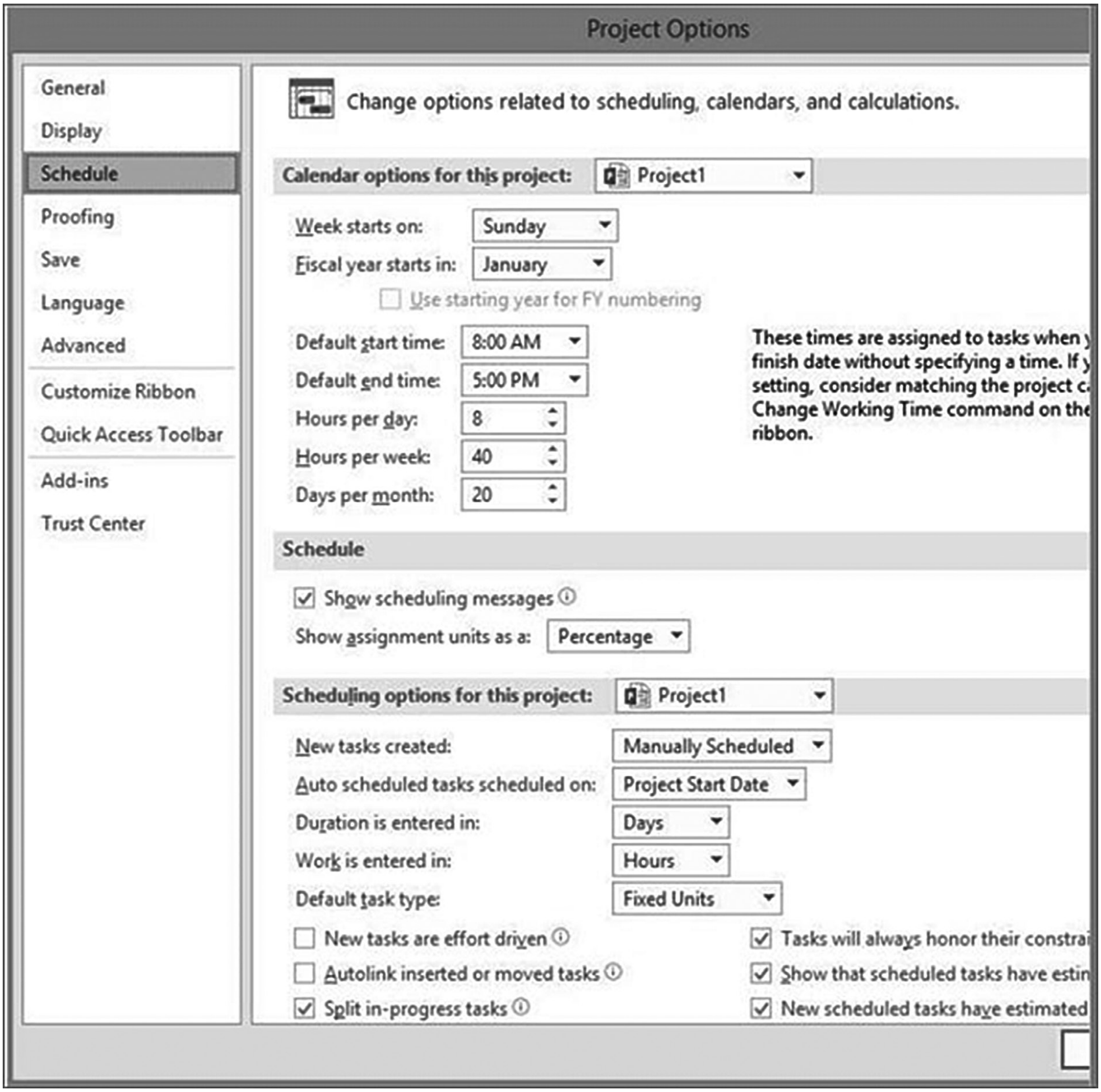
You're not connected to Project Web App

Organize Global Template

Move views, reports, and other elements between project files and the global templat

Figure 6.10: MS Project - 10

3. **Change Schedule Options** When the Project Options form appears on the screen, click *Schedule* in the left column.



Change options related to scheduling, calendars, and calculations.

Calendar options for this project: Project1

Week starts on: Sunday

Fiscal year starts in: January

☐ Use starting year for FY numbering

Default start time: 8:00 AM

Default end time: 5:00 PM

Hours per day: 8

Hours per week: 40

Days per month: 20

These times are assigned to tasks when y finish date without specifying a time. If y setting, consider matching the project c Change Working Time command on the ribbon.

Schedule

☑ Show scheduling messages

Show assignment units as a: Percentage

Scheduling options for this project: Project1

New tasks created: Manually Scheduled

Auto scheduled tasks scheduled on: Project Start Date

Duration is entered in: Days

Work is entered in: Hours

Default task type: Fixed Units

☐ New tasks are effort driven

☐ Autolink inserted or moved tasks

☑ Split in-progress tasks

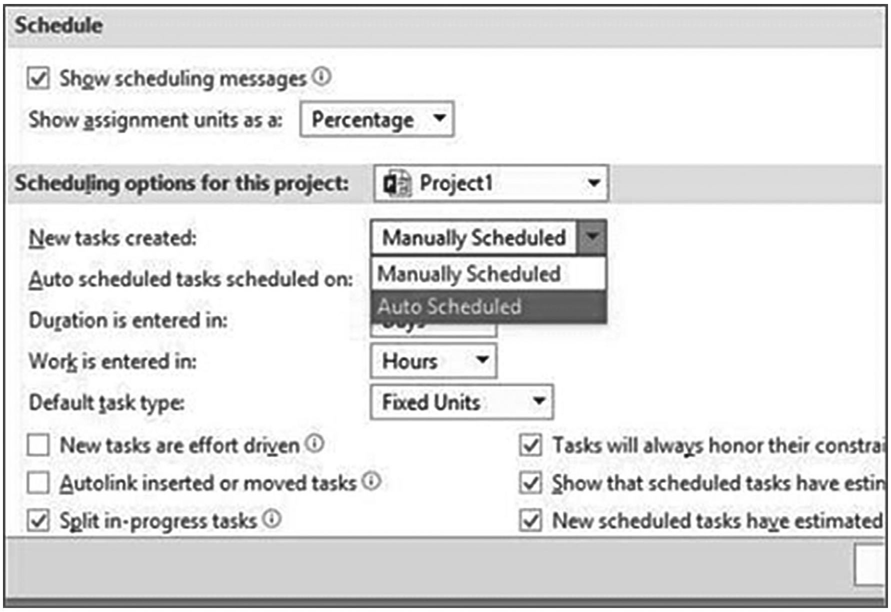
☑ Tasks will always honor their constrai

☑ Show that scheduled tasks have estin

☑ New scheduled tasks have estimated

Figure 6.11: MS Project - 11

Next, under Scheduling Options for this Project section, click the drop-down menu for New Tasks Created. The default is set to Manually Scheduled. Select and click Auto Scheduled and click the OK button.



Schedule

☑ Show scheduling messages

Show assignment units as a: Percentage

Scheduling options for this project: Project1

New tasks created: Manually Scheduled

Auto scheduled tasks scheduled on:

Duration is entered in:

Work is entered in: Hours

Default task type: Fixed Units

☐ New tasks are effort driven

☐ Autolink inserted or moved tasks

☑ Split in-progress tasks

☑ Tasks will always honor their constrai

☑ Show that scheduled tasks have estin

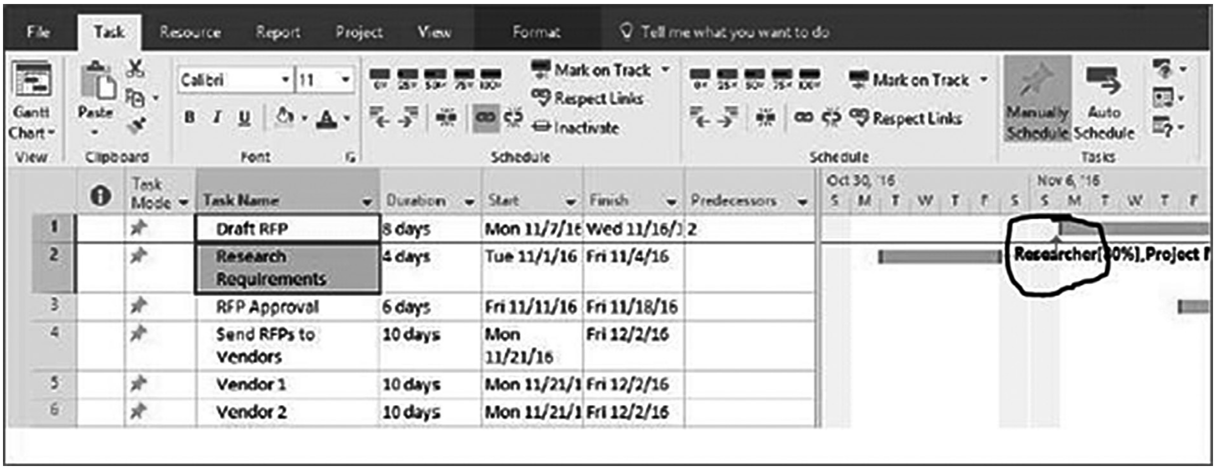
☑ New scheduled tasks have estimated

Figure 6.12: MS Project - 12

How to Create Task Dependencies

Dependencies occur when one task can't move on to the next phase until a particular task is completed before it. Creating dependencies involves linking tasks in the Gantt chart view. In Microsoft Project, you can link any two tasks. Once tasks are linked, every change made to the predecessor affects the successor.

1. **Switch to Gantt Chart View** You should still be in the Gantt chart view. If you're not, click the Gantt chart icon in top left corner of the window.
2. **Select Tasks to Link** Click the *Task* tab in the menu bar. Identify the two tasks in the list that you want to link. Click the first task and press and hold the Ctrl key and select the second task. Click the chain icon in the ribbon to link the tasks. You'll see an arrow appear on the Gantt chart that connects the items.



	Task Mode	Task Name	Duration	Start	Finish	Predecessors
1		Draft RFP	8 days	Mon 11/7/16	Wed 11/16/1	2
2		Research Requirements	4 days	Tue 11/1/16	Fri 11/4/16	
3		RFP Approval	6 days	Fri 11/11/16	Fri 11/18/16	
4		Send RFPs to Vendors	10 days	Mon 11/21/16	Fri 12/2/16	
5		Vendor 1	10 days	Mon 11/21/1	Fri 12/2/16	
6		Vendor 2	10 days	Mon 11/21/1	Fri 12/2/16	

Figure 6.13: MS Project - 13

Generate a Cost Report in Microsoft Project 2016

Once you've entered time and resources information to the best of your ability, you can use Project to run a Cost Overview report. Here's how to create a Resource Cost Overview report:

1. **Select the Report Tab** Click the *Report* tab to get a quick overview of the reports you can run.
2. **Choose a Cost Report to Run** Click the arrow below *Costs* in the ribbon and click *Resource Cost Overview*.

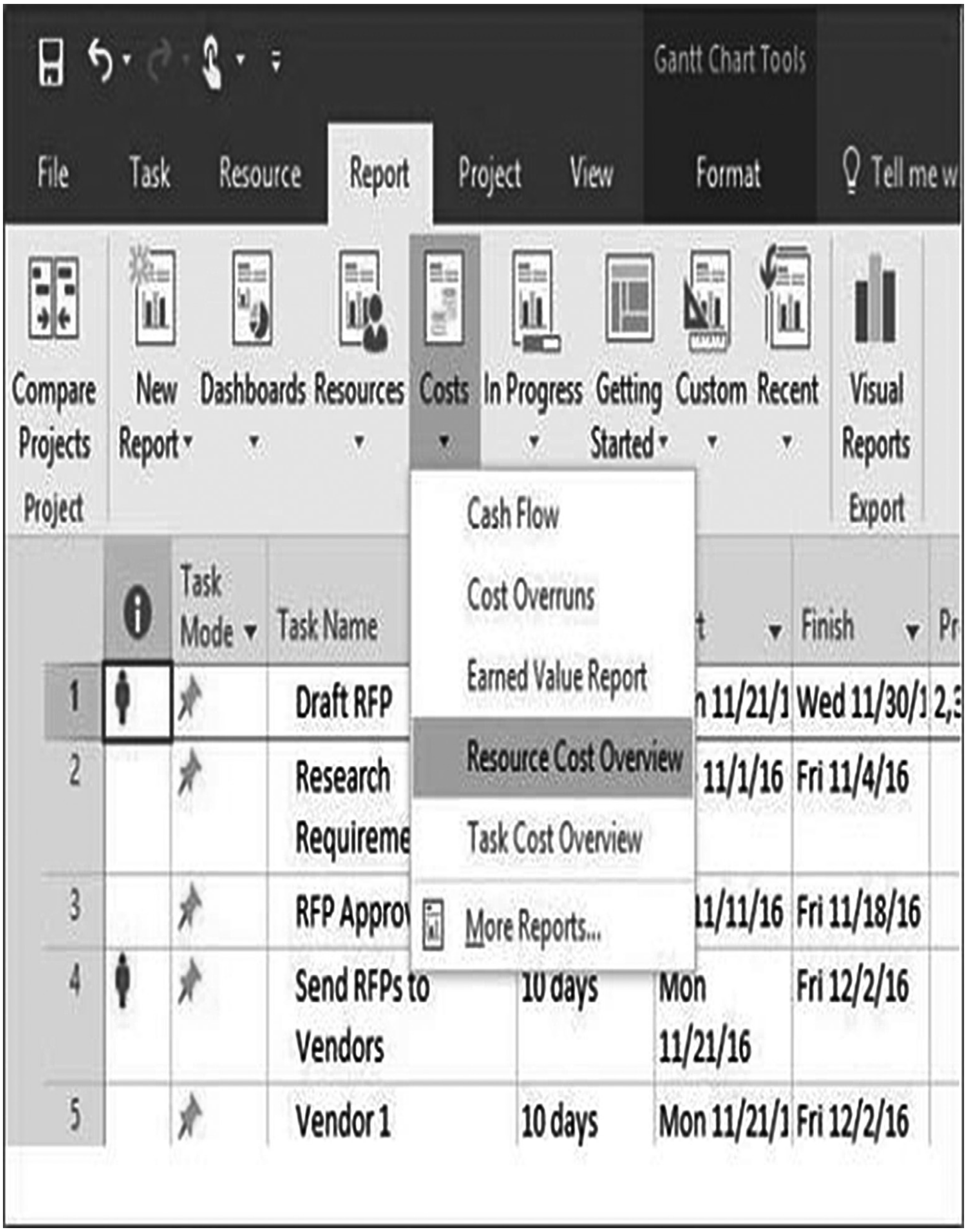
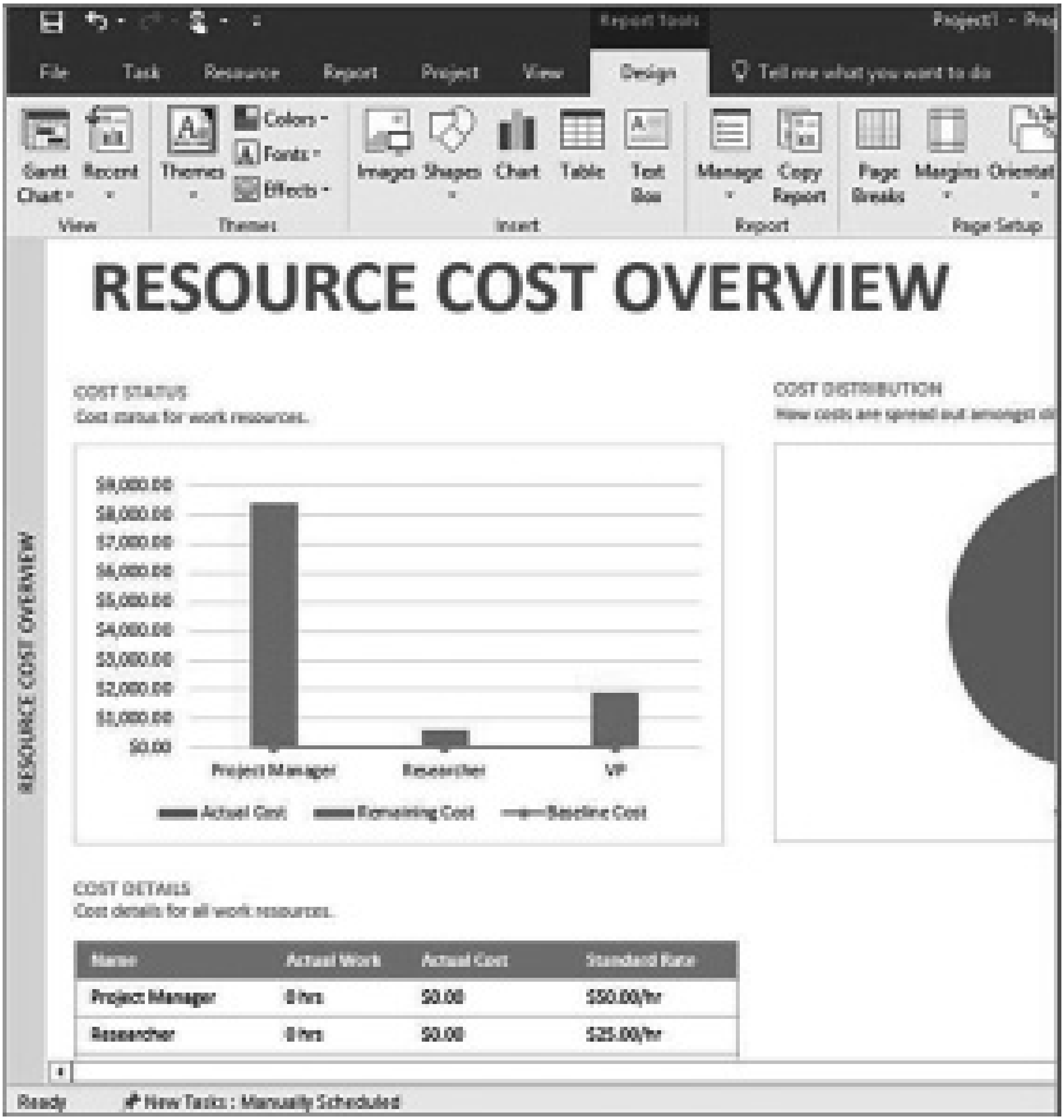


Figure 6.14: MS Project - 14



RESOURCE COST OVERVIEW

COST STATUS
Cost status for work resources.

COST DISTRIBUTION
How costs are spread out amongst al

COST DETAILS
Cost details for all work resources.

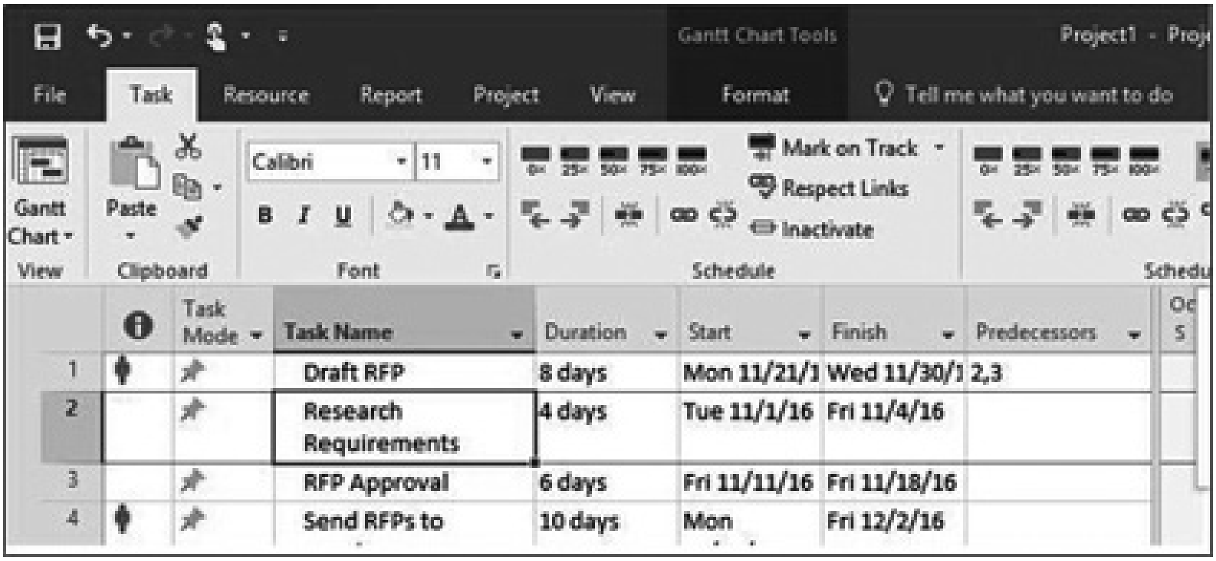
Name	Actual Work	Actual Cost	Standard Rate
Project Manager	0 hrs	$0.00	$50.00/hr
Researcher	0 hrs	$0.00	$25.00/hr

Figure 6.15: MS Project - 15

Track the Progress of Your MS Project

With Microsoft Project, you can keep an eye on tasks to see if things are running on time or behind schedule. This will be easy to view as long as you keep the status of tasks updated during the length of your project.

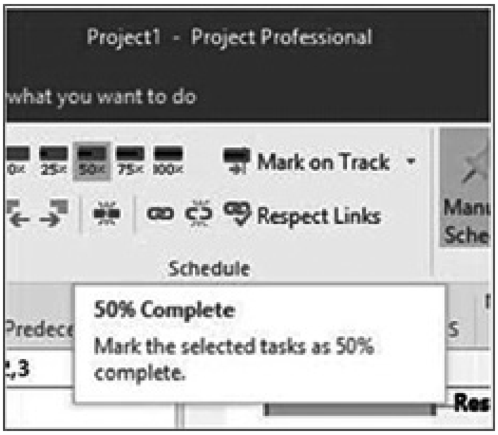
1. **Mark Tasks That Are on Track** Click the Task tab in the menu bar to see all the task options. Click a task that you want to update. If the task is on track, click the Mark on Track button in the ribbon.



	Task Mode	Task Name	Duration	Start	Finish	Predecessors
1		Draft RFP	8 days	Mon 11/21/1	Wed 11/30/1	2,3
2		Research Requirements	4 days	Tue 11/1/16	Fri 11/4/16	
3		RFP Approval	6 days	Fri 11/11/16	Fri 11/18/16	
4		Send RFPs to	10 days	Mon	Fri 12/2/16	

Figure 6.16: MS Project - 16

2. **Use Predetermined Percentages to Track Tasks** To the left of the Mark on Track option, there are percentages that you can use to denote the progress of a task. Click a task to update and click 0%,25%, 50%, 75%, or 100%. You'll see a line drawn through the corresponding bar on the Gantt chart that signifies how much of the task is complete.



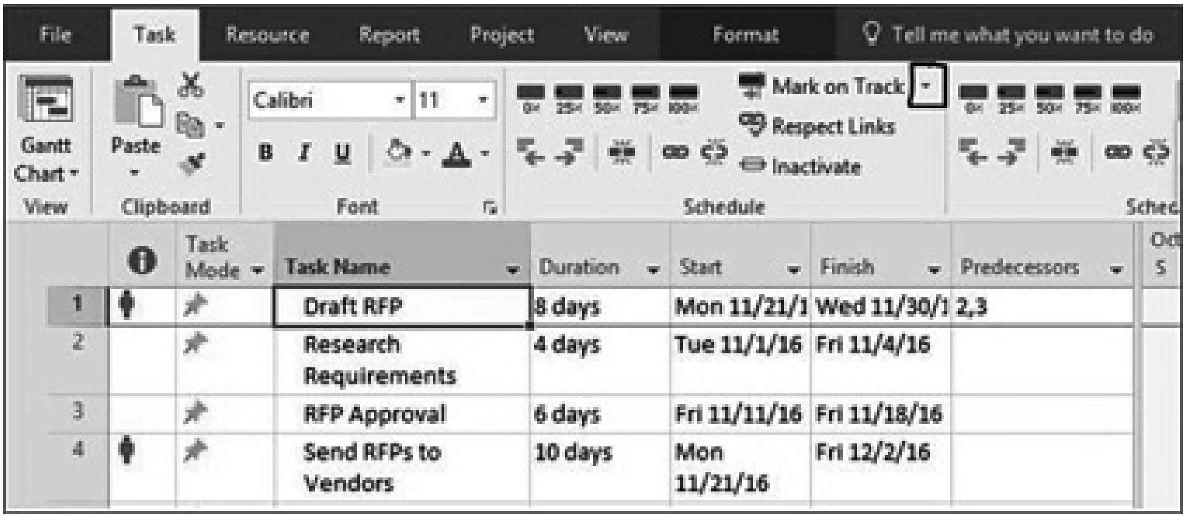
50% Complete

Mark the selected tasks as 50% complete.

Figure 6.17: MS Project - 17

3. **Update Tasks**

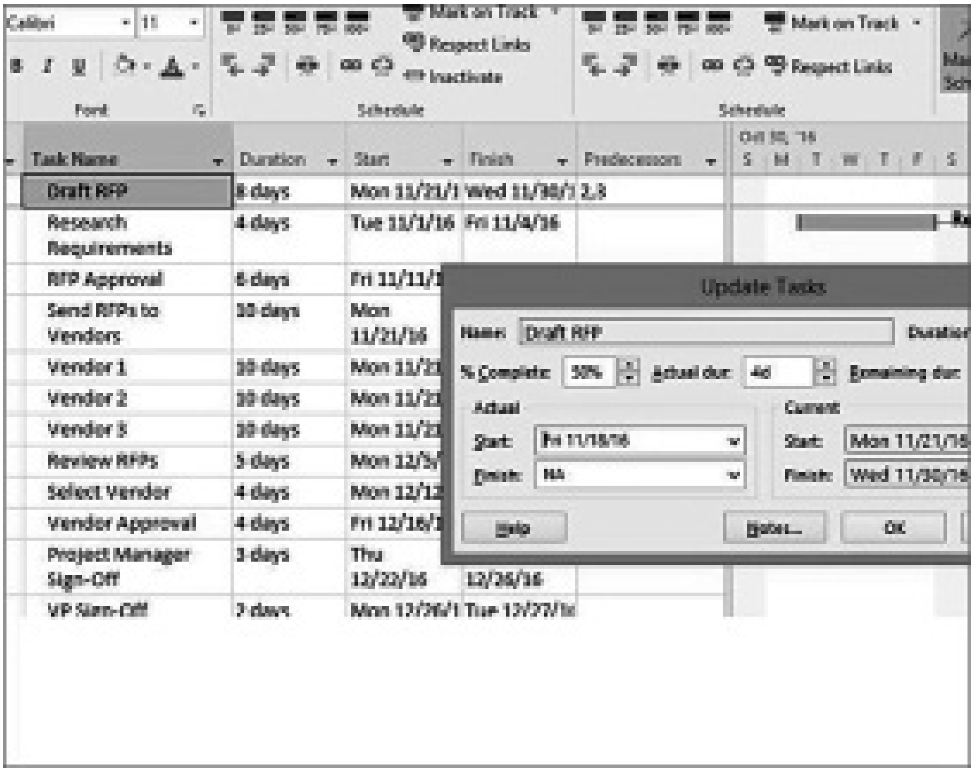
Sometimes tasks fall behind or get accomplished ahead of schedule. You can use the Update Task option to update the status. Click the down arrow next to Mark on Track and click Update Tasks



	Task Mode	Task Name	Duration	Start	Finish	Predecessors
1		Draft RFP	8 days	Mon 11/21/1	Wed 11/30/1	2,3
2		Research Requirements	4 days	Tue 11/1/16	Fri 11/4/16	
3		RFP Approval	6 days	Fri 11/11/16	Fri 11/18/16	
4		Send RFPs to Vendors	10 days	Mon 11/21/16	Fri 12/2/16	

Figure 6.18: MS Project - 18

A dialogue box will appear where you can update status and change start and end dates. Make any changes and click OK.



Task Name	Duration	Start	Finish	Predecessors
Draft RFP	8 days	Mon 11/21/1	Wed 11/30/1	2,3
Research Requirements	4 days	Tue 11/1/16	Fri 11/4/16	
RFP Approval	6 days	Fri 11/11/1		
Send RFPs to Vendors	10 days	Mon 11/21/16		
Vendor 1	10 days	Mon 11/2		
Vendor 2	10 days	Mon 11/2		
Vendor 3	10 days	Mon 11/2		
Review RFPs	5 days	Mon 12/5/		
Select Vendor	4 days	Mon 12/12		
Vendor Approval	4 days	Fri 12/16/1		
Project Manager Sign-Off	3 days	Thu 12/22/16	12/26/16	
VP Sign-Off	2 days	Mon 12/26/1	Tue 12/27/16	

Name: Draft RFP

% Complete: 50%

Actual dur: 4d

Remaining dur:

Actual

Start: Fri 11/18/16

Finish: NA

Current

Start: Mon 11/21/16

Finish: Wed 11/30/16

Figure 6.19: MS Project - 19

These are all the steps you need to get started and create a project, assign and manage tasks, and run reports in Microsoft Project 2016.

Economics of Maintenance and Spares Management

7

This Module Includes

Economics of Maintenance and Spares Management

SLOB Mapped against the Module

To appreciate the importance and gather knowledge about processesfor spares management in mitigatingrelated risks and optimising costs.

Module Learning Objectives:

After studying this module, the students will be able to:

- Understand the difference between preventive maintenance and breakdown maintenance
- Understand the concept of maintenance management
- Understand the objective and types of spare parts management inMaintenance Management
- Understand cost control and unique problem associated with spare partsmanagement

Breakdown Maintenance

7.1

Here the production facility is run without much routine maintenance until it is breakdown. Once the machine breakdown it is taken for repair and inspected to find out the defects. After identifying the defect, the required repair is planned and the spares are procured to repair the machine. As the breakdowns are random in nature and the machine cannot be used during the repair period, production hours are lost hence the productivity is reduced. Repair maintenance is not a recommended practice, in general, but many a time many organizations prefer this, because they do not want to keep the machine idle for maintenance. But they ignore the fact that the break down repair costs more than the regular maintenance practice. It is however, an economical way of maintaining certain non-critical items whose repair and down time costs are less this way than with any other system of maintenance.

Preventive Maintenance

7.2

A system of scheduled, planned or preventive maintenance tries to minimize the problems of breakdown maintenance. It locates weak parts in all equipments, provides them regular inspection and minor repairs thereby reducing the danger of unanticipated breakdowns. The underlying principle of preventive maintenance is that prevention is better than cure. It involves periodic inspection of equipment and machinery to uncover conditions that lead to production breakdown and harmful depreciation. The system of preventive maintenance varies from plant to plant depending on the requirement of the plant. Any company, adopting the preventive maintenance should keep the record of failure of various components and equipment, which help the maintenance department to statistically analyze the failure pattern and replace the item before it fails, so that the breakdown can be eliminated. This reduces the unanticipated breakdowns, increases the availability of the equipment for production purpose, maintain optimum productive efficiency of equipment and machinery reduces the work content of maintenance job, increases productivity and safety of life of worker.

Production department or maintenance department depending on the size of the plant generally takes up preventive maintenance work. As the preventive maintenance is a costly affair, it is better to maintain records of cost (both labour, materials used and spares used) and a valuation of the work done by the department will show us what benefits are derived from preventive maintenance. The analytical approach to evaluate the work done by preventive maintenance is

(i) (Inspections incomplete) / (Inspections scheduled) × 100 should be less than 10%

(ii) (Hours worked for maintenance) / (Scheduled hours) × 100 = Performance of the department.

(iii) Down time to be given as a ratio of the available hours and to be compared against a standard to be worked out for each company or against a figure of the past. The ratio is given as:

= Down time in hours/ Available hours (where Available Hours = working days × hours per day × number of machines). Here down time is the total time of stoppage of the machine for scheduled and unscheduled maintenance work.

(iv) Frequency of break downs = (Number of break downs) / (Available machine hours)

(v) Effectiveness of planning = (Labour hours on scheduled maintenance) / (Total labour hours spent on maintenance).

OR

(Down time due to scheduled maintenance)/(Down time due to total maintenance work)

Advantages of preventive maintenance:

(i) Reduced breakdowns and downtime,

(ii) Greater safety to workers,

(iii) Fewer large scale repairs,

(iv) Less standby or reserve equipment or spares,

(v) Lower unit cost of the product manufactured,

(vi) Better product quality,

(vii) Increased equipments life and

(viii) Better industrial relations.

Routine Maintenance

7.3

It includes lubrication, cleaning, periodic overhaul; etc. This is done while the equipment is running or during pre-planned shut-downs. Running maintenance is the work which can be carried out while the facility is in service.

Maintenance Techniques

It can be discussed as under:

In some cases the loss and inconvenience due to breakdown of equipment is so high that standby equipment is kept. As soon as the original equipment fails, the standby facility is employed to avoid interruption and downtime. Standby machines are often kept to reduce the loss due to the breakdown of a key machine. Breakdown maintenance also requires use of standby machines. The main question here is how many standby machines to keep and for how long. In order to decide this, a cost benefit analysis of standby machines should be made. There are various costs involved in standby machines. First, there is interest cost on capital investment. Secondly, space is needed to keep standby machines. Thirdly, there is depreciation in the value of standby machines. Fourthly, periodic checking and servicing is necessary to keep the standby machines in good condition. The benefits of standby machines consist of protection against a complete shutdown or shut down of operations. It avoids loss of production and, therefore, it is necessary to estimate loss of future failures a table of expected costs and benefits can be prepared.

Shifting production during breakdown. Under this method spare capacity is maintained not in the form of standby machines but by allowing rest to running machines at intervals and by rotation. If one machine in a production line requires shutdown, the output is maintained by shifting to under uitilised machines in other lines. For such application, the capacities of different machines must be properly matched.

Maintenance Organization

At least 50 to 60 percent of investment of any organization is spent on Building and Production facilities. Hence, it is worthwhile to give due consideration for effective maintenance of these items. The maintenance department will looks after the upkeep of equipments, buildings and other. For effective contribution of its work, the maintenance department must have proper place in the organization and it must also have a good organizational structure. While organizing a maintenance department one must remember that there should be clear division of authority with little or no overlap. Vertical lines of authority and responsibility must be kept as short as possible. Keep the span of control to an extent of 3 to 6 for a manager. The organizational structure should be flexible. The structure should be designed to suit the types of maintenance work involved. Depending on the need, the maintenance activity may be centralized or decentralized.

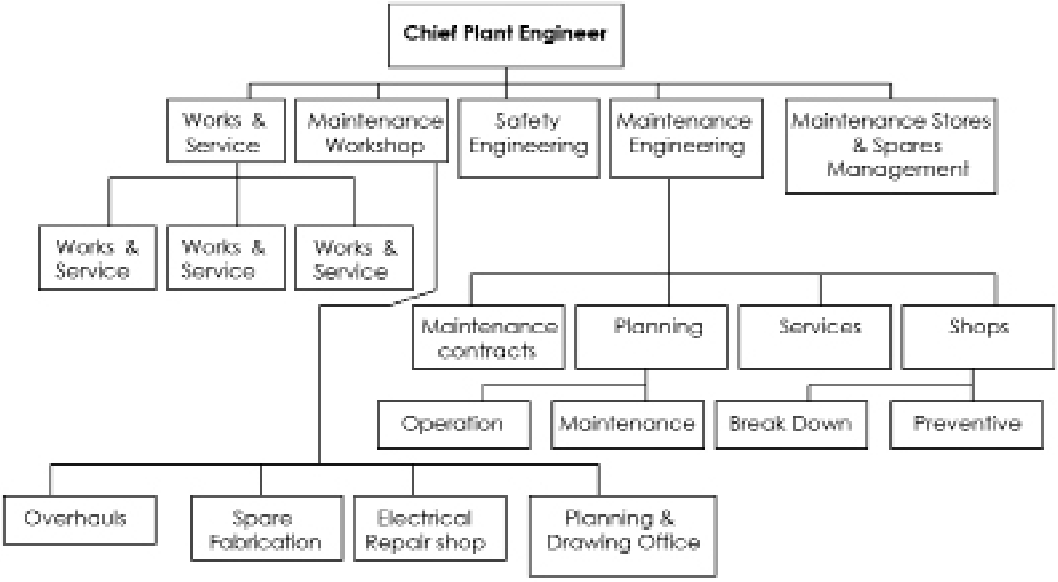


Figure 7.1: Outline of a maintenance department of a large organisation

Organizing Maintenance Work

In order to facilitate proper control of maintenance work; we must enforce three rules as below.

Maintenance Request

This must be made in writing to a central point in the organization. No work should be carried out without the knowledge and approval of maintenance superviser - if this discipline is not followed by the organization, it leads to wastage of skilled manpower and inability of the maintenance personnel to schedule essential maintenance work.

Maintenance Stores

Non-availability of vital spare parts when required to meet an emergency like breakdown, may lead to excessive shutdown of the plant and equipment. A large number of items or materials are required to be stored and it involves investing valuable funds from the working capital. A proper stores management is essential as a backup service of good maintenance.

Records of Maintenance Work Done

Paper work for maintenance is crucial for establishing a good maintenance organization and is often neglected. The records of maintenance work carried out from time to time have to be kept equipment wise. History cards or logbooks of all the plants and equipment must be compiled meticulously giving details of materials used, components replaced and time spent by the workforce.

Creation and maintaining this database is essential for proper planning and control, which alone will lead to effective and efficient maintenance.

To get the full benefits of effective maintenance the following requirement is to be fulfilled:

(i) Good Supervision and administration of maintenance department,

(ii) Good and clear instructions to be given to maintenance crew regarding the repair,

(iii) Proper control of work in coordination with production department,

(iv) Good training should be given to the maintenance personnel,

(v) Good scheduled maintenance program should be chalked out,

(vi) Proper maintenance record keeping is a must,

(vii) There should be adequate stock of spare parts, particularly insurance spares.

Maintenance Problem

The main problem in maintenance analysis is to minimise the overall cost of maintenance without sacrificing the objectives. There are two alternatives before management. One is to repair a machine or equipment only when it breaks down. This will save expense of inspection and replacement of a part before its lifetime ends. The other alternative is to replace the equipment before the expiry of its working life. This will involve cost of periodic shutdown for check up and repairs. However, it will avoid the loss due to sudden failure or breakdown.

The two types of cost - cost of premature replacement and cost of breakdown - need to be balanced. The objective is to minimise total maintenance cost and downtime. Economic analysis is helpful in finding a judicious combination of two types of maintenance. The relationship between preventive maintenance time and repair time is also significant. Preventive maintenance policy is justified only when the average downtime and its cost is less than the average time taken to carry out breakdown repairs. If the machine happens to be part of production line, the breakdown of a machine would throw the entire production line out of gear while a preventive maintenance schedule might enable the repair to be performed during a scheduled idle time of the line.

Replacement of Machine

7.4

Wear and obsolescence are the two main causes for replacement of machinery in every aspect of life. The reduction of wear is therefore a primary concern while designing appliances. Wear and tear due to passage of time and/or normal usage of plant and machinery is an accepted fact. Technological obsolescence is a major danger which business firms face in modern era. With the development of new and better techniques or equipment of performing a particular function, existing equipment and machines become uneconomical. Whenever a firm decides to switch over to new machines or improved product designs, existing machine designs are said to be obsolete. Hence, obsolescence is a major issue in the procurement and installation of machinery and equipment. A machine is technically obsolete when another machine can do the same job more efficiently, with reduced time and also at a lower cost. Technological obsolescence arises due to continuous improvements in the methods and techniques of production and sometime the rate of improvement is so fast that it becomes economical to replace the machinery before its expected life. A machine may be replaced to reduce the running costs of the concerned machine and the new machines productivity will be more. In replacement decisions, the basic problem is to decide whether to replace a machine or equipment at present or at a future date. It is, therefore, necessary to determine whether obsolescence or deterioration has reached the point where the reduction in operating costs expected from replacement justifies the net capital expenditure involved in installing the new machine and disposing of the old one.

Any function aimed at bringing back or restoring an item to its original or acceptable condition or to keep it and retain its health as well as workability is known as Maintenance.

Objectives of Maintenance:

(i) To keep all the production facilities and other allied facilities such as building and premises, power supply system, etc in an optimum working condition,

(ii) To ensure specified accuracy to products and time schedule of delivery to customers,

(iii) To keep the down time of the machine at minimum, so that the production program is not disturbed,

(iv) To keep the production cycle with in the stipulated range,

(v) To modify the machine tools to meet the augmented need for production,

(vi) To improve productivity of existing machine tools and to avoid sinking of additional capital,

(vii) To keep the maintenance cost at a minimum as far as possible, there by keeping the factory Overheads at minimum,

(viii) To extend the useful life of plant and machinery, without sacrificing the level of performance.

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 ₹ 150 to attend a failed machine and rectify the same. Compute the yearly cost of servicing the broken down machines.

Solution:

Expected time before failure.

= 0.20×1 + 0.15×2 + 0.15×3 + 0.15×4 + 0.15×5 + 0.20×6 = 3.5 months

Therefore number or repair/machine/annum = 12/3.5

Considering 20 machines and ₹ 150 to attend a failed machine the yearly cost of servicing

= 12/3.5 × 20 × 150 = ₹ 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 ₹ 2,800. For a cost of ₹ 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?

Solution:

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/Σf)	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
	Σf = 24	Σp = 1	Total 1.710 = Σpx

Expected Breakdown cost per month; Expected no. of breakdowns per month × cost of each breakdown = 1.710 × ₹ 2800 = ₹ 4788.

Preventive maintenance cost per month: -

Average cost of one breakdown/month	=	₹ 2, 800
Maintenance contract cost/month	=	₹ 1,500
Total	=	₹ 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?

Solution:

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 $= 2 \times \frac{2000}{2} = 2000$ 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

$\frac{1,98,000}{2} \times 10,000 \times 365 \times 4 = 147.47 = 148$ tubes approximately.

Mean time between failures $= \frac{\text{1,98,000 tubes hrs. of testing}}{\text{2 failure}}$

$= 99,000$ tubes hours per failure $= \frac{99,000}{4 \times 365} = 67.8$ 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 ₹ 20 and ₹ 100 respectively. The company wants to reduce the breakdown occurrence while minimizing Cp. Given is the data on breakdown occurance.

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

Solution:

The mean time before failure is 5.4 months and the expected cost with no preventive maintenance would be 100 $\times \frac{50}{5.4} =$ ₹ 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.

$B_1 = MP_1 = 50\ (0.10) = 5$

$B_2 = m\ (P_1 + P_2) + B_1P_1 = 50(0.10+0.05) + 5(0.10) = 8$

$B_3 = 50\ (0.10 + 0.05 + 0.05) + 8\ (0.10) + 5\ (0.05) = 11.05$

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)	Bj Expected Number of Breakdown in j months	Expected cost/ month to Repair Breakdown $C_R \times Bj/j$	Cost per month for preventive service every j month $C_R(M)/j$	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 ₹ 669. This amount is ₹ 257 per month less than the ₹ 926 expected cost without preventive maintenance. This policy would reduce the costs by (257 ÷ 926) × 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?

Solution:

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
		∑2.5months/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
		∑4.4months/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
		∑3.3months/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 = ₹100 & Cost of Preventive maintenance C_{PM} = ₹75, Cost of Individual Replacement CI = ₹80, Cost of Group Replacement = ₹50/machine

For a pool of 100 machines, Could you recommend PM? When you will go for Replacement?

Solution:

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
		∑4.9 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 = ₹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 x ₹100)	Expected Monthly PM Cost (₹75 x 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

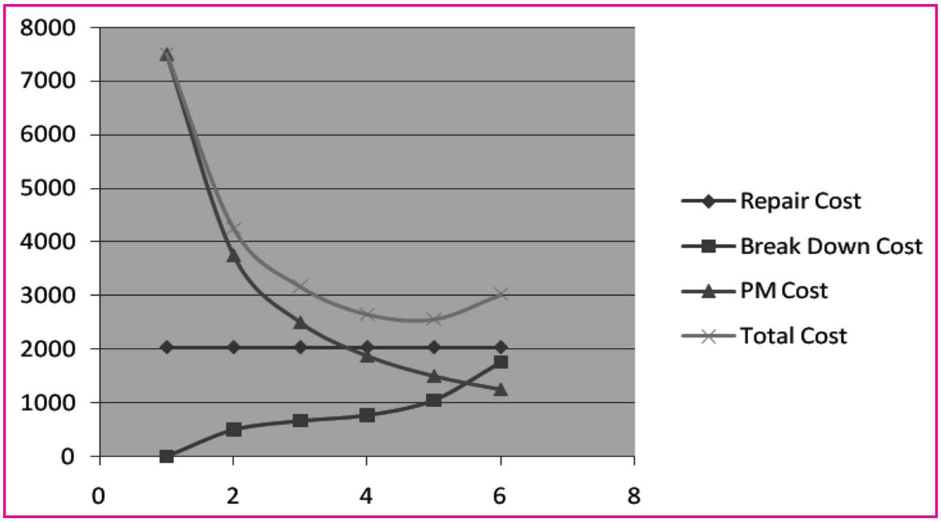
Month 3: 100*(0.0+0.1+0.1) + 0*0.1 +10*0.0 = 20

Month 4: 100*(0.0+0.1+0.1+0.1) + 0*0.1+10*0.1+20*0.0 = 31

Month 5: 100*(0.0+0.1+0.1+0.1+0.2) +0*0.1+10*0.1+20*0.1+31*0.0 = 53

Month 6: 100*(0.0+0.1+0.1+0.1+0.2+0.5) +0*0.2+10*0.1+20*0.1+31*0.1+53*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 x 80)	Group (100 X 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 X 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 C_R = ₹90 & Cost of Preventive maintenance C_{PM} = ₹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 × Average repair cost on breakdown = 40 × 90 = ₹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 x ₹90)	Expected Monthly PM Cost (₹30 x 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*0.5 = 50

Month 2: 100*(0.5+0.1) +50*0.5 = 85

Month 3: 100*(0.5+0.1+0.1) + 50*0.1 +85*0.5 = 117.5

Month 4: 100*(0.5+0.1+0.1+0.1) + 50*0.1+85*0.1+117.5*0.5 = 152.25

Month 5: 100*(0.5+0.1+0.1+0.1+0.1) +50*0.1+85*0.1+117.5*0.1+152.25*0.5 = 191.38

Month 6: 100*(0.5+0.1+0.1+0.1+0.1+0.1) +50*0.1+85*0.1+117.5*0.1+152.25*0.1+191.38*0.5 = 236.16

Graphical Representation Policy 1:

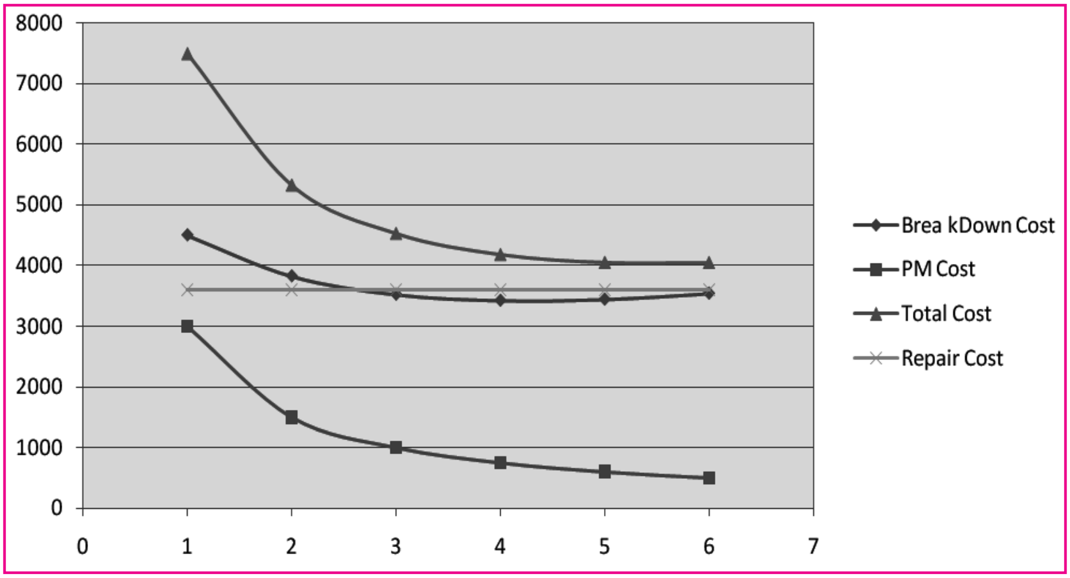


Fig -I

Repair Policy Cost of Policy 2 = Average number of repairs per month × Average repair cost on breakdown = 22.73 × 90 = ₹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 × ₹90)	Expected Monthly PM Cost (₹30 × 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*0.1 = 10

Month 2: 100*(0.1+0.1) +10*0.1 = 21

Month 3: 100*(0.1+0.1+0.1) + 10*0.1 +21*0.1 = 33.1

Month 4: 100*(0.1+0.1+0.1+0.1) + 10*0.1+21*0.1+33.1*0.1 = 46.41

Month 5: 100*(0.2+0.1+0.1+0.1+0.1) +10*0.1+21*0.1+33.1*0.1+46.41*0.1 = 71.05

Month 6: 100*(0.4+0.2+0.1+0.1+0.1+0.1)+10*0.2+21*0.1+33.1*0.1+46.41*0.1+71.05*0.1= 119.16

Graphical Representation Policy 2:

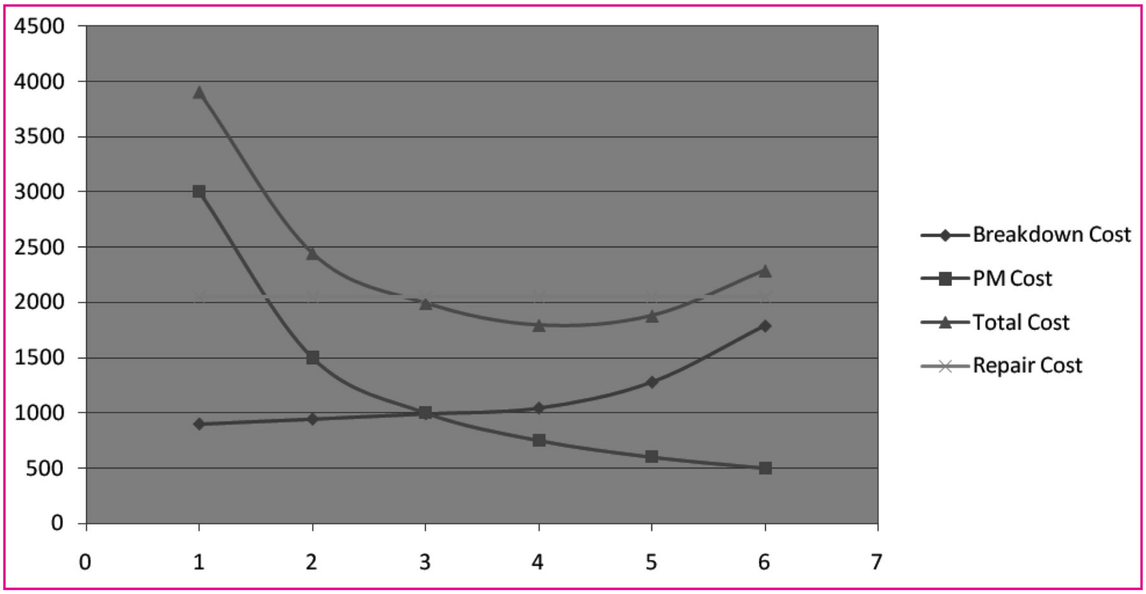


Fig -II

Repair Policy Cost of Policy 3 = Average number of repairs per month × Average repair cost on breakdown = 30.30 × 90 = ₹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 x ₹90)	Expected Monthly PM Cost (₹30 x 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*0.1 = 10

Month 2: 100*(0.1+0.1) +10*0.1 = 21

Month 3: 100*(0.5+0.1+0.1) + 10*0.1 +21*0.1 = 73.1

Month 4: 100*(0.1+0.5+0.1+0.1) + 10*0.5+21*0.1+73.1*0.1 = 94.41

Month 5: 100*(0.1+0.1+0.5+0.1+0.1) +10*0.1+21*0.5+73.1*0.1+94.41*0.1 = 118.25

Month 6: 100*(0.1+0.1+0.1+0.5+0.1+0.1)+10*0.1+21*0.1+73.1*0.5+94.41*0.1+118.25*0.1 = 160.92

Graphical Representation Policy 3:

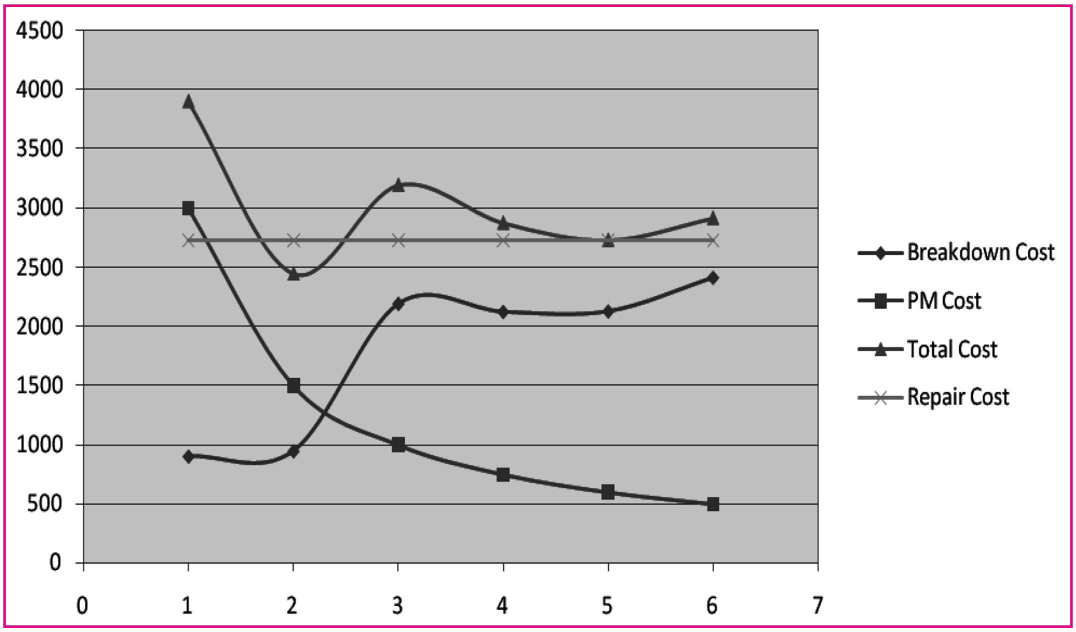


Fig-III

If we refer three graphs it is clear that –

Under Policy 1 (Fig –I) Repair cost ₹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 ₹1,794 - Refer Col.6,Row 4 of Table-II, is less than Repair cost ₹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 ₹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- ₹2,045.7 < Repair cost under policy 3- ₹2,727.

PM policy Cost under policy 2- ₹1,794 < PM policy Cost under policy 3- ₹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.

Spare Parts Management

7.5

Spare Parts Management (SPM) is a complex activity in a large manufacturing plant as it is one of the critical enablers for providing better services to the customers during several stages of the product life cycle. Usually, SPM deals with two types of parts such as one which is required very frequently ("fast moving") and the one which is used quite rarely ("slow moving or non-moving"). While the managers keep stock for the former category, the later posits a greater challenge to the works manager. Further, given the fact of changing consumer preferences and needs coupled with technological progress, organizations are compelled to bring new products and/or differentiate the existing products every now and then, SPM invokes a methodical and record-based careful approach to provide services to the customers those who have bought the products before obsolescence or differentiation. Further, for preventive maintenance also spare parts are required often. Hence, it is necessary to maintain a comprehensive database management for SPM that helps to

(a) Keep records for specific and general purpose spare parts used in preventive and breakdown maintenance
(b) Track the movement of the spare parts and consumption pattern
(c) Plan for future maintenance activities on short and mid-term basis
(d) Demand forecasting for spare parts requirement on short, medium and long-term basis.
(e) Plan for collaboration with spare parts vendors and managing them
(f) Optimize the spare parts inventory

Preventive maintainance is very important but failure cannot be able to eliminated. To avoid failures spare parts play a vital role. Failure statistics are usefull in calculatingspare parts for preventive maintainance and breakdown maintainance also. Spares can be classified as per sevice level/understocking cost.

- **Regular spares**

  The spare parts required regularly and in substantial number.Both reliabilty and per unit cost of these items are less.

  Service level = Ku/Ku + Ko, Ku = Oppertunity cost of understock of one unit Ko = Opertunity cost of overstock of one unit.

- **Insurance spares**

  An insurance spare is a spare part that you hold in your spare parts inventory, that you would not expect to use in the, normal life of the plant and equipment but if not available when needed it would result in significant losses.

- **Capital spares**

  Capital spares are spare parts which, although acknowledged to have a long life or a small chance of failure, would cause a long shutdown of equipment because it would take along time to get a replacement for them.

  $S_{i=0}^{N-1} P_i \leq C3 - C / C3 \leq \sum Pi$

- **Rotable spares**

  Rotable items are generally thought of as items of plant or assets that periodically are changed out for repair or overall.

  The management of rotable items and repairable spare parts is different to the management of other inventory items and proper control requires greater cooperation between maintenance and stores/inventory management. The successful management of these items is far more active than other spare parts as maintenance and store/ inventory personnel must work together to ensure that there is visibility of the status of items.

Illustration 5

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).

Solution:

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 Dmax of eight during the lead time. In other words we should keep a Buffer Stock = Dmax - Daverage

during a lead time = 8 - 5 = 3 items.

Thus, buffer stock desired is three numbers of the given spare part.

Illustration 6

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 ₹ 2 crore as the costs of sales lost and other relevant costs. However, this spare is quoted at ₹ 10 lakh at present. Should the shaft spare be procured along with the equipment and kept or not?

Solution:

The expected cost of down-time

= (Probability of failure) × (Cost when break-down occurs)

= (1 – 0.990) × (₹ 2 crore) = ₹ 2 lakh

However, the cost of procuring the spare now is ₹ 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 7

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 ₹ 650 and is considering adopting a preventive maintenance program which would cost ₹ 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?

Solution :

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 × 650 = ₹ 910

Cost of preventive maintenance programme per day = ₹ 200+ ₹ 650 = ₹ 850

Expected annual savings from the preventive maintenance programme = (910 – 850) × 300 days

= 60×300 = ₹ 18,000

Illustration 8

A firm is using a machine whose purchase price is ₹ 15,000. The installation charges amount to ₹ 3,500 and the machine has a scrap value of only ₹ 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 (₹)	**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.

Solution:

Cost of machine, C = ₹ 15,000 + ₹ 3,500 = ₹ 18,500

Scrap value, S = ₹ 1,500.

Year	Maintenance Cost, M_1 (₹)	Cumulative Maintenance Cost, ΣM_1 (₹)	Cost of Machine – Scrap Value (₹)	Total Cost $T_{(n)}$ (₹)	Annual Cost $A_{(n)}$ (₹)
(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 ₹4,288 approx., which corresponds to n = 7 in above table. Thus machine needs to be replaced every 7th year.

Illustration 9

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 ₹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 ₹ 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?

Solution:

(a) Computation of failures & Mean life

Month (X)	Probability of Failure (P)	P X
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 month

Average Life of a component = 3.35 Months

Average No. of Replacements = 2000/3.35 = 597 per month

Cost of Individual Replacement = 597 × ₹ 3 = ₹ 1791 per month

Computation of expected No. of Replacements:

Month	Expected number of components to be replaced by the month end	
1	$N_1 = N_0P_1 = 2000 \times 0.1$	200
2	$N_2 = N_0P_2 + N_1P_1 = 2000 \times 0.15 + 200 \times 0.1$	320
3	$N_3 = N_0P_3 + N_1P_2 + N_2P_1 = 2000 \times 0.25 + 200 \times 0.15 + 320 \times 0.1$	562
4	$N_4 = N_0P_4 + N_1P_3 + N_2P_2 + N_3P_1 = 2000 \times 0.3 + 200 \times 0.25 + 320 \times 0.15 + 562 \times 0.1$	754.2
5	$N_5 = N_0P_5 + N_1P_4 + N_2P_3 + N_3P_2 + N_4P_1 = 2000 \times 0.2 + 200 \times 0.3 + 320 \times 0.25 + 562 \times 0.15 + 754.2 \times 0.1$	699.72

Computation of Average cost

Month (x)	Cumulative number of component Replace individually by month end	Cost		Total Cost (Tc)	Average Cost = Tc/n
		Individual	Group		
		₹	₹	₹	₹ 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 ₹ 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* (₹)
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

* To obtai the value of K use the equation Average cost of Individual Replacement = Average Cost of Group Replacement

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 (₹)
1	(2000 a + 600)/1	1791	0.60
2	(2000 a + 1560)/2	1791	1.01
3	(2000 a + 3246)/3	1791	**1.06**
4	(2000 a + 5508.6)/4	1791	0.83
5	(2000 a + 7607.76)/5	1791	0.67

When unit cost is more than ₹ 1.06 then Individual Replacement policy would be better.

Illustration 10

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 ₹ 160 per pole and if we have a common group replacement policy it costs ₹ 80 per pole, find out the optimal period for group replacement.

Solution:

Chart showing Optimal Replacement Period

Average life of the pole - 1 × 0.01 + 2 × 0.02 + 3 × 0.03 + 4 × 0.05 + 5 × 0.07 + 6 × 0.12 + 7 × 0.20 + 8 × 0.3 + 9 × 0.16 + 10 × 0.04 = 7.05 years.

No. of poles to be replaced every year $= \frac{5000}{7.05} = 709$

Average yearly cost on individual replacement = 709 × ₹160 = ₹1,13,440.

Group Replacement: Initial Cost = 5,000 × ₹80 = ₹4,00,000.

Year	No. of poles to be replaced	Yearly cost of individual replacement @ ₹160/pole (₹)	Cumulative cost of individual replacement (₹)	Total cost of individual replacement as well as group replacement (₹)	Average Annual Cost $= \frac{\text{TotalCost}}{\text{Year}}$ (₹)
1	5,000 × 0.01 = 50	8,000	8,000	4,08,000	4,08,000
2	5,000 × 0.02 + 50 × .01 = 101	16,160	24,160	4,24,160	2,12,080
3	5,000 × 0.03 + 50 × 0.02 + 101 × 0.01 = 152	24,320	48,480	4,48,480	1,49,493
4	5,000 × 0.05 + 50 × 0.03 + 101 × 0.02 + 152 × 0.01 = 256	40,960	89,440	4,89,440	1,22,360
5	5,000 × 0.07 + 50 × 0.05 + 101 × 0.03 + 152 × 0.02 + 256 × 0.01 = 362	57,920	1,47,360	5,47,360	1,09,472
6	5,000 × 1.2 + 50 × 0.07 + 101 × 0.05 + 152 × 0.03 + 256 × 0.02 + 362 × 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 11

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.

(i) Which product has the higher reliability?

(ii) Which product has greater maintainability?

(iii) Which product has greater availability?

Solution:

(i) 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.

(ii) 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.

(iii) Availability of a machine/product = $\frac{\text{MTBF}}{\text{MTBF + MTTR}}$

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 12

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 ₹ 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 ₹ 500 per such preventive action. What should be the appropriate maintenance policy in terms of the mix of preventive and breakdown maintenance

Solution:

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

$$= \frac{\text{(No. of trucks) (Cost per breakdown)}}{\text{(Expected number of months between failure)}}$$

$$= \frac{(50)(₹\ 3000)}{(3.0)} = ₹\ 50,000$$

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:

$B_1 = (50) \times (0.1) = 5$

Cost of breakdown = 5 × ₹ 3000	= ₹ 15,000
Cost of preventive maintenance = ₹ 500 × 50	= ₹ 25,000
Total Cost during the PM period	= ₹ 40,000

Therefore, cost per month for this policy is

= 40,000 ÷ 1 = ₹ 40,000

(ii) Preventive maintenance (PM) period two months

No. of breakdowns within 2 months:

$B_2 = (50) \times (0.1 + 0.2) + (50) \times (0.1) \times (0.1) = 15.5$

Cost of breakdown = (15.5) × ₹ 3000 = ₹ 46,500

Cost of prev. maintenance = ₹ 500 × 50 = ₹ 25,000

Total cost during the PM period = ₹ 71,500

Therefore, cost per month for this policy:

₹ 71,500 ÷ 2 months = ₹ 35,750

(iii) Preventive maintenance period 3 months

No. of breakdowns within 3 months:

$B_3 = (50)\times (0.1 + 0.2 + 0.3) + (50 \times 0.1) (0.1 + 0.2) + (50 \times 0.1 \times 0.1) (0.1)$

$= 30 + 1.5 + 0.05 = 31.55$

Cost of breakdown = 31.55 × ₹ 3000 = ₹ 94,650

Cost of preventive maintenance = 50 × ₹ 500 = ₹ 25,000

Total = ₹ 1,19,650

Therefore, cost per month for this policy

= ₹ 1,19,650 ÷ 3 months = ₹ 39,883.33

(iv) Preventive maintenance period 4 months

No. of breakdowns within 4 months

$$B_4 = [(50) \times (1.0)] + [(50) \times (0.1) \times (0.1 + 0.2 + 0.3) + (50\times 0.1 \times 0.1) \times (0.1 + 0.2) + (50 \times 0.1 \times 0.1 \times 0.1) \times (0.1)$$
$$+ (50 \times 0.1 \times 0.2) \times (0.1)] + [(50 \times 0.2) \times (0.1 + 0.2) + (50 \times 0.2 \times 0.1) \times (0.1)] + [(50 \times 0.3 \times (0.1)]$$
$$= 57.855$$

Cost of breakdown = (57.855) × (₹ 3,000) = ₹ 1,73,565

Cost of preventive maintenance = 50 × ₹ 500 = ₹ 25,000

Total = ₹ 1,98,565

Therefore, cost per month for this policy is ₹ 1,98,565 ÷ 4 months = ₹ 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.

Exercise

⊙ Multiple Choice Questions:

1. Number of product varieties that can be manufactured in Job production is:
   (a) Limited to one or two
   (b) Large varieties of products
   (c) One only
   (d) None of the above.

2. Number of product varieties that can be manufactured in Mass production is:
   (a) One only
   (b) Two only
   (c) Few varities in large volumes
   (d) Large varities in small volumes.

3. In general number of product varities that can be manufactured in Flow production is:
   (a) One only
   (b) Ten to twenty varities
   (c) Large varities
   (d) Five only.

4. Generally the size of the order for production in Job production is:
   (a) Small
   (b) Large
   (c) Medium
   (d) Very large.

5. Generally in continuous production the production is carried out to:
   (a) Customer's order
   (b) Government orders only
   (c) For stock and supply
   (d) Few rich customers.

6. Inventory cost per product in intermittent production is:
   (a) Higher
   (b) Lowest
   (c) Medium
   (c) Abnormal.

7. The material handling cost per unit of product in Continuous production is:
   (a) Highest compared to other systems
   (b) Lower than other systems

(c) Negligible

(d) Cannot say.

8. Routing and Scheduling becomes relatively complicated in

(a) Job production

(b) Batch production

(c) Flow production

(d) Mass production.

9. The starting point of Production cycle is:

(a) Product design

(b) Production Planning

(c) Routing

(d) Market research.

10. Variety reduction is generally known as:

(a) Less varities

(b) Simplification

(c) Reduced varities

(d) None of the above.

11. Preferred numbers are used to:

(a) To determine the number of varities that are to be manufactured

(b) To the test the design of the product

(c) To ascertain the quality level of the product

(d) To evaluate the production cost.

12. The act of assessing the future and make provisions for it is known as

(a) Planning

(b) Forecasting

(c) Assessment

(d) Scheduling.

13. For a marketing manager, the sales forecast is:

(a) Estimate of the amount of unit sales or a specified future period

(b) Arranging the sales men to different segments of the market

(c) To distribute the goods through transport to satisfy the market demand

(d) To plan the sales methods.

14. The time horizon selected for forecasting depends on:
    (a) The salability of the product
    (b) The selling capacity of Salesman
    (c) Purpose for which forecast is made
    (d) Time required for production cycle.

15. For production planning:
    (a) Shot term forecasting is useful
    (b) Medium term forecasting is useful
    (c) Long term forecasting is useful
    (d) Forecasting is not useful.

16. In general, medium range forecasting period will be approximately:
    (a) 5 to 10 Years
    (b) 2 to 3 days
    (c) 3 to 6 months
    (d) 10 to 20 years.

17. The range of Long range forecasting period may be approximately:
    (a) 1 to 2 weeks
    (b) 2 to 3 months
    (c) 1 year
    (d) above 5 years.

18. To plan for future man power requirement:
    (a) Short term forecasting is used
    (b) Long range forecasting is used
    (c) Medium range forecasting is used
    (d) There is no need to use forecasting, as future is uncertain.

19. Long range forecasting is useful in:
    (a) Plan for Research and Development
    (b) To Schedule jobs in Job production
    (c) In purchasing the material to meet the present production demand
    (d) To assess manpower required in the coming month.

20. Medium range forecasting is useful in:
    (a) To assess the loading capacity of the machine

(b) To purchase a materials for next month

(c) To plan for-capacity adjustments

(d) To decide whether to receive production orders or not.

21. To decide work load for men and machines:
    (a) Medium range forecasting is used
    (b) Short term forecasting is used
    (c) Long range forecasting is used
    (d) A combination of long range and medium range forecasting is used.

22. Important factor in forecasting production is:
    (a) Environmental changes
    (b) Available capacity of machines
    (c) Disposable income of the consumer
    (d) Changes in the preference of the consumer.

23. Application of technology or process to the raw material to add use value is known as:
    (a) Product
    (b) Production
    (c) Application of technology
    (d) Combination of technology and process.

24. In Production by disintegration the material undergoes:
    (a) Change in economic value only
    (b) Change in physical and chemical characteristics
    (c) Change in technology only
    (d) None of the above.

25. In Production by service, the product undergoes the changes in:
    (a) Shape and size of the surface
    (b) Shape of the surface only
    (c) Size of the surface only
    (d) Chemical and Mechanical properties.

26. Use of any process or procedure designed to transform a set of input elements into a set of output elements is known as:
    (a) Transformation process
    (b) Transformation of input to output

(c) Production

(d) Technology change.

27. Conversion of inputs into outputs is known as:
    (a) Application of technology
    (b) Operations management
    (c) Manufacturing products
    (d) Product.

28. The desired objective of Production and Operations Management is:
    (a) Use cheap machinery to produce
    (b) To train unskilled workers to manufacture goods perfectly
    (c) Optimal utilisation of available resources
    (d) To earn good profits.

29. The scope of Production Planning and Control is:
    (a) Limited to Production of products only
    (b) Limited to production of services only
    (c) Limited to production of services and products only
    (d) Unlimited, can be applied to any type of activity.

30. Manufacturing system often produces:
    (a) Standardised products
    (b) Standardised products in large volumes
    (c) Substandardproducts in large volumes
    (d) Products and services in limited volume.

31. The difference between product system and project system is:
    (a) Project system the equipment and machinery are fixed where as in product system they are movable
    (b) In Product system the machinery and equipment are fixed and in project system they are not fixed
    (c) Project system produces only standardized products and product system produces only unstandardised products
    (d) Products cannot be stocked whereas projects can be stocked.

32. Most important benefit to the consumer from efficient production system is:
    (a) He can save money
    (b) He will have product of his choice easily available
    (c) He gets increased use value in the product
    (d) He can get the product on credit.

33. Two important functions that are to be done by Production department are:
    (a) Forecasting
    (b) Costing
    (c) Scheduling and loading
    (d) Inspecting.

34. Fixing the flow lines of materials in production is known as:
    (a) Scheduling
    (b) Loading
    (c) Planning
    (d) Routing.

35. The act of releasing the production documents to the production department is known as:
    (a) Planning
    (b) Routing
    (c) Dispatching
    (d) Releasing.

36. The activity of specifying when to start the job and when to end the job is known as:
    (a) Plaining
    (b) Scheduling
    (c) Timing
    (d) Follow-up.

37. In an organisation the production planning and control department comes under:
    (a) Planning department
    (b) Manufacturing department
    (c) Personal department
    (d) R & D department.

38. In Job production system, we need:
    (a) More unskilled labours
    (b) Skilled labours
    (c) Semi-skilled labours
    (d) Old people.

39. In Continuous manufacturing system, we need:
    (a) General purpose machines and Skilled labours

(b) Special machine tools and highly skilled labours

(c) Semi automatic machines and unskilled labours

(d) General purpose machines and unskilled labours.

40. Most suitable layout for Job production is:

(a) Line layout

(b) Matrix layout

(c) Process layout

(d) Product layout.

41. Most suitable layout for Continuous production is:

(a) Line layout

(b) Process Layout

(c) Group technology

(d) Matrix layout.

42. One of the product examples for Line layout is:

(a) Repair workshop

(b) Welding shop

(c) Engineering College

(d) Cement.

43. The act of going round the production shop to note down the progress of work and feedback the information is known as:

(a) Follow up

(b) Dispatching

(c) Routing

(d) Trip card.

44. Line of Best fit is another name given to:

(a) Method of Least Squares

(b) Moving average method

(c) Semi average method

(d) Trend line method.

45. One of the important basic objectives of Inventory management is:

(a) To calculate EOQ for all materials in the organisation

(b) To go in person to the market and purchase the materials

(c) To employ the available capital efficiently so as to yield maximum results

(d) Once materials are issued to the departments, personally check how they are used.

46. The best way of improving the productivity of capital is:
    (a) Purchase automatic machines
    (b) Effective Labour control
    (c) To use good financial management
    (d) Productivity of capital is to be increased through effective materials management.

47. MRP stands for:
    (a) Material Requirement Planning
    (b) Material Reordering Planning
    (c) Material Requisition Procedure
    (d) Material Recording Procedure.

48. JIT stands for:
    (a) Just in time purchase
    (b) Just in time production
    (c) Just in time use of materials
    (d) Just in time order the material.

49. The cycle time, selected in balancing a line must be:
    (a) Must be greater than the smallest time element given in the problem
    (b) Must be less than the highest time element given in the problem
    (c) Must be slightly greater than the highest time element given in the problem
    (d) Left to the choice of the problem solver.

50. The lead-time is the time:
    (a) To placeholders for materials
    (b) Time of receiving materials
    (c) Time between receipt of material and using materials
    (d) Time between placing the order and receiving the materials.

51. Production planning deals with:
    (a) What production facilities is required and how these facilities should be laid out in space available
    (b) What to produce and when to produce and where to sell
    (c) What should be the demand for the product in future?
    (d) What is the life of the product?

52. The first stage in production planning is:
    (a) Process Planning
    (b) Factory Planning
    (c) Operation Planning
    (d) Layout planning.

53. In Process Planning we plan:
    (a) Different machines required
    (b) Different operations required
    (c) We plan the flow of material in each department
    (d) We design the product.

54. In Operation Planning:
    (a) The planner plans each operation to be done at work centers and the sequence of operations
    (b) Decide the tools to be used to perform the operations
    (c) Decide the machine to be used to perform the operation
    (d) Decide the materials to be used to produce the product.

55. Before thinking of routing, the production planner has to:
    (a) Decide the optimal allocation of available resources
    (b) To decide what type of labour to be used
    (c) To decide how much of material is required
    (d) To count how many orders he has on his hand.

56. The quantities for which the planner has to prepare production plan are known as:
    (a) Optimal quantity of products
    (b) Material planning
    (c) Quantity planning
    (d) Planning quantity standards.

57. The document, which is used to show planning quantity standards and production plan, is known as:
    (a) Planning specifications
    (b) Route sheet
    (c) Bill of materials
    (d) Operation sheet.

58. In route sheet or operation layout, one has to show:
    (a) A list of Materials to be used

(b) A list of machine tools to be used

(c) Every work center and the operation to be done at that work center

(d) The cost of product.

59. The cycle time in selected in balancing a line must be:

(a) Must be greater than the smallest time element given in the problem

(b) Must be less than the highest time element given in the problem

(c) Must be slightly greater than the highest time element given in the problem

(d) Left to the choice of the problem solver.

60. In solving a problem on LOB, the number of workstations required is given by:

(a) Cycle time/Total time

(b) Cycle time/Element time

(c) Total time/Element time

(d) Total time/ Cycle time.

61. (Total station time/Cycle time × Number of work stations) × 100 is know as:

(a) Line Efficiency

(b) Line smoothness

(c) Balance delay of line

(d) Station efficiency.

62. Final stage of production planning, where production activities are coordinated and projected on a time scale is known as:

(a) Scheduling

(b) Loading

(c) Expediting

(d) Routing.

63. Scheduling shows:

(a) Total cost of production

(b) Total material cost

(c) Which resource should do which job and when

(d) The flow line of materials.

64. Scheduling deals with:

(a) Number of jobs to be done on a machine

(b) Number of machine tools used to do a job

(c) Different materials used in the product

(d) Fixing up starting and finishing times of each operation in doing a job.

65. The study of relationship between the load on hand and capacity of the work centers is known as:

(a) Scheduling

(b) Loading

(c) Routing

(d) Controlling.

66. One of the aims of loading is:

(a) To finish the job as early as possible

(b) To minimise the material utilisation

(c) To improve the quality of product

(d) To keep operator idle time, material waiting time and ancillary machine time at minimum.

67. One of the principles of Scheduling is:

(a) Principle of optimal product design

(b) Principle of selection of best material

(c) Principle of optimal operation sequence

(d) Principle of optimal cost.

68. The method used in scheduling a project is:

(a) A schedule of breakdown of orders

(b) Outline Master Programme

(c) PERT & CPM

(d) Schedule for large and integrated work.

69. Production planning in the intermediate range of time is termed as:

(a) Production planning

(b) Long range production planning

(c) Scheduling

(d) Aggregate planning.

70. One of the requirements of Aggregate Planning is:

(a) Both output and sales should be expressed in a logical overall unit of measuring

(b) Appropriate time period

(c) List of all resources available

(d) List of operations required.

71. In aggregate planning, one of the methods in modification of demand is:
    (a) Differential Pricing
    (b) Lay off of employees
    (c) Over time working
    (d) Sub contracting.

72. In aggregate planning one of the methods used to modification of supply is:
    (a) Advertising and sales promotion
    (b) Development of complimentary products
    (c) Backlogging
    (d) Hiring and lay off of employees depending on the situation.

73. The first stage of Production control is:
    (a) Dispatching
    (b) Scheduling
    (c) Routing
    (d) Triggering of production operations and observing the progress and record the deviation.

74. The act of releasing the production documents to production department is known as:
    (a) Routing
    (b) Scheduling
    (c) Expediting
    (d) Dispatching.

75. One of the important production documents is:
    (a) Design sheet of the product
    (b) List of materials
    (c) Route card
    (d) Control chart.

76. One of the important charts used in Programme control is:
    (a) Material chart
    (b) Gantt chart
    (c) Route chart
    (d) Inspection chart.

77. The way in which we can assess the efficiency of the production plant is by:
    (a) Efficient dispatching

(b) By manufacturing a good product

(c) By comparing the actual performance with targets specified in the specified programme

(d) By efficient production planning.

78. Production control concerned with:

(a) Passive assessment of plant performance

(b) Strict control on labours

(c) Good materials management

(d) Good product design.

79. When work centers are used in optimal sequence to do the jobs, we can:

(a) Minimise the set up time

(b) Minimse operation time

(c) Minimise the break down of machines

(d) Minimise the utility of facility.

80. The act of going round the production shop to note down the progress of work and feedback the information is known as:

(a) Follow up

(b) Dispatching

(c) Routing

(d) Trip card.

81. One of the activities of expediting is:

(a) To file the orders in sequence

(b) To decide the sequence of operation

(c) To record the actual production against the scheduled production

(d) To examine the tools used in production.

82. 'Z' chart is a chart used in:

(a) Programme control

(b) Job control

(c) Cost control

(d) Quality control.

83. Z-chart can be used to show:

(a) Process used in production

(b) Quality level of the product

(c) Both the plan and the performance, and deviation from the plan

(d) To show cost structure of the product.

84. Computers are used in Production control in this area:

(a) Follow-up activity

(b) To control labour

(c) To disseminate information

(d) Loading, Scheduling and Assignment works.

85. The following establishes time sequence of operations:

(a) Routing

(b) Sequencing

(c) Scheduling

(d) Dispatching

86. Arrangement of machines depending on sequence of operations happens in:

(a) Process Layout

(b) Product Layout

(c) Hybrid Layout

(d) Group Technology Layout.

87. Linear Programming is a technique used for determining:

(a) Production Programme

(b) Plant Layout

(c) Product Mix

(d) Manufacturing sequence.

88. Issuing necessary orders, and taking necessary steps to ensure that the time targets set in the schedules are are effectively achieved is known as:

(a) Routing

(b) Dispatching

(c) Scheduling

(d) Inspection.

89. Preventive maintenance is useful in reducing:

(a) Inspection Cost

(b) Shutdown Cost

(c) Cost of pre- mature replacement

(d) Set-up cost of machine

90. One of the important charts used in Programme control is:
    (a) Material chart
    (b) Gantt chart
    (c) Route chart
    (d) Inspection chart.

91. Generally the size of the order for production in Job production is:
    (a) Small
    (b) Large
    (c) Medium
    (d) Very large.

92. One of the product examples for Line Layout is :
    (a) Repair Workshop
    (b) Welding shop
    (c) Engineering College
    (d) Cement.

93. The card which is prepared by the dispatching department to book the labour involved in each operation is :
    (a) Labour card
    (b) Wage card
    (c) Credit card
    (d) Job card.

94. Cost reduction can be achieved through :
    (a) Work sampling
    (b) Value analysis
    (c) Quality assurance
    (d) Supply chain management.

95. Addition of value to raw materials through application of technology is :
    (a) Product
    (b) Production
    (c) Advancement
    (d) Transformation.

96. (Total station time/cycle time × Number of work stations) × 100 is known as
    (a) Line efficiency

(b) Line smoothness

(c) Balance delay of line

(d) Station efficiency

97. The most powerful and popular method for solving linear programming problem is
    (a) Simplex method
    (b) Graphical method
    (c) Transportation method
    (d) Assignment method

98. Most suitable layout for continuous production is
    (a) Line layout
    (b) Process layout
    (c) Group technology
    (d) Matrix layout

Answer:

1.	**2.**	**3.**	**4.**	**5.**	**6.**	**7.**	**8.**	**9.**	**10.**	**11.**	**12.**	**13.**	**14.**	**15.**	**16.**	**17.**	**18.**	**19.**	**20.**
b	**c**	**a**	**a**	**c**	**a**	**b**	**b**	**d**	**b**	**a**	**b**	**a**	**c**	**a**	**c**	**d**	**b**	**a**	**c**
21.	**22.**	**23.**	**24.**	**25.**	**26.**	**27.**	**28.**	**29.**	**30.**	**31.**	**32.**	**33.**	**34.**	**35.**	**36.**	**37.**	**38.**	**39.**	**40.**
b	**b**	**b**	**b**	**d**	**c**	**b**	**c**	**d**	**a**	**b**	**c**	**c**	**d**	**c**	**b**	**b**	**b**	**b**	**c**
41.	**42.**	**43.**	**44.**	**45.**	**46.**	**47.**	**48.**	**49.**	**50.**	**51.**	**52.**	**53.**	**54.**	**55.**	**56.**	**57.**	**58.**	**59.**	**60.**
a	**d**	**a**	**a**	**c**	**d**	**a**	**b**	**c**	**d**	**a**	**b**	**c**	**a**	**a**	**d**	**a**	**c**	**c**	**d**
61.	**62.**	**63.**	**64.**	**65.**	**66.**	**67.**	**68.**	**69.**	**70.**	**71.**	**72.**	**73.**	**74.**	**75.**	**76.**	**77.**	**78.**	**79.**	**80.**
a	**a**	**c**	**d**	**b**	**d**	**c**	**c**	**d**	**a**	**a**	**d**	**d**	**d**	**c**	**b**	**c**	**a**	**a**	**a**
81.	**82.**	**83.**	**84.**	**85.**	**86.**	**87.**	**88.**	**89.**	**90.**	**91.**	**92.**	**93.**	**94.**	**95.**	**96.**	**97.**	**98.**		
c	**a**	**c**	**d**	**c**	**b**	**c**	**b**	**b**	**b**	**a**	**d**	**d**	**b**	**b**	**a**	**a**	**a**		

- **State True or False.**

1. Method Study should precede Work Measurement.
2. Merit Rating is used to determine the cost of a product.
3. Production planning is an essential function in a factory.
4. Training boosts employee morale.
5. A good Materials Handling system always consists of conveyors.
6. Increased productivity leads to cost reduction.

7. Project costs increase as the duration of the project increases.
8. When demand does not exist in the market, we should start Production Incentives.
9. A work stoppage generally reduces the cost of production.
10. No handling is the best handling.
11. It is desirable to conduct work measurement after Method study.
12. Job Evaluation is used to measure absolute job worth.
13. Incentive scheme is introduced by Management with a view to reduce direct labour cost.
14. The increase in productivity can be attributed to the application of Industrial Engineering/Techniques, particularly the work study.
15. Operation process chart incorporates all five symbols.
16. Multiple Activity chart deals with layout problems.
17. Standard performance is the natural rate of working of an average operator when he works tinder proper supervision but without any financial motivation.
18. Allowances for non-availability of materials power failure and breakdown of machines are provided for in the standard time for an operation/job.
19. In carrying-out Job Evaluation studies, point system is the best method.
20. It is justified to consider the effect of working condition both in Work Measurement and Job-Evaluation.
21. Increase in productivity leads to retrenchment of work force.
22. In view of rapid technological advancement we would not concentrate on labour productivity.
23. Piece wage system is a substitute for proper supervision.
24. Personnel Manager has nothing to do with productivity. It is the job of Technical Personnel.
25. Ranking is one of the Job Evaluation Techniques.
26. Results available from work sampling study is not 100% accurate.
27. Since breakdown of Plant and machineries is a random phenomenon, it is impossible to do any work measurement in Maintenance Area.
28. Job Evaluation does not help in performance Rating i. There is no difference between Method study and Value Engineering.
29. Two-handed process chart is the most suitable Recording Technique in Electronics Assembly Industry.
30. Project cost increases as the duration of the project increases.
31. With increase in lot size the setup cost per unit decreases, whereas the inventory carrying cost increases.
32. If the total float value is zero, it means the resources are just sufficient to complete the activity without delay.
33. A special purpose Machine Tool performs only a limited number of specialised operations with great speed and precision.
34. Strikes and lock-out are controllable factors affecting Capacity Planning.

35. Incentives are substitute for lower wages.
36. Linear Programming does not consider uncertainties
37. Depending on the need, the maintenance activity may be centralized or decentralized.
38. In general, long-range forecasting is more useful in production planning.
39. A work stoppage generally reduces the cost of production.
40. There is a limit beyond which labour productivity cannot be improved.
41. When demand does not exist in the market, we should start Production Incentives.
42. Breakdown maintenance doesn’t require use of standby machines.
43. Activity Sampling is not a technique of Job Evaluation.
44. A good plant layout is one of the factors in effective utilization of labour.

Answer:

1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
T	**F**	**T**	**T**	**F**	**T**	**T**	**F**	**F**	**T**	**T**	**F**	**F**	**T**	**T**
16	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
F	**F**	**F**	**T**	**T**	**F**	**F**	**F**	**F**	**T**	**T**	**F**	**F**	**F**	**T**
31	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**	**40**	**41**	**42**	**43**	**44**	
T	**T**	**T**	**F**	**F**	**T**	**T**	**F**	**F**	**T**	**F**	**F**	**T**	**T**	

- **Fill up the blanks**

1. Statistical analysis is used to determine the optimum policy of __________ maintenance.
2. Watch and ward personnel are responsible for __________ aspects in a factory.
3. General purpose machine are less prone to __________ .
4. The pattern shop in a factory should ideally be near the __________ .
5. Factor Comparison is a method of __________ .
6. Taylor originated the idea of __________ relationships in an organisation.
7. __________ cannot be delegated.
8. Ergonomics is another name for __________.
9. Gantt chart is used for __________ control.
10. __________ focuses on such areas as inventory goals and wages budgets.
11. IBFS is optimal and unique when all numbers in the __________ are non-negative.
12. The investment on machines in a straight line layout is __________ than the investment on machines in a functional layout.
13. To evaluate the work done by preventive maintenance, __________ is derived at from the total time of stoppage of the machine for scheduled and unscheduled maintenance work.

14. In linear programming, the word ‘linear’ establishes certain relationships among different _________ .
15. _________ is the interval between placing an order for a particular item and its actual receipt.
16. Product is a combination of potential utilities for a _________ .
17. A jig contains a device for guiding the _________ .
18. Machines are purchased or replaced to _________ the productive capacity.
19. _________ can be determined using the Northwest Corner Rule.
20. A _________ is an appliance which holds the work when it is machined.
21. _________ systems replace human beings to read data from products and documents and interpret the data.
22. The user’s expectation method of _________ provides a subjective feel of the market.
23. _________ control is typically found wherever a particular bottleneck machine exist in the process of manufacturing.
24. General purpose machines are less prone to _________.

Answer:

1.	preventive	**2.**	security
3.	obsolescence	**4.**	foundry
5.	job evaluation	**6.**	functional
7.	responsibility	**8.**	human engineering
9.	production	**10.**	Short-range planning
11.	Net Evaluation Table	**12.**	Higher
13.	Down time	**14.**	Variables
15.	Lead time.	**16.**	Consumer.
17.	Tools.	**18.**	Increase
19.	IBFS	**20.**	Fixture
21.	Barcode	**22.**	Sales forecasting
23.	Load	**24.**	Obsolescence

SECTION-B

Strategic Management

Introduction

8

This Module Includes

Introduction

SLOB Mapped against the Module

1. To analyse the dynamics of national and global business environment in order to assess the potential impact of changes on existing strategies and risks and challenges.
2. To gain a comprehensive view and ability towards achieving the overall organisational vision, mission, always remaining in search of excellence for value creation and high ESG score.

Module Learning Objectives:

The term strategy is often used synonymously as a plan which is not correct. The term 'strategy' can be used for such decisions which adhere to the characteristics of a strategy. The terms 'strategy' and 'strategic management' have different meaning altogether. In order to have a fair understanding of strategic management as a subject, it is very important that the students must be conceptually correct. The module tries to provide an insight in to the following areas:

- Meaning of the term 'strategy'.
- The characteristic features of a strategic decision.
- The strategy making process.
- Organisation objectives vis-a vis individual objectives.
- The concept of strategic leadership.
- The balancing of financial objectives with strategic objectives. (Balanced Score Card)

Introduction to Strategy and Strategic Management

8.1

Strategy is a set of goal-directed actions a firm takes to gain and sustain superior performance relative to competitors. To achieve superior performance, companies compete for resources. A strategy is good when it enables a firm to achieve superior performance. It consists of three elements

- a diagnosis of the competitive challenge
- a guiding policy to address the competitive challenge
- a set of coherent actions to implement a firm's guiding policy.

Strategic managers should remember that strategy is neither about making great statements nor being able to face a competitive challenge. People casually refer to a host of different policies and initiatives as some sort of strategy: pricing strategy, internet strategy, alliance strategy, operations strategy, IT strategy, brand strategy, marketing strategy, HR strategy, etc. All these elements may be a necessary part of a firm's functional and global initiatives to support its competitive strategy, but these elements are not sufficient to achieve competitive advantage.

- A firm's competitive advantage is always relative, not absolute.
- To assess competitive advantage, we compare firm's performance to a benchmark that is, either the performance of other firms in the same industry or an industry average.
- A firm that achieves superior performance relative to other competitors in the same industry or the industry average has a competitive advantage.
- A firm that is able to outperform its competitors or the industry average over a prolonged period has a sustainable competitive advantage.
- If a firm underperforms its rivals or the industry average, it has a competitive disadvantage.
- Two or more firms that perform at the same level have competitive parity.
- An effective strategy requires that strategic trade-offs be recognized and addressed—for example, between value creation and the costs to create the value.

The key to successful strategy is to combine a set of activities to stake out a unique strategic position within an industry.

Competitive advantage has to come from performing different activities or performing the same activities differently than rivals are doing. Ideally, these activities reinforce one another rather than create trade-offs. Since clear strategic positioning requires trade-offs, strategy is as much about deciding what not to do, as it is about deciding what to do. Because resources are limited, managers must be careful while considering their strategic choices in the quest for competitive advantage.

Trying to be everything to everybody will likely result in inferior performance. In addition, operational effectiveness, marketing skills, and other functional expertise all strengthen a unique strategic position. Those capabilities, though, do not substitute for competitive strategy.

Finally, strategy is not just the preserve of top management.

- Middle and lower level managers have to work within their organisation's strategy, meeting the objectives set by the strategy and observing the constraints.
- Managers have to communicate strategy to their teams, and will achieve greater performance from them the more convincing they are in interpreting it. Indeed, middle and lower-level managers can increasingly play a part in shaping strategy.

An important implication for the strategic leader is the recognition that effective corporate governance and solid business ethics are critical to gaining and sustaining competitive advantage. Governance and ethics are closely intertwined in an intersection of setting the right organisational core values and then ensuring compliance. A variety of corporate governance mechanisms can be effective in addressing the principal-agent problem. These mechanisms tend to focus on monitoring, controlling, and providing incentives, and they must be complemented by a strong code of conduct and strategic leaders who act with integrity. Corporate governance is a system of mechanisms to direct and control an enterprise in order to ensure that it pursues its strategic goals successfully and legally. Corporate governance is about checks and balances and about asking the tough questions at the right time.

Business ethics are an agreed-upon code of conduct in business, based on societal norms. Business ethics lay the foundation and provide training for "behaviour that is consistent with the principles, norms, and standards of business practice that have been agreed upon by society." These principles, norms, and standards of business practice differ to some degree in different cultures around the globe. But a large number of research studies have found that some notions such as fairness, honesty, and reciprocity are universal norms. As such, many of these values have been codified into law.

Law and ethics, however, are not synonymous. This distinction is important and not always understood by the general public. Staying within the law is a minimum acceptable standard. A note of caution is therefore in order. A manager's actions can be completely legal, but ethically questionable.

Strategy

The term strategy is derived from the Greek word *strategia*, meaning "generalship'. Although the word is Greek, yet the concept has its origins from the classic, *The Art of War,* written by Sun Tzu written about 500 BC. This is regarded as the first methodical documentation on strategy. A strategy of an organisation provides the basic framework thorough which the organisation will achieve its mission and objectives. The sole objective of a strategy is to provide competitive advantage.

Strategy may be defined as the direction and scope of an organisation over the long term, which achieves advantage for the organisation through the configuration of resources within a changing environment and to fulfill stakeholder expectations.

The following are some of the characteristics of strategy or strategic decisions.

- Strategy is likely to be concerned with the long term direction of an organisation.
- Strategic decisions are normally about trying to achieve some advantage for the organisation over competition.
- Strategic decisions are concerned with the scope of the organisation's activities.
- Strategy can be seen as matching the resources and activities to the environment in which it operates.
- Strategy can be seen as stretching an organisation's resources and competences to create new opportunities or to capitalise on them.
- Strategies may require major resource changes for an organisation.

- Strategic decisions are likely to affect operational decisions.
- The strategy of an organisation is affected not only by environmental forces and resource availability but also by the values and expectations of those who have power in and around the organisation.

From the characteristics one can easily understand the consequences that are likely to arise from the strategic decisions. The following are the consequence of the characteristics of strategy or strategic decisions:

- Strategic Decisions are likely to be complex in nature.
- Likely to be made in situations of uncertainty.
- Likely to demand an integrated approach.
- Manage change relationships and networks outside the organisation.
- Strategic Decisions will very often involve change in organisations.

A typical business firm usually considers three types of strategy

- **Corporate strategy:** It is concerned with the overall purpose and scope of an organisation and how value will be added to the different parts (business units) and product lines of the organisation. Corporate strategies typically fit within the three main categories of stability, growth and retrenchment. Decisions include investment in diversification, vertical integration, acquisitions, new ventures, the allocation of resources between the different businesses of the firm and divestments.
- **Business strategy:** It is about how to compete successfully in particular markets. It emphasises improvement of the competitive position of a organisation's products or services in the specified industry or market segment served by that business unit. These strategies fit within the two overall categories namely, competitive and cooperative strategies.
- **Functional strategy or Operational Level Strategy:** It is concerned with how the component parts of an organisation deliver effectively the corporate and business level strategies in terms of resources, processes and people. It is concerned with developing and nurturing competence to provide a business unit with a competitive advantage. These strategies are taken at the functional level directed towards maximising resource productivity.

It may be mentioned that organisations use all the three types of strategies simultaneously. The term 'hierarchy of strategy' is commonly used to explain the nesting of one strategy within another so that they complement and support one another. It also refers to the grouping of strategies by level in the organisation. Functional strategies support business strategies, which in turn support the corporate strategy.

Solved Case 1

Red oceans vs. Blue Oceans

Red oceans represent all the industries that are currently in existence and are the known market space. In the red oceans, industry boundaries are defined and accepted, and the competitive rules of the game are known. Here companies try to outperform their rivals to grab a greater share of product or service demand. As the market space gets crowded, prospects for profits and growth are reduced. Products become commodities or niche, and cutthroat competition turns the ocean bloody; hence, the term "red oceans".

In a red ocean market or a red ocean strategy, there is a concentrated market and will be highly competitive. These are normally found by the small but unpopular market. In a red ocean market, the competition would normally be high and the existing companies compete with each other using competitive methods.

One of the examples of a red ocean company can be different automobile companies. All the various companies are competing with each other to solve the same problem or the demand faced by the consumers. A red ocean market is highly competitive and would be riskier for a new company especially a startup.

The concept of Blue Ocean Strategy was first coined by W. Chan Kim and Renee Mauborgne in their book, Blue Ocean Strategy: How to Create Uncontested Market Space and Make the Competition Irrelevant, published in 2004. According to them Blue oceans denote all the industries which are currently not existence and remain unexplored, unknown and untainted by competition. In blue oceans, demand is created rather than fought over. There is ample opportunity for growth that is both profitable and rapid. In blue oceans, competition is irrelevant as the landscape is new and unexplored. Blue ocean has been used here as an analogy to describe the wider, deeper potential of market space that is not yet explored.

A blue ocean strategy is focused more on the new trends and demands of the consumers in creating a new market based on it. Blue oceans are a more unoccupied market and not much known. The blue ocean market is mostly concentrated on providing value and is created based on that.

In the blue ocean strategy, a new product or service is created which is not available in the market which would solve a problem that is already there in the market. The blue ocean market pays a lot of attention to value and innovation aspects. This is what the authors call the reconstructionist view.

Table 8.1 Red Ocean Strategy vs. Blue Ocean Strategy

Red Ocean Strategy Focus on current customers	Blue Ocean Strategy Focus on noncustomers
Compete in existing markets	Create uncontested markers to serve
Boat the competition	Make the competition irrelevant
Exploit existing demand	Create and capture new demand
Make the value-cost trade-off	Break the value-cost trade-off
Align the whole system of a firm's activities with its strategic choice of differentation or low cost	Align the whole system of a firm's activities in pursuit of differentiation and low cost.

Source:https://www.linkedin.com/pulse/imagining-new-career-using-blue-ocean-strategy-gopal-a-iyer/?trk=related_artice_Imagining%20a%20New%20Career!%20-using%20the%20Blue%20Ocean%20Strategy_article-card_title

Strategic Management

It refers to a set of managerial decisions and actions that determines the long term performance of an organisation. Originally called 'corporate planning', the shift from 'corporate planning' to what became termed as 'strategic management' was associated with increasing focus on competition as the central characteristic of the business environment and competitive advantage as the primary goal of strategy.

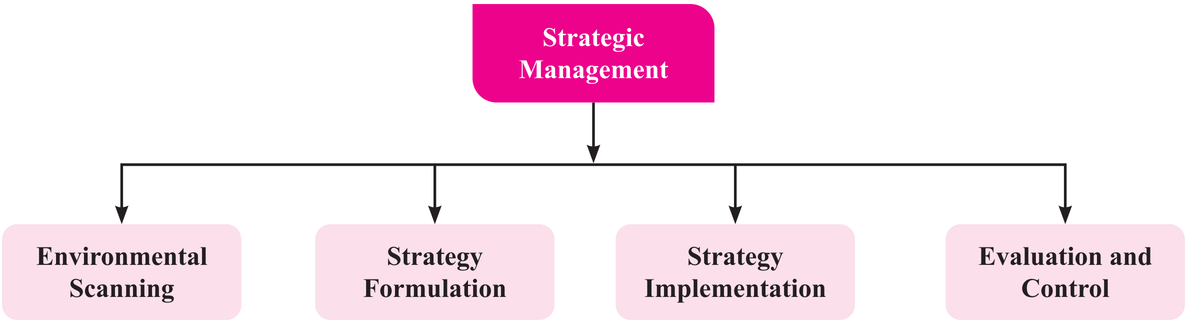


Figure 8.1: Strategic management consists of four basic elements:

- **Environmental scanning:** It refers to the monitoring, evaluating and disseminating of information from the external and internal environments to key people within the organisation. The purpose is to identify the strategic factors both internal and external elements that will shape the future of the organisation. The range of methods and techniques available for environmental scanning is wide. There are formal and systematic techniques as well as intuitive methods available. The techniques are single variable extrapolation, theoretical limit envelopes, dynamic modes, mapping, multivariate interaction analysis, unstructured expert opinion, structured expert opinion, structured inexpert opinion and unstructured inexpert speculation.

- **Strategy Formulation:** It refers to the development of long range plans for the effective management of environmental opportunities and threats, in the light of corporate strengths and weaknesses (SWOT). It includes defining the mission, setting objectives, developing strategies and setting policy guidelines.

- **Strategy Implementation:** It is the process by which strategies and policies are put into practise though the development of programs, budgets and procedures. This includes day to day decisions in resource allocation and is typically conducted by the middle and lower level managers with review by the top management. It involves taking actions at the functional, business and corporate levels to execute a strategic plan. Implementation include, for example, putting quality improvement programs, changing the way product is designed, positioning the product differently, market segmentation, expanding through mergers and acquisitions and downsizing the company.

- **Evaluation and control:** It involves the process through which organisational activities and performances are monitored. The actual performances are compared to the desired performances and corrective actions are taken to resolve problems. The process of evaluation and control helps to identify the weakness and lacunae of the previously implemented strategic plan and thereby, stimulates the entire process to begin again.

Alignment of Strategy with Vision, Mission and Culture

8.2

Vision: It is the desired future state of an organisation. It is an aspiration around which a strategist, perhaps a chief executive, might seek to focus the attention and energies of members of the organisation. It is a vividly descriptive image of what a company wants to become in the future. The critical point is that a vision articulates a view of a realistic, credible, attractive future for the organisation, a condition that is better in some important ways that what now exists. Well conceived visions are distinctive and specific to a particular organisation; they avoid generic, feel-good statements.

Product-oriented vision statements define a business in terms of a good or service provided. Customer-oriented vision statements define business in terms of providing solutions to customer needs. Customer-oriented vision statements provide managers with more strategic flexibility than product-oriented missions. To be effective, visions and missions need to be backed up by hard-to-reverse strategic commitments and tied to economic fundamentals.

A number of organisations have summed up their visions in a brief phrase for e.g.:

- **Nike:** 'To bring innovation and inspiration to every athlete in the world.'
- **Scotland Yard:** 'to make London the safest major city in the world.'
- **Dabur:** 'Dedicated to the health and well being of every household.'
- **Infosys:** 'To be a globally respected organisation that provides best-of- breed business solutions, leverage technology, delivered by best- in class people.'
- **Amazon:** 'To be Earth's most customer-centric company, where customers can find and discover anything they might want to buy online.'
- **Facebook**: 'To make the world more open and connected.'
- **GE:** 'To move, cure, build, and power the world.'
- **Tesla:** 'To accelerate the world's transition to sustainable energy.'
- **Walmart:** 'To be the best retailer in the hearts and minds of consumers and employees.'

The benefits of having a Vision

As mentioned by Azhar (2008) organisation's having a good vision enjoys the following benefits:

- Good visions are inspiring and exhilarating.
- Vision represents a discontinuity, a step function and a jump ahead so that the company knows what it is to be.
- Good vision helps in the creation of a common identity and a shared sense of purpose.
- Good visions are competitive, original and unique. The make sense in the market place as they are practical.

- Good visions foster risk taking and experimentation.
- Good visions foster long term thinking
- Good visions represent integrity: they are truly genuine and can be used to the benefit of the people.
- The visions are customer-oriented.
- Internal stakeholders are invested in defining the vision.
- Organisational structures such as compensation systems align with the firm's vision statement.

Mission: A company's mission describes its purpose and its present business (who we are? what we do? and why we are here?). It announces what the company is providing to society; either a service or a product. A well conceived mission statement defines the fundamental, unique purpose that sets a company apart from other firms of its type and identifies the scope or domain of the company's operations in terms of products offered. A mission statement may also include the firm's values and philosophy about how it does business and treats its employees; however, that is usually better kept as a separate document. In simple terms, a mission statement promotes a sense of shared expectations in employees and communicates a public image to important stakeholder groups in the company's task environment.

The first step in the strategy making process involves selecting the corporate mission and major corporate goals.

The mission statement of an organisation can be either product oriented or customer oriented. A product-oriented business definition focuses on the characteristics of the products sold and the markets served, not on which kinds of customer needs the products are satisfying. Such an approach obscures the company's true mission because a product is only the physical manifestation of applying a particular skill to satisfy a particular need for a particular customer group. A customer –oriented view of a company's business focuses on customer needs rather than a particular product (or solution) for satisfying those needs. The need to take customer-oriented view of a company's business has often been ignored. A broad customer-oriented business definition identifies the ways to safeguard companies from being caught unaware by major shifts in demand. A customer-oriented mission statement also assists companies in capitalizing on changes in their environment.

Mission Statement of some organisations and the nature of the statement:

- **Alibaba:** 'To make it easy to do business anywhere.' (It is a Mission statement, Link: https://www.alibabagroup.com/en-US/about-alibaba)
- **Better World Books:** 'To harness the power of capitalism to bring literacy and opportunity to people around the world.' (It is a Mission Statement, Link: https://press.betterworldbooks.com/about/)
- **Google:** 'To organise the world's information and make it universally accessible and useful.' (It is a Mission statement, Link: https://about.google/)
- **SpaceX:** 'To make human life multi planetary'. (It is a Mission statement - Making Humanity Multiplanetary, Link:https://www.spacex.com/mission/#:~:text=MAKING%20HUMANITY%20MULTIPLANETARY, destinations%20in%20the%20solar%20system.)

Organisational culture: Organisational culture is the 'basic assumptions and beliefs that are shared by members of an organisation, that operate unconsciously and define in a basic taken-for-granted fashion an organisation's view of itself and its environment'. Related to this are taken-for-granted ways of doing things, the routines that accumulate over time. In other words, culture is about that which is taken for granted but none the less contributes to how groups of people respond and behave in relation to issues they face. It therefore has important influences on the development and change of organisational strategy.

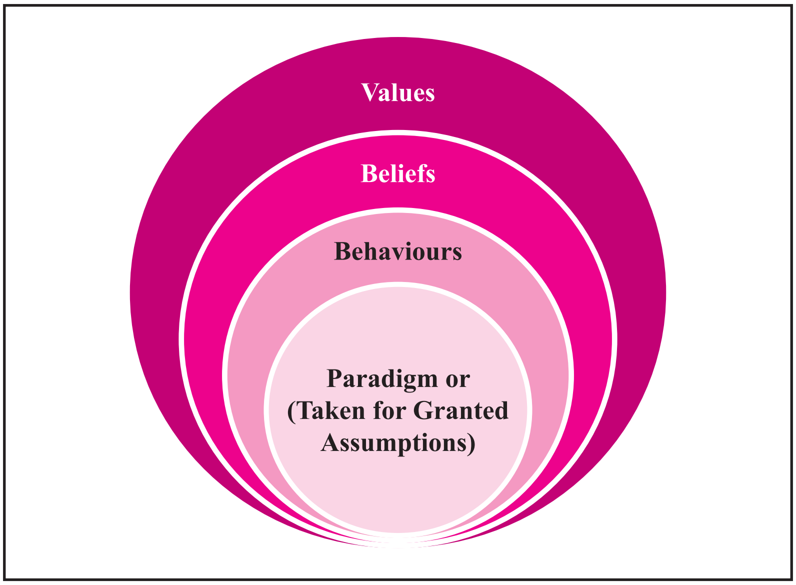


Figure 8.2: Organisation Culture in Four Layers

The culture of an organisation is often conceived as consisting of four layers.

- The values of a company state how managers and employees should conduct themselves? How they should do business? and what kind of organisation they should build to achieve the mission? Values are commonly seen as the bedrock of a company's organisational culture: the set of values, norms, and standards that control how employees work to achieve an organisation's mission and goals. An organisation's culture is commonly seen as an important source of its competitive advantage. Values may be easy to identify in an organisation, and are often written down as statements about an organisation's mission, objectives or strategies Values should not be stated in vague terms such as 'service to the community' or 'honouring equal employment opportunities'
- Beliefs are more specific, but again they can typically be discerned in how people talk about issues the organisation faces; for example, a belief that the company should not trade with particular countries or that professional staff should not have their professional actions appraised by managers. With regard to both values and beliefs it is important to remember that in relation to culture, the concern is with the collective rather than individuals' values and beliefs. Indeed it may be that individuals in organisations have values and beliefs that at times run counter to their organisations, which can give rise to the sort of ethical tensions and problems.
- Behaviours are the day-to-day way in which an organisation operates and can be seen by people both inside and outside the organisation. This includes the work routines, how the organisation is structured and controlled and 'softer' issues around symbolic behaviours.
- Taken-for-granted assumptions are the core of an organisation's culture. They are the aspects of organisational life which people find difficult to identify and explain. Here they are referred to as the organisational paradigm. The paradigm is the set of assumptions held in common and taken for granted in an organisation.

Culture's influence on strategy

The taken-for-granted nature of culture is what makes it centrally important in relation to strategy and the management of strategy. There are two primary reasons for this:

- Managing culture: Because it is difficult to observe, identify and control that which is taken for granted, it is difficult to manage. This is why having a way to analyse culture so as to make it more evident is important.
- Culture as a driver of strategy: Organisations can be 'captured' by their culture and find it very difficult to change their strategy outside the bounds of that culture. Managers, faced with a changing business environment, are more likely to attempt to deal with the situation by searching for what they can understand and cope with in terms of the existing culture.

Ethical behaviour

To foster ethical behaviour, businesses must build an organisation culture that places a high value on ethical behaviour. Three actions are particularly important.

- Firstly, businesses must explicitly articulate values that place a strong emphasis on ethical behaviour. Many companies now do this by drafting a code of ethics, a formal statement of the ethical priorities to which a business adheres.
- Secondly, having articulated values in a code of ethics or some other document, it is important that leaders in the business give life and meaning to those words by repeatedly emphasizing their importance and then acting on them. This means using every relevant opportunity to stress the importance of business ethics and making sure that key business decisions not only make good economic sense but also are ethical. Many companies have gone a step further and hired independent firms to audit them and make sure that they are behaving in a manner consistent with their ethical codes.
- Finally, building an organisation culture that places a high value on ethical behaviour requires incentive and reward systems, including promotional systems that reward people who engage in ethical behaviour and sanction those who do not.
- Ethical core values underlay the vision statement to ensure the stability of the strategy, and thus lay the groundwork for long-term success. Ethical core values are the guard rails that help keep the company on track when pursuing its mission and its quest for competitive advantage.

Goals:

Well construed goals denote what an organisation hopes to accomplish in a future period of time. They represent future state of outcome of effort put in now. The set of goals that an organisation sets addresses a wide range of financial and non financial issues. Goals are close-ended attributes which are precise and expressed in specific terms.

Objectives:

Objectives form the basis of the functioning of an organisation. It is the setting of strategic objectives that the strategic vision of a firm into a specific performance targets. Objectives play a very important role in the organisation. They define the organisation's relationship with the environment, help an organisation pursue its vision and mission, provide the basis for strategic decision making and provide the standards for performance appraisal.

Objectives are defined as the ends that state specifically how the goals shall be achieved. They are concrete and much specific compared to goals and are open ended attributes that denote the future states or outcomes. Objectives should possess certain desirable characteristics in order to be effective. They are as follows:

- **Specific:** The first step towards setting objectives is to specify what the company wants to achieve. This involves answer to five specific set of questions namely, what the organisation wants to achieve? Why the company wants to achieve? Who are being involved in the process? Where it wants to achieve and which are the resources and constraints that needs to be identified? Specific objectives are more likely to lead and motivate the managers.

- **Understandable:** The objectives should be such that they are understandable to those who are expected to achieve them. Clarity in objectives helps to avoid ambiguity which in turn helps to achieve the desired results.
- **Measurable:** Objectives should be precise and measurable. There has to be a standard against which they can judge their performance. It is often considered to be a good practice to quantify objectives rather than to state them in qualitative terms. It helps to measure and control the achievement of the objectives with respect to comparable companies in a particular industry and in general.
- **Attainable:** Objectives must be cchallenging but realistic or attainable. They give all employees an incentive to look for ways of improving the operations of an organisation. If an objective is unrealistic in the challenges it poses, employees may give up; an objective that is too easy may fail to motivate managers and other employees.
- **Relevant:** Objectives must be linked to the overall vision and mission of the organisation. There should not be any conflict between the objectives that the management has set with the goals of the organisation. This is a very important task as misalignment between the two can lead to failure in achieving the corporate vision.
- **Time Bound:** Objectives should specify a time period. Time constraints tell employees that success requires an objective to be attained by a given date, not after that date. Deadlines can inject a sense of urgency into objective attainment and act as a motivator. However, not all objectives require time constraints.

The important issues that need to be kept in mind while setting objectives are as follows:

- **Specificity:** Specificity is related to the organisational level for which a set of objectives have been stated. Objectives may be stated at different levels of specificity. At one extreme they might be very broadly stated goals and on the other extreme it may be translated in to performance targets. This issue of specificity may be resolved by stating specificity at different levels of the organisation and prefixing terms such as corporate, general and particular so that they serve the needs of performance and its evaluation.
- **Multiplicity:** The issue of multiplicity arise from the fact that it is rare for an organisation to work on a single objective or a few objectives. Since objectives deal with a large number of functional areas, a large number of them have to be formulated to cover the diverse aspects of the organisation's functioning. It may be mentioned that neither too few nor too many objectives are considered realistic. The issue of multiplicity takes into account the number and types of objectives that are being set.
- **Periodicity:** Objectives may be set for different time frame. It is possible to set long term, medium term and short term objectives. Normally organisations determine objectives for the long term and the short term. These different time frame of objectives need to be integrated with each other in order to achieve the desired result. Long term objectives tend to be general in nature as the outcomes tend to be less certain. On the other hand short term objectives tend to be more specific and comprehensive given the certainty involved in it.
- **Verifiability:** The issue of verifiability revolves around the question of deciding whether an objective has been met or not. Moreover, linked to verifiability is the concept of quantification. A definite way to measure an objective is to quantify it. In cases where objectives cannot be quantified, qualitative objectives may be set. Qualitative objectives may require some value judgements of experts from within and outside the organisation.
- **Reality:** It is often found that organisations have two set of objectives namely, official and operative. While the official objectives are those which the organisation professes to attain, the operative objectives are those which they seek to attain in reality. For example developing human resource is the official objective of most of the organisations. However to determine whether it is the operative objective will depend on the amount of

resource allocation that has been made towards the development of human resource.

- **Quality:** The capability of an objective to provide a specific direction and a tangible basis for evaluating performance determines the quality of an objective. For example stating that "to increase revenue" is considered to be a bad objective as it lacks the element of measurability. If the same objective is rephrased as "to increase the revenue by 30% in the next 6 months and thereafter increase it by 40%, maintainable for the next two years" can be considered to be a good objective.

Solved Case 2

Tesla's Secret Strategy

IN 2017, TESLA INC.— an American manufacturer of all-electric cars—boasted a market capitalization1 of over $60 billion, an appreciation of more than 1,400 percent over its initial public offering price in 2010. How can a California startup achieve a market valuation that exceeds that of GM, the largest car manufacturer in the world, making some 10 million vehicles a year? The answer: Tesla's Secret Strategy. Elon Musk, Tesla's co-founder and CEO, explained the start-up's master plan: 1. Build sports car. 2. Use that money to build an affordable car. 3. Use that money to build an even more affordable car. 4. While doing above, also provide zero-emission electric power generation options. In 2008, Tesla introduced its first car: the Roadster, a $110,000 sports coupe with faster acceleration than a Porsche or a Ferrari. Tesla's first vehicle served as a prototype to demonstrate that electric vehicles can be more than mere golf carts. Tesla thus successfully completed Step 1 of the master plan. In Step 2, after selling some 2,500 Roadsters, Tesla discontinued its production in 2012 to focus on its next car: the Model S, a four-door family sedan, with a base price of $73,500 before tax credits. The line appeals to a somewhat larger market and thus allows for larger production runs to drive down unit costs. The Model S received an outstanding market reception. It was awarded not only the 2013 Motor Trend Car of the Year, but also received the highest score of any car ever tested by Consumer Reports (99/100). Tesla manufactures the Model S in the Fremont, California, factory that it purchased from Toyota. By the end of 2016, it had sold some 125,000 of the Model S worldwide. Hoping for an even broader customer appeal, Tesla also introduced the Model X, a crossover between an SUV and a family van with futuristic falcon-wing doors for convenient access to second- and third-row seating. The $100,000 starting sticker price of the Model X is quite steep, however; thus limiting mass-market appeal. Technical difficulties with its innovative doors delayed its launch until the fall of 2015. Tesla has now reached Step 3 of its master plan. In 2017, Tesla delivered the company's newest car: the Model 3, an all-electric compact luxury sedan, with a starting price of $35,000. Tesla had received over 500,000 pre orders. This customer enthusiasm amounted to $500 million in interest free loans for Tesla. The Model 3 was slated for delivery by late 2017. Tesla hoped to sell 500,000 total vehicles by the end of 2018. To accomplish this ambitious goal, Musk also promised that Tesla would increase its annual production from 50,000 in 2015 to 1 million vehicles a year by 2020. Step 4 of Musk's master plan for Tesla aims to provide zero-emission electric power generation options. To achieve this goal, Tesla acquired Solar City, a solar energy company, for more than $2 billion in the fall of 2016. This joining creates the world's first fully integrated clean-tech energy company by combining solar power, power storage, and transportation. A successful integration of Tesla and Solar City, where Musk is also chairman and an early investor, would allow completion of Step 4 of Tesla's master plan.

Source: Rothaermel, F. T. (2019). Strategic Management. 4th Edition, McGraw-Hill Education, pgs-5- 6

A. What was the vision of the Tesla Inc.? How is Tesla trying to achieve its mission?

Tesla was founded with the vision to "accelerate the world's transition to sustainable transport."

To accomplish this mission, Tesla is building zero-emission electric vehicles that are attractive and affordable. Beyond achieving a competitive advantage for Tesla, Musk is working to set a new standard in automotive technology. He hopes that zero-emission electric vehicles will one day replace gasoline-powered cars. Tesla's competitive challenge is sizable: To succeed it must manufacture attractive and affordable vehicles using its new technology, which will compete with traditional cars running on gasoline. It also needs the required infrastructure for electric vehicles, including a network of charging stations to overcome "range anxiety" by consumers; many mass-market electric vehicles cannot drive as far on one charge as gasoline-powered cars can with a full tank of gas. Gas stations can be found pretty much on any corner in cities and every couple of miles on highways.

B. Explain the mission of the Tesla Inc.?

Tesla is investing billions of dollars to equip its car factory in California with cutting-edge robotics and to build the Giga factory producing lithium-ion batteries in Nevada. These investments by Tesla are examples of strategic commitments because they are costly, long-term, and difficult to reverse. They are clearly supporting Tesla's vision to accelerate the world's transition to sustainable transport. Tesla hopes to translate this vision into reality by providing affordable zero-emission mass-market cars that are the best in class, which captures Tesla's mission.

C. How does Tesla address the competitive challenge?

To address the competitive challenge, Tesla's current guiding policy is to build a cost competitive mass-market vehicle such as the new Model 3. Tesla's formulated strategy is consistent with its mission and the competitive challenge identified. It also requires significant strategic commitments such as Tesla's $5 billion investment in a new lithium-ion battery plant in Nevada, the so-called Giga factory. Batteries are the most critical component for electric vehicles. To accomplish this major undertaking, Tesla has partnered with Panasonic of Japan, a world leader in battery technology. To achieve its massive scale-up in Model 3production, Tesla invested over $2 billion in a new manufacturing facility.

D. Customer-oriented visions also frequently change over time – Explain this statement in the context of Tesla Inc.

When Telsa was founded in 2003, its mission was to accelerate the world's transition to sustainable transport. Over the last decade or so, Tesla completed several steps of its initial master plan, including providing zero emission electric power generation options, through the acquisition of the Solar-City. Tesla, therefore, no longer views itself as a car company but as a fully integrated clean-tech company. To capture this ambition more accurately Tesla changed its vision to accelerate the world's transition to sustainable energy. To reposition Tesla as an integrated clean-tech energy company, in 2017, Tesla changed its official name from Tesla Motors to Tesla, Inc.

E. How does TESLA become successful auto manufacturing start-up in the United States?

Tesla's manufacturing process was highly automated, with extensive use of 8- to 10-foot-tall red robots. Each robot had a single, multi jointed arm. While typical auto factory robots perform only one function, Tesla's robots perform up to four tasks: welding, riveting, bonding, and installing a component. Eight robots might work on a single car at each station of the assembling line in a choreographed pattern. The robots produce up to 83 cars a day and can be reprogrammed to produce the Model X on the same assembly line.

Musk saw the franchise-dealership arrangements that U.S. car companies use to sell cars as an expensive, margin-killing model. Furthermore, selling an electric vehicle is more complicated than selling an internal combustion vehicle. Because consumers are less familiar with electric vehicles, they required more explanation about the electricity costs, service issues, potential resale value issues, and more. Musk thus chose to sell direct to consumers with boutique-like stores in upscale shopping malls where sales people could provide high-touch service and answer customer questions without using high-pressure sales tactics. The company also sold direct to consumers on the Internet.

Tesla spends no money on advertising, nor does it have any plans to hire advertising agencies or run ads in the future. Its in-house marketing team has only seven people on staff, and an internal team runs the website. Nissan, by contrast, spent $25 million advertising the Leaf in 2012. According to Tesla spokesperson, "Right now, the stores are our advertising. We're very confident we can sell 20,000 plus cars a year without paid advertising …It may be something we'll do years down the road. But it's certainly not something we feel is crucial for sales right now.

F. What are the competitive challenges faced by TESLA?

In order to succeed in the all-electric -car segment TESLA must manufacture attractive and affordable vehicles using its new technology, which will compete with traditional cars running on gasoline. It also needs the required infrastructure for electric vehicles, including a network of charging stations to overcome "range anxiety" by consumers; many mass-market electric vehicles cannot drive as far on one charge as gasoline-powered cars can with a full tank of gas. Gas stations can be found pretty much on any corner in cities and every couple of miles on high ways. In this context, Tesla must build zero-emission electric vehicles that are attractive and affordable. Beyond achieving a competitive advantage for Tesla, Musk is working to set a new standard in automotive technology. He hopes that zero-emission electric vehicles will one day replace gasoline-powered cars.

Source: Rothaermel, F. T. (2019). Strategic Management. 4th Edition, McGraw-Hill Education.

Objectives of Strategic Management

8.3

The term strategic management underlines the importance of managers with regard to strategy. Strategies do not happen just by themselves. Strategy involves people, especially the managers who decide and implement strategy. The strategic management role is different in nature from other aspects of management. An operational manager is most often required to deal with problems of operational control, such as the efficient production of goods, the management of a sales force, the monitoring of financial performance or the design of some new system that will improve the level of customer service. These are all very important tasks, but strategic management involves a greater scope than that of any one area of operational management.

Strategic management is concerned with complexity arising out of ambiguous and non-routine situations with organisation wide rather than operation-specific implications. This is a major challenge for managers who are used to managing on a day-to-day basis the resources they control. It can be a particular problem because of the background of managers who may typically have been trained, perhaps over many years, to undertake operational tasks and to take operational responsibility.

The objectives of strategic management may be listed as under:

- To identify opportunities and adapt resources to exploit the opportunities created.
- To create opportunities by stretching the resources and competences of the organisation and capitalise them.
- To help managers to understand the key relationships among actions, context, and performance by providing the conceptual frameworks.
- To help an organisation enjoy competitive advantage.
- To sustain and improve the competitive position by the deployment and acquisition of appropriate resources and by monitoring and responding to environmental changes.
- To monitor and remain responsive to the demands of key stakeholders.
- To identify the critical success factors and meet the needs and wants of the customers.
- To avoid failure by focusing on the building blocks of competitive advantage (superior efficiency, superior quality, superior innovation and superior responsiveness to customers), instituting continuous improvement and learning, tracking the best industrial practices and using benchmarking.
- To overcome inertia and accept the changes in the ever-changing environment to remain competitive and at times to survive.
- To develop a creative and innovative attitude and to think strategically.

Organisational Genomics

8.4

Genomics is the study of all of a person's genes (the genome), including interactions of those genes with each other and with the person's environment. The organisation of modern corporations helps in interaction with stakeholders. A stakeholder is any person or group associated with the organisation that has a stake in the organisation's output. Corporations face a massive challenge in trying to organise, communicate and respond to all of their different stakeholders. The most efficient way for corporations to interact with each different stakeholder group is to establish boundary-spanning departments, which are offices within an organisation that interact across boundaries that divide the company between different stakeholders. Department of Public Affairs, investor relations, customer relations, community relations, etc. are some of the examples of boundary- spanning departments. All managers and employees need to be aware of how people behave in order to provide the best working environment.

Organisational behaviour is about how people may be motivated to work together in more effective ways. The interaction required to direct a group toward a set of common goals is called organisational communication. An effective and efficient communication system requires managerial proficiency in delivering and receiving messages. A manager must discover various barriers to communication; analyse the reasons for their occurrence and take preventive steps to avoid those barriers. Thus, the primary responsibility of a manager is to develop and maintain an effective communication system in the organisation. So, organisational communication refers to the forms and channels of communication among members of organisations such as corporations, nonprofits or small businesses. Studies have found a strong relationship between the levels of communication in an organisation and job performance and satisfaction. Organisational communication can be formal or informal, flow in various directions and make use of various media.

A positive attitude towards work depends on mutual relationships within a workgroup which can be related to the inner and outer system. The outer system is defined by organisation and technologies while the inner system refers to mutual relationships created as a result of business cooperation and living together. Interaction is reflected in mutual activities within the group or outside of it, or an employee's activity related to the integral work environment or any other matter.

One develops many interactions towards people who constitute a workgroup. A person's behaviour, as well as his/her activities in a work environment, depends on the cognitive, emotional, and conative processes. In a work environment, a person performs certain activities which may be observed. Through interaction, communication, and perception, certain feelings develop within one's personality which may be demonstrated publicly or be hidden in verbal and symbolic expressions which can also be interpreted differently from one individual to another. The reason for that is that everyone has an established attitude about a certain type of behaviour and verbal and symbolic meanings.

Employees constantly judge and compare themselves to others in a work environment. Based on those comparisons, they form an opinion of their own worth and abilities. But there is the question of how objectively and to what extent can individuals estimate him/her. It depends on the nature, personality, and mental health of that individual which have to be in accordance with reality and perceiving real-life values.

Incorrect self-estimation can result from underestimating people in the following situations:

- People with lower qualifications;
- People who do not tolerate on a higher social, educational, and financial level;
- People who hold a high opinion of themselves which is not based on facts;
- People who feel inferior;
- People who do a great job even though they conceal their true opinion of themselves.

Strategic Leadership

It is about how to effectively manage a company's strategy making process to create competitive advantage. Strategic leaders must strive towards maximising shareholders value by balancing the profit growth and profitability of the organisation. A strategic leader is seen as an individual upon whom strategy development and change are seen to be dependent. Strategic leaders should possess some key characteristics that can lead to high performance. Some of the key qualities that a strategic leader is expected to have are as follows:

- Strategic leader should be a visionary. He should have a strong sense of direction and a clear and compelling vision of where the organisation should go.
- He should be capable of eloquently communicating this vision to others within the organisation in order to sensitise them and consistently articulate this vision to them until it becomes a part of the organisational culture.
- A good strategic leader must have the ability to identify and articulate the business model the organisation will use to attain the vision. This requires a fit between the organisational strategies with the organisational vision.
- A good strategic leader should demonstrate a sense of commitment towards the vision and the business model through his actions and words.
- He should develop a strong network of both formal and informal sources to remain well informed about whatever is happening in and around the organisation.
- A good strategic leader should be able recognise and empower subordinates to make decisions. This not only acts as a motivator for the subordinates but also relives the leader from being overloaded with responsibilities. In this process of delegation, the strategic leader may delegate many important responsibilities to his subordinates but he will not delegate those which are of critical importance to the success of the organisation.
- A good strategic leader should try to develop a consensus for his ideas among his subordinates rather than attempt to use his authority to force the ideas through.

Emotional Intelligence

In order to estimate someone's psychological capabilities Goleman (1998) used a term called emotional intelligence. Emotional intelligence is a term that Daniel Goleman coined to describe a bundle of psychological attributes that many strong and effective leaders exhibit

- Self-awareness—the ability to understand one's own moods, emotions, and drives, as well as their effect on others.
- Self-regulation—the ability to control or redirect disruptive impulses or moods, that is, to think before acting.
- Motivation—a passion for work that goes beyond money or status and a propensity to pursue goals with energy and persistence.

- Empathy—the ability to understand the feelings and viewpoints of subordinates and to take those into account when making decisions.
- Social skills—friendliness with a purpose.

According to Goleman (1998)

- Self aware and self regulating individuals tend to be more confident and better able to cope with ambiguity and more open to change.
- People respect leaders who are self aware and self regulating.
- People who are self aware recognise their own limitations and being self regulated consider their decisions carefully. These two attributes, self awareness and self regulation, help to elicit the trust and confidence of subordinates.
- Strong motivation exhibited in a passion for work can also be infectious. It motivates subordinates to a great extent to give their best.

Organisational Change

In any business environment, change should happen. It shows one's commitment to the kind of growth and evolution it takes to stay modern, relevant, and competitive. Countless factors make change inevitable. But what kind of change we are thinking about is important. Change can include things like:

- Introducing new software or updating marketing practices
- Updated business processes
- A full-on restructuring
- Leadership changes
- Updated thinking
- New project management tools
- Budget constraints
- Shifts in strategy

These all fall under the umbrella of organisational change.

The term organisational change management refers to a methodology that helps businesses adapt to adjustments of all kinds.

- It helps employees, stakeholders, and project teams prepare and set expectations for coming change.
- It helps businesses roll out and acclimate to change.

There are countless organisational change management (OCM) methods. Each involves a basic series of steps or practices that could be linear or cyclical in approach. Some of the most popular methods include:

- Kotter 8-Step Process for Leading Change: Create → Build → Form → Enlist → Enable → Generate → Sustain → Institute
- McKinsey & Company's 7-S Framework: Style, Skills, Systems, Structure, Staff, and Strategies = Shared Values & Goals
- Kurt Lewin's Change Model: Unfreeze → Change → Refreeze

- ADKAR Model: Awareness → Desire → Knowledge → Ability → Reinforcement
- The Kubler-Ross Model: Shock → Anger → Bargaining → Depression → Acceptance
- Satir Change Management Model: Late Status Quo → Resistance → Chaos → Integration → New Status Quo
- William Bridges' Transition Model: Ending → Neutral Zone → New Beginnings

However, there is no right or wrong in terms of which method to choose. Any method can facilitate smooth transitions and positive change. The best method depends on the organisation and stakeholder needs and preferences. Methods are generally seen as interchangeable.

One of the most popular and widely accepted guiding approaches out there is The Association of Professional Change Management (ACMP) Standard for Change Management. The ACMP Standard includes a definition of practices, processes, tasks, and activities for change management. It also includes guidance for any type of change and generally accepted practices and processes across industries, organisations, and roles. The following are the steps as recommended by ACMP:

- Evaluate Change Impact & Readiness
- Formulate Your Strategy
- Develop Change Management Plans
- Executing Change Management Plan
- Closing the Change Management Effort
- It's important to look at employee involvement during this process.

Organisations can't run successful change management without people's power. That's why companies should involve employees in the organisation's change management process from start to finish, whether through something as involved as an online focus group or simply as a survey. Without employee buy-in, change management can fail. But uninvested stakeholders aren't the only reason organisational change management fails. It also takes a knowledgeable, prepared leadership, and an HR team that is equipped for the process.

Alignment with Individual Level Objective and Organisational Objective

8.5

Personal objectives refer to the job-specific goals of each individual employee. They are important because they communicate to employees what is important and what is expected of them. Managers usually set between five and seven goals per employee using a mix of those that are activity-based such as number of sales calls per week and/or outcome-based measures such as closed sales in dollar amounts. When completed at the individual level, managers may add more objectives specifically designed to maximize team efforts. The goal is to achieve quantity and quality of effort between individuals and the team.

- Employee objectives are ways to measure progress and performance for members of a team.
- These can help employees better understand their roles and help managers guide their teams in achieving important organisational and personal goals.
- Knowing how to write effective objectives can help leaders and team members create a more productive work environment.
- Employee objectives are targets that an employee and their manager agree on to measure the employee's job performance.
- Companies may set new objectives for their employees quarterly, biannually or annually.
- These objectives provide employees with guidance for their responsibilities that contribute to larger company goals.
- Employees and managers periodically review the employee's progress toward achieving their goals.

To create effective objectives, make sure they're specific, measurable, attainable, relevant and time-based. These guidelines are often abbreviated using the acronym SMART. Here are more details regarding the SMART goal framework:

- **Specific:** Specific goal provides the employee with the exact result needed for their performance to be successful. A clear objective can optimize productivity and effectiveness.
- **Measurable:** Successful goals can usually be measured using metrics that determine an employee's success or progress. A quota, for example, is one way to measure an employee's success.
- **Attainable:** Effective goals are often those which are ambitious and also possible to achieve. Consider if and how an employee can attain their objectives with the tools and resources available to them within a specified time frame.
- **Relevant:** A relevant objective contributes to the larger goals of a company. Consider the upward impact of employees achieving certain goals, like how they tie to bigger company strategies like growth.
- **Time Based:** Set realistic timelines for employees to complete their tasks. If a task is ongoing, you might consider your next review as a deadline for achieving objectives.

SMART goals help clarify responsibilities and ensure both manager and employee knows what to expect. They can help develop employees' skills and move goals forward toward larger, higher-level goals.

FAST framework

It was in the year 1954 when Peter Drucker, the great management guru, introduced "management by objectives". Management by objectives according to Drucker is an approach where employees would agree with their boss on a set of goals and work toward achieving those objectives throughout the year. The importance of goal setting and accomplishment of objectives has been the central for managers who follow a well-established set of practices. Traditionally the managers aspired to make their goals SMART, by ensuring they are specific, measurable, achievable, realistic, and time-bound. However, over the past few decades, a handful of leading companies including Google, Intel, etc. have pioneered and refined an alternative approach to harness the power of goals to drive and align action.

The four core principles that underpin effective goal systems can be summarised into the acronym FAST. Goals should be embedded in frequent discussions; ambitious in scope; measured by specific metrics and milestones; and transparent for everyone in the organisation to see. The modern concept views goals to be FAST and not SMART.

Table 8.2 Four Core Principles and their Benefits of FAST

Acronym	Term	Definition	Advantages
F	Frequently discussed	Goals should be frequently discussed in order to see the progress, allocate resources as and when needed, prioritise of initiatives and provide feedback	➢ Gives guidance for important decisions. ➢ Helps employees remain focused on the most important matters. ➢ Links performance feedback to concrete goals. ➢ Evaluates the progress and helps in course corrections.
A	Ambitious	Goals should be challenging or ambitious but not impossible to achieve	➢ Motivates performance of individuals and teams towards goal. ➢ Helps in minimising the risk of downplaying the achievements of the subordinates. ➢ Focuses on the innovative ways to achieve goals.
S	Specific	Goals should be translated into specific metrics so that there is clarity in achieving the goals.	➢ Clearly mentions what the employees are expected to deliver. ➢ Helps in easy identification of deviations from the goals and offers quick course corrections. ➢ Enhances performance of individuals and teams.
T	Transparent	Goals and their achievements should be made public for all employees to see.	➢ Use of peer pressure to perform on goals. ➢ Clearly showcases the activities and contribution of the employees towards goal achievement. ➢ Helps employees understand the agenda of other employees and the teams. ➢ Helps to identify the strategies those are redundant and are not aligned to the overall organisational goals.

Performance objectives

Performance objectives for employees are set so that they can know what is expected of them and understand what they are accountable for. They can be performance-based, or they can be development-led. The following are some of the examples of performance objectives for employees.

- **Productivity:** This has to do with the amount of work that an employee is expected to perform within a specific time. This is one of the most important performance objectives for employees. In the service industry such as banking, this could be the number of clients that a service consultant has assisted. This helps to increase productivity within a business, and it can increase sales and revenue.

- **Quality and efficiency:** This has to do with the manner of performing activities. It takes productivity further to deal with how fast the worker can perform a task. This measure also takes quality into consideration. Not only should the service be fast, but it must be of good quality. This is one of the most vital performance objectives for employees because it makes them pay more attention to the quality of their work which reduces human error while increasing productivity.

- **Education and self-development:** This performance objective for employees considers the needs of workers. It focuses on the goals workers set to develop themselves. It can include things such as an employee learning a new skill, doing a new course or simply job-shadowing someone. This makes workers more valuable due to continuous growth in their respective fields. This also encourages employers to see how committed workers are to their own growth and personal development.

These are some of the performance objectives for employees. They are measured differently from one company to the next. They are also assigned different weightings depending on the industry. These performance objectives for employees must be documented and reviewed constantly.

Employees must also sign off their performance objective contracts to show their commitment to meeting them. Employees are integral part of an organisation so organisations should support them in their personal growth. The work that employees take up must prepare them to meet their individual goals, by enhancing knowledge or building skills. On the other side everyone works to meet the organisational-level goals. The managers and leaders drive performance of employees so that they can achieve the larger goals set at the organisational or business level. However, if these larger goals are not aligned to individual goals, employee motivation will deteriorate after some time.

The reasons why aligning individual goals to organisational goals is important:

- It helps to sustain employee motivation by helping employees measure the impact of their actions. When personal goals are aligned, an individual takes accountability of the tasks in hand. They relate with the contributions they make and measure the success and way forward.

- Aligning goals also help in prioritization of tasks and responsibilities.

- When individuals understand how their personal goals relate to one another and to the larger goals of the organisation, collaboration and team cohesiveness increases.

Balanced Score Card

8.6

Figure 8.3: The balanced scorecard: a framework to translate a strategy into operational terms. Source: Robert S. Kaplan and David P. Norton, ‘‘Using the balanced scorecard as a strategic management system,’’ Harvard Business Review January. February 1996 .: 76.

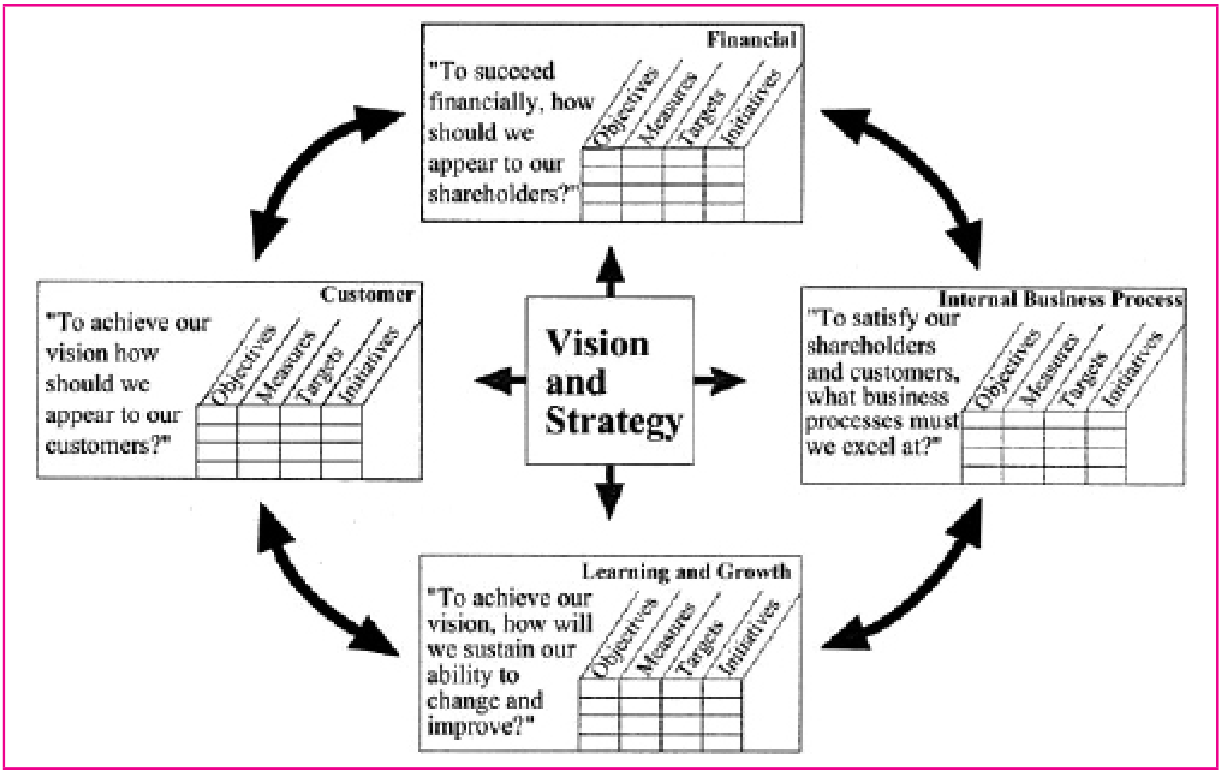


Figure 8.3: The balanced scorecard: a framework to translate a strategy into operational terms

The sole purpose of setting objectives is to convert the vision and mission into specific measurable targets. There are broadly two types of objectives namely, financial and strategic.

- Financial objectives relate to the financial performance targets that the management has established for the organisation to achieve.
- Financial objectives of an organisation can include increasing the annual revenues, annual increase in the earnings per share, profit margins of fixed percent, increased shareholder value, generating internal cash flows, etc.

- Strategic objectives relate to target outcomes that indicate whether a company is strengthening its market standing, competitive position and future business prospects.
- Strategic objectives of an organisation can include winning a certain per cent of market share, achieving lower overall costs than competitors, developing broader, better and deeper technological capabilities than rivals, consistently getting new or improved products to market ahead of the rivals, having stronger national and global sales and distribution capabilities than rivals, etc.

There is a need to balance the financial objectives with the strategic objectives. It is imperative that attaining financial objectives that includes adequate profitability and financial strength is of paramount importance as the organisation's long term health and ultimately its survival will depend on it. However, one cannot ignore the need for accomplishment of strategic objectives as it signals whether the organisations competitive position is on the rise or not. It may be mentioned that one can expect a strong financial performance if the competitive strength and market position is on the rise.

The most widely used method for combining the use of both strategic and financial objectives, tracking their achievement, and giving management a more complete and balanced view of how well as organisation is performing is known as the balanced score card. This is a method for linking financial objectives to specific strategic objectives that derive from a company's business model. It provides a company's employees with clear guidelines about how their jobs are linked to overall objectives of the organisation, so that they can contribute most productively and collaboratively to the achievements of these goals.

The balanced score card was developed by Robert S. Kaplan and David Norton of Harvard Business School. This system tries to do away with the overemphasis on short term financial objectives and tries to improve organisational performance by focusing attention on measuring a wide range of non-financial, operational objectives. Later, the system also tried to incorporate the strategic planning technique.

The balanced score card is a top-down approach to performance management. It starts with the strategic intent and ends with operationally relevant targets. The balance score card model requires an evaluation of organisational performance from four different perspectives.

- **Financial Perspective:** It considers the financial measures such as revenues, earnings, return on capital and cash flow arising out from the strategic intent of the organisation.
- **Customer's Perspective:** This measures the ability of the organisation to provide quality goods and services, effective delivery and overall customer's satisfaction. Customer's perspective includes market share, customer satisfaction measures and customer loyalty.
- **Internal Business Perspective:** The mechanisms through which the performance expectations are achieved are called as internal businesses processes. This provides data regarding the internal business results that have led to financial success and satisfied customers. It is very important to identify the key business processes that should be excelled to meet the organisational objectives and customer satisfaction.
- **Learning and Growth Perspective:** This perspective focuses on the ability of the organisation to manage its business and adapt to changes in the environment. Organisations take on new responsibilities that require its employee to develop new skills and capabilities in order to cope with the changing environment and customer expectations.

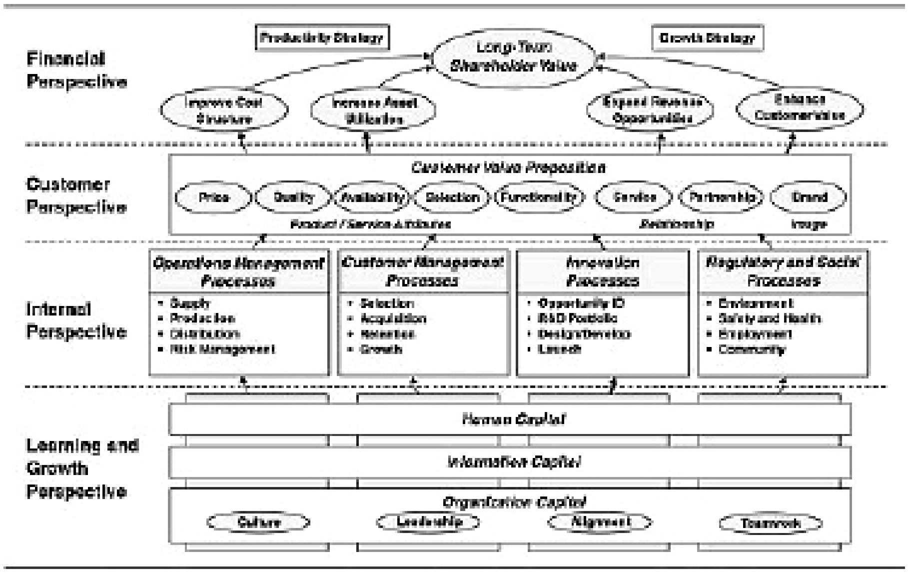


Figure 8.4: Strategy Map Kaplan and Norton

A visual representation of the organisation’s strategy through strategy maps have been used by Kaplan and Norton. In these maps, the four perspectives have been connected to each other in a ‘cause and effect’ fashion thus making clear the relationship of all the strategic objectives to the strategic intent of the organisation.

The balanced score card approach involves the following steps:

- The first step involves establishing the organisation’s strategic intent including the vision and mission.
- In the second step, the design of the balanced score card is determined by identifying the specific measures related to the four perspectives namely; financial, customer, internal and learning or innovation perspective. In this step the specific strategies that should be formulated and implemented to realise the organisation’s vision is also determined.
- The next step involves strategy mapping through identification of organisational activities that are derived from the strategies.
- In the final step, quantitative measures or metrics should be established to measure accurately the performance of the organisation in the specific areas.

EVA – Driven Responsibility Accounting

8.7

Profit is the surplus of revenues over costs available for distribution to the owners of the firm. The transition from accounting profit to economic profit was triggered due to a major problem of accounting profit as it combines two types of returns: the normal return to capital that rewards investors for the use of their capital; and economic profit, which is the pure surplus available after all inputs (including capital) have been paid for. Economic profit represents a purer and more reliable measure of profit that is a better measure of performance. In order to distinguish economic profit from accounting profit, economic profit is often referred to as rent or economic rent.

A widely used measure of economic profit is economic value added (EVA), devised and popularised by the New York consulting firm Stern Stewart & Company.

EVA = Net Operating Profit After Tax (NOPAT) - Cost Of Capital

Cost of capital is calculated as: capital employed multiplied by the weighted average of capital (WACC).

Economic profit has two main advantages over accounting profit as a performance measure.

- First, it sets a more demanding performance discipline for managers. As Stern Stewart's calculations show, many major corporations' apparent profitability disappears once cost of capital is taken into account.
- Second, using economic profit improves the allocation of capital between the different businesses of the firm by taking account of the real costs of more capital intensive businesses. (Grant, 2012)

Solved Case 3

Teach for America: How Wendy Kopp Inspires Future Leaders

Teach for America (TFA) is a cadre of future leaders who work to ensure that underprivileged youth get an excellent education. The non-profit organisation recruits both graduates and professionals to teach for two years in economically disadvantaged communities in the United States. TFA's vision is: One day, all children in this nation will have the opportunity to attain an excellent education. The idea behind TFA was developed by then-21-year-old Wendy Kopp as her college senior thesis (in 1989). Kopp was convinced that young people generally search for meaning in their lives by making a positive contribution to society. The genius of Kopp's idea was to turn on its head the social perception of teaching—to make what could appear to be an unattractive, low-status job into a high-prestige professional opportunity. Kopp works to eliminate educational inequality by enlisting the nation's most promising future leaders in the effort. Thus to be chosen for TFA is a badge of honor. In the first four months after creating TFA, Kopp received more than 2,500 applicants. Her marketing consisted of flyers in dorm rooms. During its first academic year (1990–91), TFA was able to serve five states and reached some 36,000 students. After 25 years, during the 2015–16 academic year, some 20,000 TFA corps members were teaching in 36 states (and Washington, D.C.) and more than 1,000 schools. To date, TFA has reached over 10 million students. To see how all three components—vision, mission, and values—work together, see Exhibit 1.1, which provides a snapshot of aspirations at Teach for America. While initially targeted at college seniors, today, one-third of all TFA corps members applied as graduate students or professionals. In 2015, TFA added 4,100 new teachers to its corps from over 27,300 applications, representing more than 800 colleges and universities throughout the United States. This equates to about 15 percent acceptance, roughly equivalent to the admission rate of highly selective universities such as Northwestern, Cornell, or University of California, Berkeley. TFA's teaching cohort is also much more diverse than the national average: While some 20 percent of teachers nationwide are people of color, about 50 percent of TFA corps members are. TFA corps members receive the same pay as other first-year teachers in the local school district. Most importantly, TFA makes a significant positive impact on students. Some 95 percent of all school principals working with TFA members say these teachers make a positive difference. A study commissioned by the U.S. Department of Education found that students being taught by TFA corps members showed significantly higher achievement, especially in math and science. In 2016, after celebrating its 25th anniversary, TFA CEO Elisa Villanueva Beard recalls that she was inspired to sign up for TFA (when a freshman in high school) by Wendy Kopp's "audacity to believe young people could make a profound difference in the face of intractable problems standing between the ideals of a nation I loved and a starkly disappointing reality; who were bound by a fierce belief that all children, from American Indian reservations in South Dakota to Oakland to the Rio Grande Valley to the Bronx, should have the opportunity to write their own stories and fulfill their true potential

Source: Rothaermel, F. T. (2019). Strategic Management. 4th Edition, McGraw-Hill Education, pgs-12 -13

Describe the vision, mission and values of Teach for America

Vision: One day, all children in this nation will have the opportunity to attain an excellent education.

Mission: Our mission is to enlist, develop, and mobilize as many as possible of our nation's most promising future leaders to grow and strengthen the movement for educational equity and excellence.

Values:

- **Transformational Change:** We seek to expand educational opportunity in ways that are lifechanging for children and transforming for our country. Given our deep belief in children and communities, the magnitude of educational inequity and its consequences, and our optimism about the solvability of the problem, we act with high standards, urgency, and a long-term view.
- **Leadership:** We strive to develop and become the leaders necessary to realize educational excellence and equity. We establish bold visions and invest others in working towards them. We work in purposeful, strategic,

and resourceful ways, define broadly what is within our control to solve, and learn and improve constantly. We operate with a sense of possibility, persevere in the face of challenges, ensure alignment between our actions and beliefs, and assume personal responsibility for results.

- **Team:** We value and care about each other, operate with a generosity of spirit, and have fun in the process of working together. To maximize our collective impact, we inspire, challenge, and support each other to be our best and sustain our effort
- **Diversity:** We act on our belief that the movement to ensure educational equity will succeed only if it is diverse in every respect. In particular, we value the perspective and credibility that individuals who share the racial and economic backgrounds of the students with whom we work can bring to our organisation, classrooms, and the long-term effort for change.
- **Respect & Humility:** We value the strengths, experiences, and perspectives of others, and we recognize our own limitations. We are committed to partnering effectively with families, schools, and communities to ensure that our work advances the broader good for all children.

Source: Rothaermel, F. T. (2019). Strategic Management. 4th Edition, McGraw-Hill Education, pgs-12 -13

British Airways and their strategy

British Airways is a leading global airline. Privatised in 1987, the company enjoyed strong growth and profitability throughout the 1990s. After 2000 BA's fortunes dipped in the face of competition from 'no-frills' operators, government failure to establish Open Skies agreements with the US and the terror attacks in September 2001that led to a slump in demand for air travel. BA's website explains how it developed new strategies in this context:

Vision

'The BA Way' – Service that matters for people who value how they fly Goals/Objectives

The BA Way outlines five over-riding goals with associated measures (in brackets)

1. Profitability, in terms of operating margin (a 10% target)
2. Customer advocacy (the number of customers who recommend BA)
3. Safety and security (the number of customers who feel safe with BA)
4. Respected company (the number of community stakeholders who respect BA)
5. Employee motivation (the number of employees who feel motivated to deliver BA's goals)

Values

The BA Way is based upon five core values: Understanding . . . Focused . . . Cost-conscious . . .Supportive . . . Trustworthy

Strategies

The BA Way provides a high-level statement of strategies:

- To be the best UK-based network
- To understand customers better than competitors
- To develop a powerful brand that people know and trust

- To establish a competitive cost base
- To work together as one team

Competitive Strengths

Within this BA identifies its competitive strengths as:

- A 'full service' airline with a strong brand identity, associated with high standards of service, comfort and safety.
- Clearly defined and well-branded products targeting specific customer segments (e.g. Club World, developed to address the needs of long-haul business travellers).
- Membership of the One World Alliance providing customers with . . . a far more extensive network than BA could provide alone.
- Dominance of national and international slot allocations at London Heathrow airport.
- A modern, flexible and cost-effective aircraft fleet.
- As a listed company, BA must satisfy shareholder expectations, achieving profitability through a combination of service quality and operational efficiency.
- Source: Johnson, G., Scholes, K. and Whittington, R. (2008). *Exploring Corporate Strategy*. 7th Edition. Pearson India. India, pg 14

Solved Case 4

Strategy at Apple

In 2000, Apple Computer held a loyal customer base but was limping along as a relatively minor player in the personal computer market. Launched by Steve Jobs and Steve Wozniak, Apple was one of the pioneers in the industry. Unlike other PC makers that relied on Microsoft's operating system and application software, Apple wrote its own operating system software and much of its application software, which was known as being easy to use. In fact, Apple was the first to introduce software on a low cost personal computer with drop-down menus and a graphical user interface that allowed customers to easily complete a task, such as dragging a file to the trash to delete it. However, Apple's investment in unique software led to high-priced computers and created files that were originally incompatible with those of Microsoft's Windows operating system and Office software suite. As a result, Apple rarely achieved more than about a 5 percent share of the computer market.

That all changed in 2001, however, when Apple entered an entirely new market with the launch of an MP3 portable music player called the iPod. Apple's MP3 player was not the first on the market. A company called Rio had offered an MP3 player for a couple of years before iPod's entry into the market. But iPod quickly took market share from the Rio, for three primary reasons:

- iPod had a mini hard drive that allowed it to hold 500 songs, as opposed to the roughly 15 songs the Rio could hold using flash memory.
- iPod was the first to introduce a "fly wheel" navigation button—the round button that was easy to use and allowed users to quickly scroll through menus and songs.
- iPod was backed with Apple's name and an innovative design

These advantages helped iPod quickly move to industry leadership, despite the fact that an iPod cost 15 to

25 percent more than a Rio. At the time the iPod was launched, it was difficult for most consumers to access digital download of songs legally. Initially, the iPod was snapped up only by a relatively small group of users, mostly teenagers and college students, who were illegally downloading songs through Napster and other free downloading sites. Apple recognized that to grow the market for iPods, it needed to help consumers legally access songs to play on their iPods. As a result, Apple developed software called iTunes, allowing customers to legally download songs. One main reason iTunes was able to provide legal downloads before its competitors was because SteveJobs, as CEO of both Apple and Pixar (the animation movie production company), understood that music companies, like movie companies, were concerned about people pirating their products. So Apple worked with the music companies to sell songs that had been digitized using software that prevented customers from copying the songs to more than a few computers. i Tunes was designed o be easy to use with the iPod. Customers now could easily and legally access songs simply by connecting their iPods to their computers and letting the software do the rest. Even a technology challenged grandparent could do it. But Apple wasn't done with its music player strategy. Apple's experience in the computer business was that other companies could make similar products, often at lower prices. Indeed, while Apple and IBM were the pioneers of the personal computer industry and dominated it during the early years, lower-priced competitors such as Dell, Hewlett-Packard, Lenovo, and ASUS eventually came to dominate the market. Apple realized it needed to prevent easy imitation of its music offering. So it created proprietary software called Fairplay that restricted the use of music downloaded from iTunes to iPods only. That meant consumers couldn't buy a lower-priced MP3 player and use it with iTunes because it was incompatible. If they wanted to use a different MP3 player, they would have to download and pay for music a second time.5 Now Apple has bundled an MP3 player into the i Phone, which makes it more convenient for customers because they don't have to carry two devices. To top it off, Apple did something that no other maker of computers, music players, or any other electronic device company had done. It opened its own stores to sell Apple products. This required that Apple learn how to operate retail stores. The Apple Stores helped Apple create a direct link to its customers, making it easier for consumers to learn about and try out Apple products—and get their products serviced.

As a result of Apple's strategic initiatives, it has built a very secure market position in music players, currently holding over 70 percent of that market. But the battle isn't over. Amazon has entered the industry, offering music buyers unrestricted use of its songs with a subscription to Amazon Music Unlimited. Moreover, other competitors offering music via subscription include e Music, Pandora.com, and Spotify. Users can listen to any song they want for a small monthly subscription fee. The $17 billion music industry is so large that it will continue to attract new competitors who want to dethrone Apple. [https://catalogimages.wiley.com/images/db/pdf/9781119411604.excerpt.pdf]

A. How did Apple enter the music industry and within 10 years become the dominant seller of both songs and music players?

Answer:

Apple's theory of how to gain a competitive advantage in the music download business was to create cool and easy-to-use MP3 players and smartphones that could easily—and legally—download digital songs from a computer through the iTunes store. Apple sought to sustain its advantage by making it difficult for competitor MP3 players or phones to download songs from the iTunes store. The Apple Stores contributed to Apple's advantage by providing a direct physical link to customers that competitors couldn't match. In this particular instance, Apple's plan to gain, and sustain, competitive advantage worked. But there have been other times, such as with the Apple Newton Message Pad (the first handheld computer that Apple sold as a personal digital assistant), that Apple's approach to gaining and sustaining competitive advantage did not work.

B. 'Leaders must choose the industries a company competes in and the specific customer segments or needs it will address within those industries'–What industry, customer segment, and geographic markets have been chosen by Apple?

Answer:

Before iPod, Apple competed only in the computer industry. Its product markets included desktop and laptop computers. Launching iPod and iTunes took Apple into the music industry. Later, when Apple launched the iPhone, it entered the cell phone business.

Apple targets the high-end customer segments within its industries. Its customers want the latest in technology, see themselves as innovators, appreciate design and elegance, and are not price sensitive. It is also important to select geographic markets to serve. Apple competes on a worldwide basis, which allows it to spread heavy research and development costs across its many geographic markets. By contrast, Walmart started by focusing on rural markets, which allowed it to offer lower prices than the "mom and pop" retail stores in small towns

C. After a company chooses the markets in which to compete, it then attempts to offer unique value in those markets. This is often referred to as a company's value proposition – Explain the value proposition of Apple.

Answer:

Apple's unique value is offering iPods (music players), iPhones (smart phones), and iPads (tablets) that are well designed, innovative, easy to use, and have features that competing products don't have ("there's an App for that"). In similar fashion, Starbucks wins through differentiation by offering multiple blends of high-quality coffee in convenient locations.

D. How Apple create barriers to imitation to prevent other companies from offering that same value?

Answer:

By being the first to offer music downloads through its easy- to-use iTunes software, Apple encouraged its customers to store their entire music libraries on iTunes. Designing iTunes so that it wouldn't easily download songs to other music players helped Apple to prevent competing MP3 players from taking market share from iPod. Of course, Apple's brand image and its Apple Stores also prevent competitors from easily imitating its products and services. These actions helped Apple capture and sustain the value it created.

E. Vertical integration, or the make–buy decision, is also a vehicle for achieving objectives – Explain this statement in the context of Apple.

Answer:

When Apple decided to move into retailing by establishing Apple Stores, the company made a decision to "make" stores that sold their own products, rather than simply "buy" the retailing services of stores run by other companies, such as Best Buy or Walmart. Finally, companies use international expansion as a vehicle to achieve economies of scale, access key resources, or learn new skills. Indeed, some companies use international expansion as a primary source of competitive advantage.

F. Which products made transform from Apple Computer Inc. to Apple Inc?

Apple's transformation from a computer company to a company known mostly for its music players and cell phones was the result of a strategy that emerged after the introduction of the iPod. The iPod opened up opportunities—such as the i Phone and i Pad—that the company's senior executives did not necessarily foresee.

Exercise

A. Theoretical Questions:

⊙ Multiple Choice Questions

1. The monitoring, evaluating and disseminating of information from the external and internal environments to key people within the organisation is called _________.
   - a. Strategy Formulation
   - b. Evaluation and control
   - c. Strategy Implementation
   - d. Environmental scanning

2. The ______of a company state how managers and employees should conduct themselves.
   - a. values
   - b. goals
   - c. objectives
   - d. vison

3. _________are the day-to-day way in which an organisation operates and can be seen by people both inside and outside the organisation.
   - a. Performances
   - b. Targets
   - c. Behaviours
   - d. Values

4. Which among the following provide the standards for performance appraisal?
   - a. Mission
   - b. Vision
   - c. Values
   - d. Objectives

5. _________is concerned with complexity arising out of ambiguous and non-routine situations with organisation wide rather than operation-specific implications.
   - a. Operational management
   - b. Business level strategy
   - c. Strategic Management
   - d. Functional level strategy

6. _________refer to the job-specific goals of each individual employee.
   - a. Balanced Score Card
   - b. Performance objectives
   - c. Personal objectives
   - d. Organisational genomics

7. The balanced score card is a ________approach to performance management.

   a. top-down

   b. bottom up

   c. indirect

   d. direct

8. In the Balanced Scorecard framework, which perspective focuses on the organization's ability to innovate, improve, and learn?

   a) Financial Perspective

   b) Customer Perspective

   c) Internal Processes Perspective

   d) Learning and Growth Perspective

9. Blue Ocean Strategy suggests companies should focus on creating what instead of competing in existing market spaces?

   a) Brand loyalty

   b) Customer satisfaction

   c) Market differentiation

   d) New market spaces

10. What is the role of Porter's Five Forces model in strategy formulation?

    a) To identify potential target markets

    b) To assess industry attractiveness and competitiveness

    c) To set financial targets

    d) To evaluate internal strengths and weaknesses

11. Which of the following is NOT typically considered a component of competitive analysis?

    a) Market segmentation

    b) Pricing strategies

    c) Product differentiation

    d) Customer satisfaction

Answer:

1	2	3	4	5	6	7	8	9	10	11
d	a	c	d	c	c	a	d	d	b	d

⊙ State True or False.

1. Business ethics are an agreed-upon code of conduct in business, based on organisational norms.
2. Strategy is likely to be concerned with the short term direction of an organisation.
3. Strategic decisions are likely to affect operational decisions.
4. Corporate strategy is about how to compete successfully in particular markets.
5. In evaluation and control the actual performances are compared to the desired performances and corrective actions are taken to resolve problems.
6. A customer-oriented business definition focuses on the characteristics of the products sold and the markets served.
7. Self-regulation is the ability to understand one's own moods, emotions, and drives, as well as their effect on others.
8. People disrespect leaders who are self aware and self regulating.
9. The balance score card model requires an evaluation of organisational performance from five different perspectives.
10. Accounting profit represents a purer and more reliable measure of profit that is a better measure of performance.

Answer:

1	2	3	4	5	6	7	8	9	10
F	F	T	F	T	F	F	F	F	F

⊙ Fill in the Blanks.

1. __________typically fit within the three main categories of stability, growth and retrenchment.
2. _______ is about how to compete successfully in particular markets.
3. _________ is concerned with developing and nurturing competence to provide a business unit with a competitive advantage.
4. ________refers to the monitoring, evaluating and disseminating of information from the external and internal environments to key people within the organisation.
5. _________involves the process through which organisational activities and performances are monitored.
6. A _______business definition focuses on the characteristics of the products sold and the markets served,
7. A __________view of a company's business focuses on customer needs rather than a particular product (or solution) for satisfying those needs.
8. _________is the desired future state of an organisation.
9. __________is the 'basic assumptions and beliefs that are shared by members of an organisation
10. _________are the day-to-day way in which an organisation operates and can be seen by people both inside and outside the organisation.
11. _________ are defined as the ends that state specifically how the goals shall be achieved.

Answer:

1	Corporate strategies	**2**	Business strategies
3	Functional or Operational strategies	**4**	Environmental scanning
5	Evaluation and control	**6**	product-oriented
7	customer –oriented	**8**	Vision
9	Organisational culture	**10**	Behaviours
11	Objectives		

⊙ Short Essay Type Questions

1. What are the consequences of the characteristics of strategy or strategic decisions?
2. Explain a corporate level strategy.
3. What is a Business Level Strategy?
4. What is a Functional Level Strategy?
5. Describe the role of vision, mission and values in a firm's strategy.
6. Evaluate the strategic implications of product-oriented and customer-oriented vision statements.
7. Justify why anchoring a firm in ethical core values is essential for long-term success.
8. Under which circumstances a positive relationship between vision statements and firm performance is more likely to exist?
9. When a company is said to have a competitive advantage over its rivals?

⊙ Essay Type Questions

1. List the characteristics of a strategy.
2. Write a short note on Strategic management.
3. What are the benefits of having a good vision?
4. Explain culture as a driver of strategy.
5. What do you understand by objectives in strategic management?
6. What are the desirable characteristics of objectives to be effective?
7. What are the objectives of strategic management?
8. Write a short note on the balanced score card.
9. What are the steps involved in the balanced score card appraoch?
10. Explain the role of strategy in a firm's quest for competitive advantage.
11. Explain the terms competitive advantage, sustainable competitive advantage, competitive disadvantage and competitive parity.

Strategic Analysis and Strategic Planning

9

This Module Includes

Strategic Analysis and Strategic Planning

SLOB Mapped against the Module

To assess organisational strengths, weaknesses, opportunities, threats, and challenges with introspective analysis of internal realities with applications of various managerial tools and frameworks.

Module Learning Objectives:

After studying this module, the students will be able to:

An organisation needs to adapt itself to an ever-changing business environment. This requires proper internal and external analysis, strategic planning at all levels of the organisation and alternatives to strategic planning. This chapter has been designed to help students develop a fair understanding on the following areas:

- Understanding the business environment.
- Identifying the sources of competition in an industry or sector. (Porter's Five forces Framework)
- Developing corporate strategy in multiple business corporations. (Portfolio analysis).
- Understanding the steps in strategic planning.

Introduction

9

The task of a strategic manager is to manage the strategy making process. The strategy making process includes the formulation of strategy, strategy implementation and strategy evaluation and control. The formulation of strategy includes stating the organisation's vision, mission, values and major goals. It also requires analysing the organisation's internal and external environment. The success of a strategy solely rests on how well strategic managers understand the environment within which the organisation will operate now as well as in the future. Although the strategy making process is a top down approach but evidences suggest that strategies can also be a result of unplanned responses to uncertain circumstances. There can be a significant deviation from the intended strategies with the realised strategies. This chapter tries to look into the business environment, the macro-environment, the value chain of an organisation and strategic planning.

Analysis of Business Environment

9.1

- Business environment refers to the sum total of all the conditions, events and influences in and around an organisation that affects it hence, a clear understanding of business environment is of crucial importance.
- The very survival of an organisation depends on its environment. However, the environment is also the source of threats for example, hostile shifts in market demand, new regulatory requirements, innovations in technology or the entry of new competitors.
- Environmental change can be both an opportunity as well as a threat to an organisation.
- It is vital that managers analyse their environments carefully in order to anticipate and if possible influence environmental change.

The framework for analysing changing and complex environments are organised in a series of 'layers' as follows

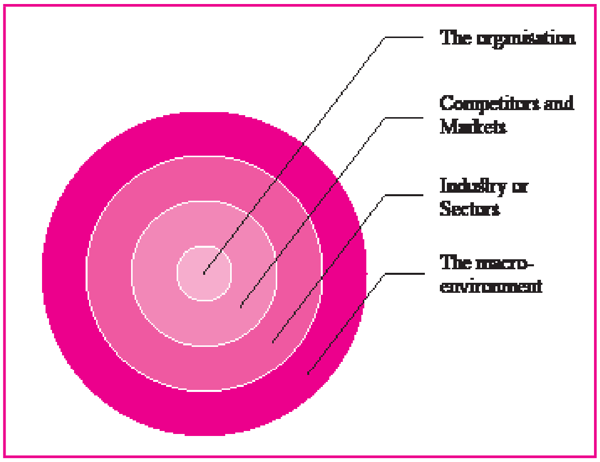


Figure 9.1: Layers of the Business Environment

- The macro-environment is the outermost and the highest-level layer. This consists of broad environmental factors that impact to a greater or lesser extent on almost all organisations. Here, the PESTEL framework can be used to identify how future trends in the political, economic, social, technological, environmental ('green') and legal environments might impinge on organisations. This PESTEL analysis provides the broad 'data' from which to identify key drivers of change. These key drivers can be used to construct scenarios of possible futures. Scenarios consider how strategies might need to change depending on the different ways in which the business environment might change.

- Industry, or sector, forms the next layer with this broad general environment. This is made up of organisations producing the same products or services. Here the Porter's five forces framework is particularly useful in understanding the attractiveness of particular industries or sectors and potential threats from outside the present set of competitors.

- Competitors and markets are the most immediate layer surrounding organisations. Within most industries or sectors there will be many different organisations with different characteristics and competing on different bases, some closer to a particular organisation, some more remote. The concept of strategic groups can help identify close and more remote competitors. Similarly, in the marketplace, customers' expectations are not all the same. They have a range of different requirements the importance of which can be understood through the concepts of market segments and critical success factors.

Characteristics of Business Environment

Business environment exhibits many characteristics. Some of the important characteristics are as follows:

- **Environment is complex:** The business environment happens to be very complex as it comprises of a number of factors namely, events, conditions and influences arising from different sources interacting with each other to create entirely new sets of influences. It is indeed difficult to instantly say what factors constitute a given environment. Environment is a complex phenomenon and it is easier to understand it in segments or compartments rather than grasp in totality.

- **Environment is dynamic:** The changing nature of environment is a constant. The dynamism of the environment is largely due to large number of factors that continuously influences its character and shape.

- **Environment is Multi-faceted:** The perception of the observer is very important to determine the shape and character of thee environment. Changes in the environment may be perceived differently by different individual. The changes and developments may be considered to be an opportunity to one and a threat to others.

- **Environment has a far reaching impact:** The impact of environment on an organisation is huge. It critically underpins the growth and profitability of an organisation. Any changes in the environment affect the organisation in more ways than one. The very survival and existence of an organisation is critically dependent on its environment.

PESTEL, Value Chain and Porter's 5 Framework

9.2

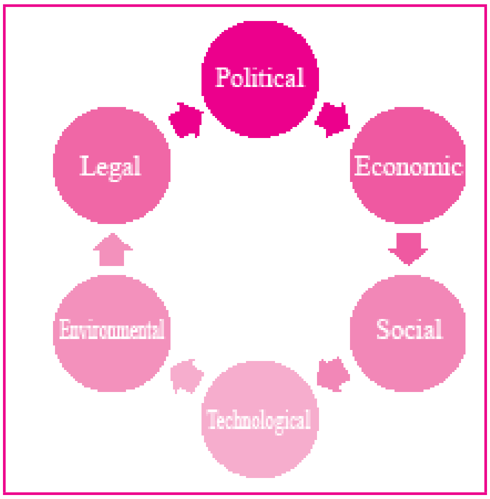


Figure 9.2: The PESTEL Framework

The PESTEL framework categorises environmental influences into six main types: political, economic, social, technological, environmental and legal. Politics highlights the role of governments.

- **Political** processes shape a society's laws, which constrain the operations of organisations and managers and thus create both opportunities and threats. Political instability creates adverse conditions for the businesses to function. Investors rarely want to invest in countries where there is political turmoil and this in turn can be detrimental to the businesses in those regions. On the other hand, political stability and favourable government attitude towards businesses can create a lot of opportunities and is considered to be a favourable business environment.

- **Macroeconomic forces** affect the general health and well-being of a nation or the regional economy of an organisation which in turn affect companies' and industries' ability to earn an adequate rate of return. The four most important macroeconomic forces are the growth rate of the economy, interest rates, currency exchange rates, and inflation (or deflation) rates.

    - Economic growth tends to ease competitive pressures within an industry as it leads to an expansion in customer expenditures. This gives companies the opportunity to expand their operations and earn higher profits. On the other hand economic decline (a recession) increases competitive pressures as leads to a reduction in customer expenditures.

    - Interest rates can determine the demand for a company's products. Interest rates are important whenever customers routinely borrow money to finance their purchase of these products. Interest rates are also important because they influence a company's cost of capital, and therefore its ability to raise funds and invest in new assets. The lower the interest rates the lower the cost of capital for companies and more opportunities for investment.

  - Currency exchange rates define the comparative value of different national currencies. Movement in currency exchange rates has a direct impact on the competitiveness of a company's product.
  - Price inflation can destabilise the economy, producing slower economic growth, higher interest rates, and volatile currency movements. If inflation continues to increase, investment planning will become hazardous. The key characteristic of inflation is that it makes the future less predictable. Price deflation also has a destabilizing effect on economic activity. If prices fall, the real price of fixed payments goes up. This is damaging for companies and individuals with a high level of debt who must make regular fixed payments on that debt.

- **Social** influences include changing cultures and demographics. Demographic forces are outcomes of changes in the characteristics of a population, such as age, gender, ethnic origin, race, sexual orientation, and social class. Like the other forces in the general environment, demographic forces present managers with opportunities and threats and can have major implications for organisations.
- **Technological** influences refer to innovations such as artificial intelligence, internet, nano-technology, or the rise of new composite materials.
- **Environmental** stands specifically for 'green' issues, such as pollution and waste. The environmental factors have now become extremely important for organisations as countries across the globe are increasingly concerned with the environmental changes and are striving towards clean, green and renewable sources of energy. The disposal of e –waste and global warming are also very important causes of concern. Organisations need to be more environment friendly.
- Finally **legal** embraces legislative constraints or changes, such as health and safety legislation or restrictions on company mergers and acquisitions.

For managers, it is important to analyse how these factors are changing now and how they are likely to change in the future, drawing out implications for the organisation. Many of these factors are linked together. Key drivers for change are the high-impact factors likely to affect significantly the success or failure of strategy. Typical key drivers will vary by industry or sector. For example, the key driver for a computer manufacturer may be technological change. Public sector managers are likely to be concerned with social change (for example, an ageing population), political change (changing government funding and policies) and legislative change (introducing new requirements). Identifying key drivers for change helps managers to focus on the PESTEL factors that are most important and which must be addressed as the highest priority.

Solved Case

Airbnb: Disrupting the Hotel Industry

IN 2019, AIRBNB had 5 million listings in over 81,000 cities in some 190 countries, ranging from spare rooms to entire islands. With its "asset-light approach" based on its platform strategy, Airbnb is able to offer more accommodations than the three biggest hotel chains combined: Marriott, Hilton, and Intercontinental. And just like global hotel chains, Airbnb uses sophisticated pricing and reservation systems for guests to find, reserve, and pay for rooms to meet their travel needs. In this sense, Airbnb is a new entrant that competes in the global hotel industry. Brian Chesky and Joe Gebbia, Airbnb founders, were roommates in San Francisco a little more than a decade earlier. Both were industrial designers, people who shape the form and function of everything from coffee cups to office furniture to airplane interiors. But since work opportunities were hit-and miss, they found themselves struggling to make their rent payments. On a whim, they decided to e-mail everyone on the distribution list for an upcoming industrial design conference in their hometown: "If you're heading out to the [industrial design conference] in San Francisco next week and have yet to make accommodations, well, consider networking in your jam-jams. That's right. For an affordable alternative to hotels in the city, imagine yourself in a fellow design industry person's home, fresh awake from a snooze on the ol' air mattress, chatting about the day's upcoming events over Pop Tarts and OJ."1 Three people took up the offer, and the two roommates made some money to subsidize their rent payments. But more importantly, Chesky and Gebbia felt that they had stumbled upon a new business idea: Help people rent out their spare rooms. They then brought on computer scientist Nathan Blecharczyk, one of Gebbia's former roommates, to create a website where hosts and guests could meet and transact, naming their site AirBedandBreakfast.com (later shortened to Airbnb). The three entrepreneurs tested their new site at the 2008 South by Southwest (SXSW), an annual music, film, and interactive media conference. SXSW also serves as an informal launch pad for new ventures; for example, Twitter was unveiled at SXSW just a year earlier to great fanfare. Airbnb's launch at SXSW flopped, however, because the conference organizers had exclusive contracts with local hotels (which Airbnb founders learned about later), and so conference organizers didn't drive any traffic to Airbnb's site.

Not to be discouraged, Airbnb decided to take advantage of the anticipated shortage of hotel rooms in Denver, Colorado, the site of the Democratic National Convention (DNC) in the summer of 2008. After all hotels were booked, the founders prepared media releases with titles such as "Grassroots Housing for Grassroots Campaign," which Obama supporters loved. As luck would have it, Airbnb was covered in both The New York Times and The Wall Street Journal. And the newly designed Airbnb site worked! It facilitated about 100 rentals during the DNC. Soon after the event, however, website traffic to Airbnb's site fell back to zero. To keep going, Chesky and Gebbia decided to become cereal entrepreneurs, creating "Obama-O's: The breakfast of change" and "Cap'n McCains: A maverick in every bite," with illustrated images of the 2008 presidential candidates on 1,000 cereal boxes. After sending samples to their press contacts and subsequent coverage in the media, the limited-edition cereal sold out quickly, providing enough cash to keep going with Airbnb a bit Longer. The fledgling venture's breakthrough came in 2009 when it was accepted into a program run by Y Combinator, a start-up accelerator that has spawned famous tech companies such as Dropbox, Stripe, and Twitch.tv. In exchange for equity in the new venture, these start-up accelerators provide office space, mentoring, and networking opportunities, including with venture capitalists looking to fund the next "big thing." In 2010, Airbnb received funding from Sequoia Capital, one of the most prestigious venture capital firms in Silicon Valley, having provided early-stage capital to companies such as Apple, Google, Oracle, PayPal, YouTube, and WhatsApp. Although not a first mover in the peer-to-peer rental space, Airbnb, with support of Y Combinator, was the first one to figure out that a sleek website design comprising professional photos of available rentals made all the difference. In addition, Airbnb developed a seamless transaction experience between hosts and guests and was able to earn a little over 10 percent on each transaction conducted on its site. Timing was now much more fortuitous; with the global financial crisis in full swing, people were looking for low-cost accommodations while hosts were trying to pay rent or mortgages to keep their homes. In 2019, Airbnb was valued at a whopping $31 billion. This makes Airbnb the fourth most valuable private startup on the planet, just after Didi Chuxing, China's version of Uber ($56 billion), WeWork ($47 billion), and JUUL ($38 billion). Even more stunning, Airbnb's valuation approaches that of Marriott ($39 billion in 2019), the world's largest hotel chain with over $20 billion in annual revenues.

Source: Rothaermel, F. T. (2019). Strategic Management. 4th Edition, McGraw-Hill Education, pgs-65- 66

A. How can an internet startup based on the idea of home sharing disrupt the global hotel industry, long dominated by corporate giants such as Marriott, Hilton, and Intercontinental?

One reason is that Airbnb, now the world's largest accommodation provider, owns no real estate. Instead, it uses a business model innovation to circumvent traditional entry barriers into the hotel industry. Just like Uber, Facebook, or Amazon, Airbnb provides an online platform for sellers (hosts) and buyers (renters) to connect and transact. While traditional hotel chains need years and millions of dollars in real estate investments to add additional capacity (finding properties, building hotels, staffing and running them, etc.), Airbnb's inventory is basically unlimited as long as it can sign up users with spare rooms to rent. Even more importantly, Airbnb does not need to deploy millions of dollars in capital to acquire and manage physical assets or manage a large cadre of employees. For example, Marriott has almost 250,000 employees, while Airbnb's headcount is approximately 2,500 employees (only 1 percent of Marriott's). Thus, Airbnb can grow much faster and respond much more quickly to local circumstances affecting the demand and supply of accommodations. The competitive intensity in the hotel industry is likely to increase, especially in high traffic metropolitan cities such as New York, Paris, Dubai, and Seoul. Unlike traditional hotel chains, Airbnb's growth is not limited by capital, hotel staff, or ownership of real estate. In 2019, Airbnb offered over 6 million listings worldwide for rent in over 81,000 cities in some 190 countries. With its asset-light approach based on its platform strategy, Airbnb is able to offer more accommodations than the three biggest hotel chains combined: Marriott, Hilton, and Intercontinental.

B. How do Political factors (result from the processes and actions of government bodies) influence the decisions and behaviour of firms like Airbnb?

Hotel chains and resort owners have challenged Airbnb in courts and lobbied local governments, some of which passed regulations to limit or prohibit short-term rentals. Local residents in New York, San Francisco, Berlin, Paris, and many other cities are also pressuring local governments to enact more aggressive rules banning short-term rentals because they argue that companies such as Airbnb contribute to a shortage of affordable housing by turning entire apartment complexes into hotels or transforming quiet family neighbourhoods into all-night, every-night party hot spots. In this context, non-market strategies play an important factor. Strategic leaders' activities outside market exchanges where firms sell products or provide services to influence a firm's general environment through, for example, lobbying, public relations, contributions, and litigation in ways that are favourable to the firm.

C. Technological factors capture the application of knowledge to create new processes and products – Justify this statement in the context of Airbnb.

Airbnb launched a process innovation of offering and renting rooms based on a business model leveraging the sharing economy. If one thing seems certain, technological progress is relentless and seems to be picking up speed.Not surprisingly, changes in the technological environment bring both opportunities and threats for companies.

D. How does network effect play a positive role in Airbnb's success story?

Airbnb is able to benefit from global network effects because of listings in 81,000 cities around the globe at all different price points, combined with an inventory of 5 million homes and apartments. This global network effect only grows stronger as more and more guests use the service and become hosts themselves.

Industry and Sector

An industry is a group of firms producing the same principal product or service. An industry may also be defined as a group of companies offering products or services that are close substitutes for each other i.e., products or services that satisfy the same basic customer needs. A company's closest competitors or its rivals are those that serve the same basic customer needs. For example, in the class of non-alcoholic beverages carbonated drinks and real fruit juices can be viewed as close substitutes for each other because they serve the same basic customer needs.

A sector is a group of closely related industries. The FMCG comprises several related industries: the food and beverages industries, the healthcare industries and the household and personal care industries.

The Value Chain

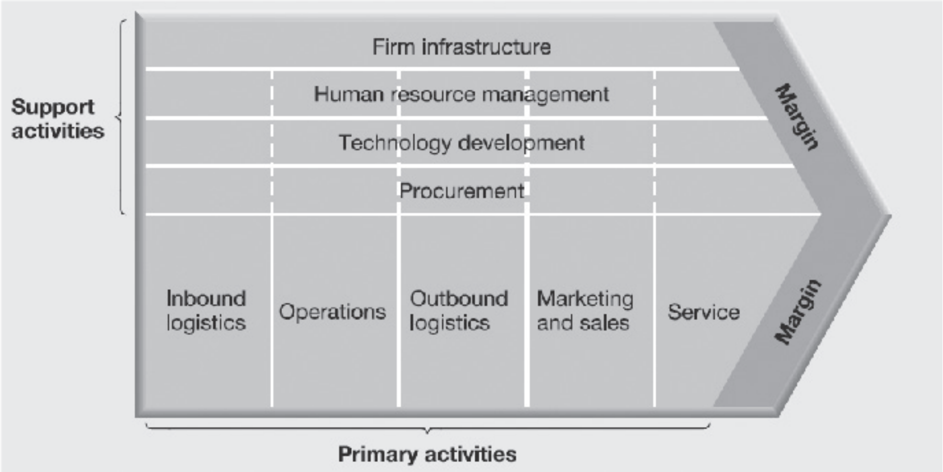


Figure 9.3 Porter's Value chain of an organisation

The value chain describes the categories of activities within and around an organisation, which together create a product or service. The concept was developed in relation to competitive strategy by Michael Porter. The term value chain refers to the idea that a company is a chain of activities that transforms inputs into outputs that customer's value. The transformation process involves both primary activities and support activities that add value to the product. Activities can be broadly divided into two types namely, primary activities and secondary or support activities.

Primary activities are directly concerned with the creation or delivery of a product or service. For example, for a manufacturing business the primary activists are as follows:

- Inbound logistics are activities concerned with receiving; storing and distributing inputs to the product or service including materials handling, stock control, transport, etc.
- Operations transform these inputs into the final product or service. Operations include machining, packaging, assembly, testing, etc.
- Outbound logistics collect, store and distribute the product to customers, for example warehousing, materials handling, distribution, etc.
- Marketing and sales provide the means whereby consumers/users are made aware of the product or service and are able to purchase it. This includes sales administration, advertising and selling.
- Service includes those activities that enhance or maintain the value of product or service, such as installation, repair, training and spares.

Support activities help to improve the effectiveness or efficiency of primary activities. The following are the support or secondary activities:

- Procurement: It refers to the processes that occur in many parts of the organisation for acquiring the various resource inputs to the primary activities.
- Technology development: All value activities have a 'technology', even if it is just know-how. Technologies may be concerned directly with a product or with processes or with a particular resource.
- Human resource management: This transcends all primary activities. It is concerned with those activities involved in recruiting, managing, training, developing and rewarding people within the organisation.
- Infrastructure: The formal systems of planning, finance, quality control, information management, and the structures and routines that are part of an organisation's culture.

In the value chain process the value can be added early in the value chain, i.e. upstream and later in the value chain, i.e. downstream.

Porter's five Forces Framework

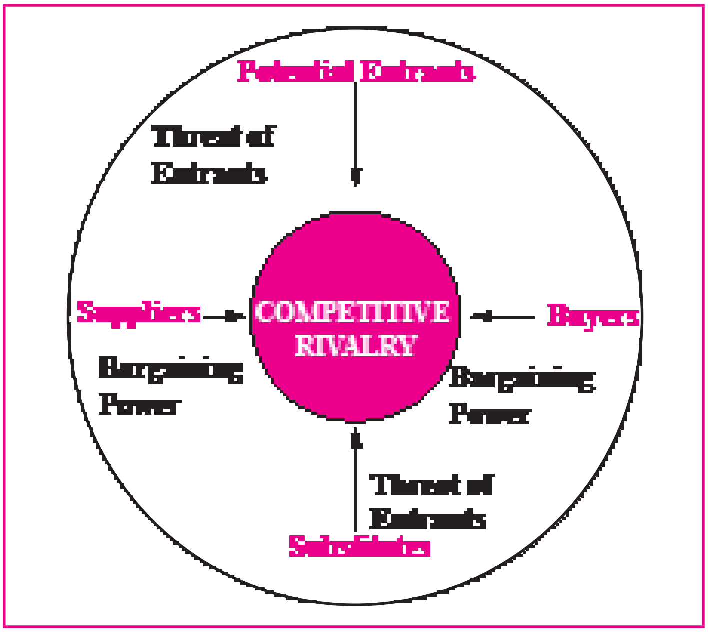


Figure 9.4: Porter's Five Forces framework

It helps to identify the sources of competition in an industry or sector.

The following are important to understand the framework

- It must be used at the level of strategic business units (SBUs) and not at the level of the whole organisation This is because organisations are diverse in their operations and markets.
- The framework must not be used just to give a snapshot in time.
- Understanding the connections between competitive forces and structural drivers is essential.
- The five forces are not independent of each other.
- Competitive behaviour may be concerned with disrupting these forces and not simply accommodating them.

The five forces are discussed hereunder:

Risk of Entry by Potential Competitors

Potential competitors are companies that are not currently competing in an industry, but have the capability to do so if they choose. Established companies are those which are already operating in an industry. They often attempt to discourage potential competitors from entering the industry because as more companies enter, it becomes more difficult for established companies to protect their share of the market and generate profits. A high risk of entry by potential competitors represents a threat to the profitability of established companies. The greater the costs potential competitors must bear to enter an industry, the greater the barriers to entry, and the weaker this competitive force. High entry barriers may keep potential competitors out of an industry even when industry profits are high.

- **Economies of Scale**

  Economies of scale arise when unit costs fall as a firm expands its output. Sources of scale economies include cost reductions gained through mass producing a standardized output; discounts on bulk purchases of raw material inputs and component parts; the advantages gained by spreading fixed production costs over a large production volume; and the cost savings associated with distributing, marketing, and advertising costs over a large volume of output. If the cost advantages from economies of scale are significant, a new company that enters the industry and produces on a small scale suffers a significant cost disadvantage relative to established companies. If the new company decides to enter on a large scale in an attempt to obtain these economies of scale, it must raise the capital required to build large-scale production facilities and bear the high risks associated with such an investment. In addition, an increased supply of products will depress prices and result in vigorous retaliation by established companies, which constitutes a further risk of large-scale entry. For these reasons, the threat of entry is reduced when established companies have economies of scale.

- **Brand Loyalty**

  Brand loyalty exists when consumers have a preference for the products of established companies. A company can create brand loyalty by continuously advertising its brand-name products and company name, patent protection of its products, product innovation achieved through company research and development (R&D) programs, an emphasis on high-quality products, and exceptional after-sales service. Significant brand loyalty makes it difficult for new entrants to take market share away from established companies. Thus, it reduces the threat of entry by potential competitors; they may see the task of breaking down well-established customer preferences as too costly.

- **Absolute Cost Advantages**

  Sometimes established companies have an absolute cost advantage relative to potential entrants, meaning that entrants cannot expect to match the established companies' lower cost structure. Absolute cost advantages arise from three main sources: (1) superior production operations and processes due to accumulated experience, patents, or trade secrets; (2) control of particular inputs required for production, such as labour, materials, equipment, or management skills, that are limited in their supply; and (3) access to cheaper funds because existing companies represent lower risks than new entrants. If established companies have an absolute cost advantage, the threat of entry as a competitive force is weaker.

- **Customer Switching Costs**

  Switching costs arise when a customer invests time, energy, and money switching from the products offered by one established company to the products offered by a new entrant. When switching costs are high, customers can be locked in to the product offerings of established companies, even if new entrants offer better products.

- **Government Regulations**

  Historically, government regulation has constituted a major entry barrier for many industries. The competitive forces model predicts that falling entry barriers due to government deregulation will result in significant new entry, an increase in the intensity of industry competition, and lower industry profit rates.

Rivalry Among Established Companies

The second competitive force is the intensity of rivalry among established companies within an industry. Rivalry refers to the competitive struggle between companies within an industry to gain market share from each other. The competitive struggle can be fought using price, product design, advertising and promotional spending, direct-selling efforts, and after-sales service and support. Intense rivalry implies lower prices or more spending on non-price-competitive strategies, or both. Because intense rivalry lowers prices and raises costs, it squeezes profits out of an industry. Thus, intense rivalry among established companies constitutes a strong threat to profitability. Alternatively, if rivalry is less intense, companies may have the opportunity to raise prices or reduce spending on non-price competitive strategies, leading to a higher level of industry profits. Four factors have a major impact on the intensity of rivalry among established companies within an industry: (1) industry competitive structure, (2) demand conditions, (3) cost conditions, and (4) the height of exit barriers in the industry.

- **Industry Competitive Structure**

  The competitive structure of an industry refers to the number and size distribution of companies in it, something that strategic managers determine at the beginning of an industry analysis. Industry structures vary, and different structures have different implications for the intensity of rivalry.

  A fragmented industry consists of a large number of small or medium-sized companies, none of which is in a position to determine industry price.

  - Low-entry barriers and commodity-type products that are difficult to differentiate characterize many fragmented industries. This combination tends to result in boom-and-bust cycles as industry profits rapidly rise and fall.

  - Low-entry barriers imply that new entrants will flood the market, hoping to profit from the boom that occurs when demand is strong and profits are high. Often the flood of new entrants into a booming, fragmented industry creates excess capacity, and companies start to cut prices in order to use their spare capacity. The difficulty companies' face when trying to differentiate their products from those of competitors can exacerbate this tendency. The result is a price war, which depresses industry profits, forces some companies out of business, and deters potential new entrants. A fragmented industry structure, then, constitutes a threat rather than an opportunity.

  - Economic boom times in fragmented industries are often relatively short-lived because the ease of new entry can soon result in excess capacity, which in turn leads to intense price competition and the failure of less efficient enterprises. Because it is often difficult to differentiate products in these industries, trying to minimize costs is the best strategy for a company so it will be profitable in a boom and survive any subsequent bust. Alternatively, companies might try to adopt strategies that change the underlying structure of fragmented industries and lead to a consolidated industry structure in which the level of industry profitability is increased.

  - A consolidated industry is dominated by a small number of large companies (an oligopoly) or, in extreme cases, by just one company (a monopoly), and companies often are in a position to determine industry prices.

  - In consolidated industries, companies are interdependent because one company's competitive actions (changes in price, quality, etc.) directly affect the market share of its rivals, and thus their profitability.

- When one company makes a move, this generally "forces" a response from its rivals, and the consequence of such competitive interdependence can be a dangerous competitive spiral.
- Rivalry increases as companies attempt to undercut each other's prices, or offer customers more value in their products, pushing industry profits down in the process.
- Companies in consolidated industries sometimes seek to reduce this threat by following the prices set by the dominant company in the industry.

⊙ Industry Demand

The level of industry demand is another determinant of the intensity of rivalry among established companies.

- Growing demand from new customers or additional purchases by existing customers tend to moderate competition by providing greater scope for companies to compete for customers.
- Growing demand tends to reduce rivalry because all companies can sell more without taking market share away from other companies. High industry profits are often the result.
- Conversely, declining demand results in increased rivalry as companies fight to maintain market share and revenues (as in the breakfast cereal industry example).
- Demand declines when customers exit the marketplace, or when each customer purchases less. When this is the case, a company can only grow by taking market share away from other companies. Thus, declining demand constitutes a major threat, for it increases the extent of rivalry between established companies.

⊙ Cost Conditions

The cost structure of firms in an industry is a third determinant of rivalry.

- Fixed costs are the costs that must be paid before the firm makes a single sale.
- In industries where fixed costs are high, profitability tends to be highly leveraged to sales volume, and the desire to grow volume can spark intense rivalry.
- Moreover, in industries where the fixed costs of production are high, firms cannot cover their fixed costs and will not be profitable if sales volume is low. Thus they have an incentive to cut their prices and/or increase promotional spending to drive up sales volume in order to cover fixed costs.
- In situations where demand is not growing fast enough and too many companies are simultaneously engaged in the same actions, the result can be intense rivalry and lower profits.
- Research suggests that the weakest firms in an industry often initiate such actions, precisely because they are struggling to cover their fixed costs.

⊙ Exit Barriers

Exit barriers are economic, strategic, and emotional factors that prevent companies from leaving an industry. If exit barriers are high, companies become locked into an unprofitable industry where overall demand is static or declining. The result is often excess productive capacity, leading to even more intense rivalry and price competition as companies cut prices, attempting to obtain the customer orders needed to use their idle capacity and cover their fixed costs. Common exit barriers include the following:

- Investments in assets such as specific machines, equipment, or operating facilities those are of little or no value in alternative uses, or cannot be later sold. If the company wishes to leave the industry, it must write off the book value of these assets.

- High fixed costs of exit, such as severance pay, health benefits, or pensions that must be paid to workers who are being made laid off when a company ceases to operate.
- Emotional attachments to an industry, such as when a company's owners or employees are unwilling to exit from an industry for sentimental reasons or because of pride.
- Economic dependence on the industry because a company relies on a single industry for its entire revenue and all profits.
- The need to maintain an expensive collection of assets at or above a minimum level in order to participate effectively in the industry.
- Bankruptcy regulations, particularly in the United States, bankruptcy provisions allow insolvent enterprises to continue operating and to reorganise under this protection. These regulations can keep unprofitable assets in the industry, result in persistent excess capacity, and lengthen the time required to bring industry supply in line with demand.

The Bargaining Power of Buyers

The third competitive force is the bargaining power of buyers. An industry's buyers may be the individual customers who consume its products (end-users) or the companies that distribute an industry's products to end-users, such as retailers and wholesalers. The bargaining power of buyers refers to the ability of buyers to bargain down prices charged by companies in the industry, or to raise the costs of companies in the industry by demanding better product quality and service. By lowering prices and raising costs, powerful buyers can squeeze profits out of an industry. Powerful buyers, therefore, should be viewed as a threat. Alternatively, when buyers are in a weak bargaining position, companies in an industry can raise prices and perhaps reduce their costs by lowering product quality and service, thus increasing the level of industry profits. Buyers are most powerful in the following circumstances:

- When the buyers have choice of who to buy from. If the industry is a monopoly, buyers obviously lack choice. If there are two or more companies in the industry, the buyers clearly have choice.
- When the buyers purchase in large quantities. In such circumstances, buyers can use their purchasing power as leverage to bargain for price reductions.
- When the supply industry depends upon buyers for a large percentage of its total orders.
- When switching costs are low and buyers can pit the supplying companies against each other to force down prices. When it is economically feasible for buyers to purchase an input from several companies at once so that buyers can pit one company in the industry against another.
- When buyers can threaten to enter the industry and independently produce the product, thus supplying their own needs, also a tactic for forcing down industry prices.

The Bargaining Power of Suppliers

The fourth competitive force is the bargaining power of suppliers—the organisations that provide inputs into the industry, such as materials, services, and labour (which may be individuals, organisations such as labour unions, or companies that supply contract labour). The bargaining power of suppliers refers to the ability of suppliers to raise input prices, or to raise the costs of the industry in other ways for e.g., by providing poor-quality inputs or poor service. Powerful suppliers squeeze profits out of an industry by raising the costs of companies in the industry. Thus, powerful suppliers are a threat. Conversely, if suppliers are weak, companies in the industry have the opportunity to force down input prices and demand higher-quality inputs (such as more productive labour). As with buyers, the ability of suppliers to make demands on a company depends on their power relative to that of the company. Suppliers are most powerful in these situations:

- The product that suppliers sell has few substitutes and is vital to the companies in an industry.
- The profitability of suppliers is not significantly affected by the purchases of companies in a particular industry, in other words, when the industry is not an important customer to the suppliers.
- Companies in an industry would experience significant switching costs if they moved to the product of a different supplier because a particular supplier's products are unique or different. In such cases, the company depends upon a particular supplier and cannot pit suppliers against each other to reduce prices.
- Suppliers can threaten to enter their customers' industry and use their inputs to produce products that would compete directly with those of companies already in the industry.
- Companies in the industry cannot threaten to enter their suppliers' industry and make their own inputs as a tactic for lowering the price of inputs.

Substitute Products

The final force in Porter's model is the threat of substitute products: the products of different businesses or industries that can satisfy similar customer needs. For example, companies in the coffee industry compete indirectly with those in the tea and soft drink industries because all three serve customer needs for non alcoholic drinks.

- The existence of close substitutes is a strong competitive threat because this limits the price that companies in one industry can charge for their product, which also limits industry profitability. If the price of coffee rises too much relative to that of tea or soft drinks, coffee drinkers may switch to those substitutes.
- If an industry's products have few close substitutes (making substitutes a weak competitive force), then companies in the industry have the opportunity to raise prices and earn additional profits.

Complementors

Andrew Grove, the former CEO of Intel, is of the opinion that both substitutes and complements influence demand in an industry. He has argued that Porter's original formulation of competitive forces ignored a sixth force: the power, vigour, and competence of complementors.

According to Grove, complementors are companies that sell products that add value to (complement) the products of companies in an industry because, when used together, the use of the combined products better satisfies customer demands. For example, the complementors to the PC industry are the companies that make software applications to run on the computers. The link between PCs and software applications can be expressed as greater the supply of high-quality software applications running on these machines, the greater will be the value of PCs to customers resulting in increased demand for PCs and ultimately increased profitability of the PC industry. [Ref: Hill, Jones and Schilling (2015)]

VRIO Framework

The VRIO framework, as given by Barney, helps an organisation to evaluate its competencies with the help of the following questions:

- Value: It questions whether the firm's competencies provide customer value and competitive advantage or not. It should be mentioned that threshold competencies only help a firm to exist in business and do not provide any competitive advantage. Competitive advantage comes from core competencies.
- Rareness: It questions the extent to which the competencies of the firm are rare. In other words, whether the competitors or the rivals possess the same competencies or not. The rarity component can help organisations to be competitively superior compared to its rivals.
- Imitability: One of the factors on which the durability of competitive advantage depends is the barriers to

imitation. The greater are the barriers the more durable will be the firm's competitive advantage. Tangible resources are easy to imitate whereas intangible resources such as reputation, capabilities, marketing strategies and technologies are difficult to imitate.

- Organisation: It refers to the level at which a firm is organised to utilise its resources. A firm where employees are able to take more risks, bring innovation and get rewarded is in a better situation in terms of utilisation of firm's resources. Having an organised structure is fundamental to the optimal utilisation of resources.

SWOTC Analysis (Industry Sector and Company)

9.3

SWOTC Analysis (Strength, Weaknesses, Opportunities and Threats or Challenges)

SWOT is the acronym for strengths, weaknesses, opportunities and threats. SWOT summarises the key issues from the business environment and the strategic capability of an organisation that are most likely to impact on strategy development. This can also be useful as a basis against which to generate strategic options and assess future courses of action. The aim is to identify the extent to which strengths and weaknesses are relevant to, or capable of dealing with, the changes taking place in the business environment. Organisations perform a SWOT analysis to understand their internal and external environments. The central purpose is to identify the strategies to exploit external opportunities, counter threats, build on and protect company strengths, and eradicates weaknesses. An effective Organisational strategy, therefore, is one that capitalises on the opportunities through the use of strengths and neutralises the threats by minimising the impact of weaknesses, to achieve pre-determined objectives.

A simple application of SWOT analysis technique involves these steps:

- Setting the objectives of the organisation or its unit.
- Identifying its strength, weaknesses, opportunities and threats.
- Maximising the areas where the organisation has strength.
- Minimising the weaknesses.
- Capitalising on the opportunities in the external environment.
- Protecting the organisation from threats in external environment.
- Recommending strategies that will help the organisation to be competitive in the business environment.

SWOT analysis is usually done with the help of a template in the form of a four-cell matrix. Each cell of the matrix represents the strengths weaknesses, opportunities and threats. The analysis for preparing the SWOT matrix could be done by a group of managers in a workshop session. The session could use the brainstorming technique for generating ideas about the SWOT factors.

SWOT analysis has several benefits such as simple to use, low cost, flexible and can be adapted to varying situations, leads to clarification of issues, development of goal-oriented alternatives, useful as a starting point for strategic analysis.

SWOT analysis should help focus discussion on future choices and the extent to which an organisation is capable of supporting these strategies. There are, however, some dangers:

- It is at times very difficult for organisations to clearly segment opportunities and threats. Sometimes an opportunity can also have an element of threat. For e.g. having a nuclear plant can be a great opportunity as it can lead to generation of low cost energy however, the threats cannot be undermined. The cost of mitigating threats can be huge.
- SWOT exercise can generate very long lists of apparent strengths, weaknesses, opportunities and threats, whereas what matters is to be clear about what is really important and what is less important.

- There is a danger of over generalisation. Identifying a very general explanation of strategic capability does not explain the underlying reasons for that capability. SWOT analysis is not a substitute for more rigorous, insightful analysis such as core competences, critical success factors, strategic gap, value chain, etc.
- Simplicity of use may turn to be simplistic by trivialising the reality that may be more complex than represented in SWOT matrices.
- May result in just compiling lists rather than think about what is really important for achieving objectives.
- Usually reflects an evaluator's position and viewpoint that can be misinterpreted to justify a previously decided course of action, rather than be used as a means to open new possibilities.
- Chances exist where strengths may be confused with opportunities or weaknesses with threats.
- May encourage organisations to take a lazy course of action of looking for strengths that match opportunities rather than developing new strengths that could match the emerging opportunities.

Source: Kazmi (2013)

Strength, Weaknesses, Opportunities and Challenges (SWOC):

The threats, or challenges, that organisations are likely to face are perhaps the most important factors of a SWOC analysis. **The term threats can also been seen as challenges.** The bottom right square reflects challenges that a business might face. For example tightening of regulations, changes in consumer demands, newer products and a changing competitive landscape can pose challenges. One might have a robust plan catered to a clear and specific set of strengths, weaknesses and opportunities, but if one does not consider the challenges in one's industry, the plan could be useless. For instance, if your technology business introduces a mobile phone application that is similar to and indistinguishable from another company's application that currently dominates the market, your product's success faces a threat. Knowing the challenges you face, helps your business to make informed and strategic decisions regarding products.

SWOT Analysis (Industry Sector)

SWOT Analysis of Indian Steel Industry

STRENGTHS	WEAKNESSES
➢ Abundance of iron ore and other minerals for steel ➢ Skilled manpower and low unit cost ➢ Mature production base	➢ High cost of capital ➢ Low labour productivity ➢ High cost of basic input ➢ High social cost ➢ Poor quality of basic insfrastructure and distribution network ➢ IT liverage
OPPORTUNITY	**THREATS**
➢ Demand for infrstructure ➢ Rapid urbanization ➢ Untapped rural demand ➢ Low per capital consumption ➢ Consolidation ➢ Low export penetration ➢ Growing domestic demand	➢ Emergence of China as a global exporter of steel ➢ Threat of substitutes such as aluminium, plastics,etc. ➢ Technological obsolescence ➢ Slow industrial growth and global economic slow down ➢ Price sensitivity and volatility ➢ Dumping of high grade low cost steel by developed countries

Portfolio Analysis and BCG Matrix

9.4

Portfolio Analysis

One of the most popular aids to developing corporate strategy in multiple business corporations is portfolio analysis. Portfolio analysis is an analytical tool which views a corporation as basket of portfolio of products or business units to be managed for the best possible returns. Portfolio analysis puts corporate headquarters into the role of an internal banker. In portfolio analysis top management views its product lines and business units as a series of investments from which it expects a profitable return. A study on 200 largest U.S. corporations made by McKinsey & Company found that companies that actively managed their business portfolios through acquisitions and divestitures created substantially more shareholder value than those companies that passively held their businesses. Given the increasing number of strategic alliances in today's corporations, portfolio analysis is also being used to evaluate the contribution of alliances to corporate and business unit objectives. Two of the most popular portfolio techniques are the BCG Growth-Share Matrix and GE Business Screen.

Objectives of Portfolio Analysis

- to analyse the current mix of business and take investment decisions.
- to develop strategies for adding new businesses in the portfolio thereby inducing growth.
- to decide the business to be retained and the one to be excluded from the portfolio.

Advantages and Limitations of Portfolio Analysis

Portfolio analysis is commonly used in strategy formulation because it offers certain advantages such as

- It encourages top management to evaluate each of the corporation's business individually and to set objectives and allocate resources for each.
- It stimulates the use of externally oriented data to supplement management's judgment.
- It raises the issue of cash-flow availability for use in expansion and growth.
- Its graphic depiction facilitates communication.

Portfolio analysis, however, has some very real limitations that have caused companies to reduce their use of this approach:

- Defining product/market segments is difficult.
- It suggests the use of standard strategies that can miss opportunities or be impractical
- It provides an illusion of scientific rigour, when in reality positions are based on subjectivity.
- Its value-laden terms such as cash cow and dog can lead to self-fulfilling prophecies.

- It is not always clear what makes an industry attractive or where a product is in its life cycle.
- Naively following the prescriptions of a portfolio model may actually reduce corporate profits if they are used inappropriately.

The growth/share (or BCG) matrix

One of the most common and long-standing ways of conceiving of the balance of a portfolio of businesses is the Boston Consulting Group (BCG) matrix.

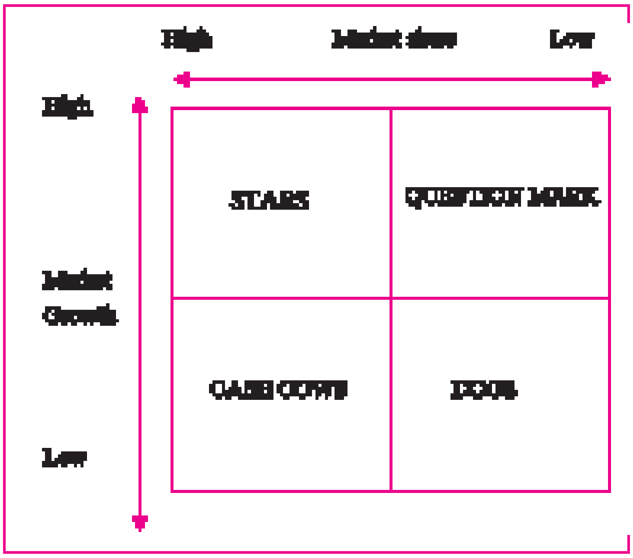


Figure 9.5: The Growth Share (or BCG) matrix

Here market share and market growth are critical variables for determining attractiveness and balance. High market share and high growth are, of course, attractive. However, the BCG matrix also warns that high growth demands heavy investment, for instance to expand capacity or develop brands. There needs to be a balance within the portfolio, so that there are some low growth businesses that are making sufficient surplus to fund the investment needs of higher growth businesses. The market growth/market share axes of the BCG matrix define four sorts of business:

- A star is a business unit which has a high market share in a growing market. The business unit may be spending heavily to keep up with growth, but high market share should yield sufficient profits to make it more or less self sufficient in terms of investment needs.
- A question mark (or problem child) is a business unit in a growing market, but not yet with high market share. Developing question marks into stars, with high market share, takes heavy investment. Many question marks fail to develop, so the BCG advises corporate parents to nurture several at a time. It is important to make sure that some question marks develop into stars, as existing stars eventually become cash cows and cash cows may decline into dogs.
- A cash cow is a business unit with a high market share in a mature market. However, because growth is low, investment needs are less, while high market share means that the business unit should be profitable. The cash cow should then be a cash provider, helping to fund investments in question marks.
- Dogs are business units with a low share in static or declining markets and are thus the worst of all combinations. They may be a cash drain and use up a disproportionate amount of company time and resources. The BCG

usually recommends divestment or closure.

The BCG matrix has several advantages.

- It provides a good way of visualising the different needs and potential of all the diverse businesses within the corporate portfolio.
- It warns corporate parents of the financial demands of what might otherwise look like a desirable portfolio of high-growth businesses.
- It also reminds corporate parents that stars are likely eventually to wane.
- Finally, it provides a useful discipline to business unit managers, underlining the fact that the corporate parent ultimately owns the surplus resources they generate and can allocate them according to what is best for the corporate whole. Cash cows should not hoard their profits. Incidentally, surplus resources may not only be investment funds: the corporate parent can also reallocate business unit managers who are not fully utilised by low-growth cash cows or dogs.

However, there are at least three potential problems with the BCG matrix:

- Definitional vagueness: It can be hard to decide what high and low growth or share mean in particular situations. Managers are often keen to define themselves as ‘high share’ by defining their market in a particularly narrow way (for example, ignoring relevant international markets)
- **Capital market assumptions:**
  - The notion that a corporate parent needs a balanced portfolio to finance investment from internal sources (cash cows) assumes that capital cannot be raised in external markets, for instance by issuing shares or raising loans.
  - The notion of a balanced portfolio may be more relevant in countries where capital markets are underdeveloped or in private companies that wish to minimise dependence on external shareholders or banks.
- **Unkind to animals:**
  - Both cash cows and dogs receive ungenerous treatment, the first being simply milked, the second terminated or cast out of the corporate home. This treatment can cause motivation problems, as managers in these units see little point in working hard for the sake of other businesses.
  - There is also the danger of the self-fulfilling prophecy. Cash cows will become dogs even more quickly than the model expects if they are simply milked and denied adequate investment.
  - Finally, the notion that a dog can be simply sold or closed down also assumes that there are no ties to other business units in the portfolio, whose performance might depend in part on keeping the dog alive. This portfolio approach to dogs works better for conglomerate strategies, where divestments or closures are unlikely to have knock-on effects on other parts of the portfolio.

Stages in Strategic Planning

9.5

The formal strategic planning process has five main steps:

i. **Select the corporate mission and major corporate goals**

The first component of the strategic planning process is crafting the organisation's mission statement, which provides the framework or context within which strategies are formulated. A mission statement has four main components: a statement of its reason for existence which is normally referred to as the mission; a statement of some desired future state, usually referred to as the vision; a statement of the key values that the organisation is committed to; and a statement of major goals.

ii. **Analyse the organisation's external competitive environment to identify opportunities and threats**

The second component of the strategic planning process is an analysis of the organisation's external operating environment. The essential purpose of the external analysis is to identify strategic opportunities and threats within the organisation's operating environment that will affect how it pursues its mission. Three interrelated environments should be examined when undertaking an external analysis: the industry environment in which the company operates, the country or national environment and the wider socioeconomic or macro environment.

iii. **Analyse the organisation's internal operating environment to identify the organisation's strengths and weaknesses**

Internal analysis, the third component of the strategic planning process, focuses on reviewing the resources, capabilities, and competencies of a company. The goal is to identify the strengths and weaknesses of the company. The next component of strategic thinking requires the generation of a series of strategic alternatives, or choices of future strategies to pursue, given the company's internal strengths and weaknesses and its external opportunities and threats. The comparison of strengths, weaknesses, opportunities, and threats is normally referred to as a SWOT analysis. More generally, the goal of a SWOT analysis is to create, affirm, or fine-tune a company-specific business model that will best align, fit, or match a company's resources and capabilities to the demands of the environment in which it operates.

iv. **Select strategies**

Managers select strategies that build on the organisation's strengths and correct its weaknesses in order to take advantage of external opportunities and counter external threats. In order to select the right strategies managers compare and contrast the various alternative possible strategies against each other and then identify the set of strategies that will create and sustain a competitive advantage. It is very important for the strategic managers to keep in mind that the strategies selected should be consistent with the mission and major goals of the organisation. They should be congruent and constitute a viable business model.

v. **Implement the strategies**

In order to achieve a competitive advantage and increase profitability managers must put those strategies selected into action. Strategy implementation involves taking actions at the functional, business, and corporate levels to execute a strategic plan.

Implementation can include, for example,

- putting quality improvement programs into place
- changing the way a product is designed
- positioning the product differently in the marketplace
- segmenting the marketing and offering different versions of the product to different consumer groups
- implementing price increases or decreases
- expanding through mergers and acquisitions
- downsizing the company by closing down or selling off parts of the company

Strategy implementation also entails designing the best organisation structure and the best culture and control systems to put a chosen strategy into action. In addition, senior managers need to put a governance system in place to make sure that all within the organisation act in a manner that is not only consistent with maximizing profitability and profit growth, but also legal and ethical.

The Feedback Loop

The strategy planning process is a continuous process and the feedback loop indicates that strategic planning never ends. In order to determine the extent to which strategic goals and objectives are actually being achieved, and to what degree competitive advantage is being created and sustained execution of the strategy must be monitored. This information and knowledge is returned to the corporate level through feedback loops, and becomes the input for the next round of strategy formulation and implementation. Top managers can then decide whether to reaffirm the existing business model and the existing strategies and goals, or suggest changes for the future.

Alternatives in Strategic Planning

9.6

The planning model suggests that a company's strategies are the result of a plan, that the strategic planning process is rational and highly structured, and that top management orchestrates the process. Several scholars have criticized the formal planning model for three main reasons: the unpredictability of the real world, the role that lower-level managers can play in the strategic management process, and the fact that many successful strategies are often the result of serendipity, not rational strategizing. These scholars have advocated an alternative view of strategy making.

Scenario Planning

One reason that strategic planning may fail over longer time periods is that strategic managers, in their initial enthusiasm for planning techniques, may forget that the future is entirely unpredictable. Even the best-laid plans can fall apart if unforeseen contingencies occur, and that happens all the time.

- Scenario planning involves formulating plans that are based upon "what-if" scenarios about the future. In the typical scenario-planning exercise, some scenarios are optimistic and some are pessimistic. Teams of managers are asked to develop specific strategies to cope with each scenario.
- A set of indicators is chosen as sign posts to track trends and identify the probability that any particular scenario is coming to pass.
- The idea is to allow managers to understand the dynamic and complex nature of their environment, to think through problems in a strategic fashion, and to generate a range of strategic options that might be pursued under different circumstances.
- The scenario approach to planning has spread rapidly among large companies

Decentralized Planning

A mistake that some companies have made in constructing their strategic planning process has been to treat planning exclusively as a top-management responsibility.

- This "ivory tower" approach can result in strategic plans formulated in a vacuum by top managers who have little understanding or appreciation of current operating realities. Consequently, top managers may formulate strategies that do more harm than good.
- Correcting the ivory tower approach to planning requires recognising that successful strategic planning encompasses managers at all levels of the corporation.
- Much of the best planning can and should be done by business and functional managers who are closest to the facts; in other words, planning should be decentralized.
- Corporate-level planners should take on roles as facilitators who help business and functional managers do

the planning by setting the broad strategic goals of the organization and providing the resources necessary to identify the strategies that might be required to attain those goals.

Given the vision, mission and objectives and having analyzed the environmental opportunities and threats as well as the internal strengths and weaknesses of the firm, the next step in the strategic management process is generating feasible alternatives, evaluating those alternatives and choosing appropriate strategies for implementation. This process of generating, evaluating and selecting appropriate strategies is broadly referred to as "strategy analysis and choice". The firms current vision, mission and objectives as well as the firm's strategy coupled with information gathered through environmental and internal analysis, provide the basis for generating and evaluating feasible alternatives strategies.

Strategic alternatives are the different courses of action available to a firm to pursue its objectives at a given point of time. Generation of feasible alternatives is crucial for formulating and selecting appropriate strategies. But this is by no means an easy task, because there may be different strategic options available for accomplishing a particular objective.

The practice of generating strategic alternatives depends upon the size, style of management, characteristics of the industry and such other factors.

In a small organisation, all decisions are made by the owner or chief executive himself. These decisions deal with what an organization should do under alternative situations, what new businesses should be added, what existing businesses should be divested, whether to integrate forward or backward and such other strategic options are decided by the owner or chief executive of the organization.

In medium and large organizations, the following mechanisms may be employed for identifying strategic alternatives:

- **Brainstorming Sessions:**

  In most organizations, strategic alternatives are identified during brainstorming sessions of top management and key executives. In such meetings, participants generate a number of alternatives. At this stage, no importance is given to the relative merits and demerits of the options. In the next stage, each alternative is reviewed and subjected to close scrutiny. The alternatives which are considered fairly appealing are further examined and analyzed for final selection.

- **Special Meetings**

  Some large organizations may hold special meetings of top executives away from their work, in a hotel or a holiday resort. This is to ensure that the process of thinking is not disturbed by interruptions during the course of deliberations. The participants present different alternative scenarios along with their recommended courses of action. Depending on the assumptions and future trends, each course of action is discussed and attempts are made to finalize the best options for further analysis.

- **Outside Consultants**

  Some organizations may engage the services of an outside consultant to handle the process of generating alternative strategies. The premise is that an outsider can observe the phenomenon objectively and dispassionately, and bring in his own expertise into the process. The outside viewpoint is expected to be new and fresh, and thus can show up many new opportunities to the organization.

- **Joint Meetings**

  Another useful way of generating alternatives is to hire the services of a consultant and also associate some internal members in the process. This method has the advantage of blending the new ideas contributed by the outside consultants with workable solutions from within the organization. (Rao. et al. 2008)

Critical Success Factors

Critical success Factors are those product features that are particularly valued by a group of customers, and, therefore, where the organisation must excel to outperform competition.

Major Sources of CSFs

Rockart has identified four major sources of CSFs

- **Structure of the Industry:**

  Some CSFs are specific to the structure of the industry for e.g., the extent of service support expected by the customers. Automobile companies have to invest in building a national network of authorizes service stations to ensure service delivery to their customers.

- **Competitive strategy, industry position and geographic location:**

  CSFs also arise from the above factors for e.g. the large pool of English- speaking manpower makes India an attractive location for outsourcing the BPO needs of American and British firms.

- **Environmental Factors:**

  CSFs may also arise out of general/business environment of a firm, like the deregulation of Indian industry. With the deregulation of telecommunication industry, many private companies had opportunities of growth.

- **Temporal factors:**

  Certain short-term organisational developments like sudden loss of critical manpower (like the charismatic CEO) or break-up of the family owned business, may necessitate CSFs like ‘appointment of a new CEO’ or ‘rebuilding the company image’. Temporarily such CSFs would remain CSFs till the time they are achieved.

  In the process of developing alternatives, it may be useful to narrow down the range of options by identifying the more promising alternatives, in the light of the Critical Success Factor (CSFs). The options relevant to those factors may be analyzed along with a forecast of their outcome.

Strategic Decision Making

- Rationality of human decision makers is bounded by our own cognitive capabilities.
- We tend to fall back on certain rules of thumb or heuristics that help us to make sense out of a complex and uncertain world.
- They at times lead to severe and systematic errors in the decision making process.
- They arise out of a series of cognitive biases.

  Some of the biases are as follows:

  - **The prior hypothesis bias:** refers to the fact that decision makers who have strong prior beliefs about the relationship between two variables tend to make decisions on the basis of these beliefs, even when presented with evidence that their beliefs are wrong.
  - **Escalating commitment:** occurs when decision makers, having already committed significant resources to a project, commit even more resources even if they receive feedback that the project is failing.
  - **Reasoning by analogy:** involves the use of simple analogies (comparisons) to make sense out of complex problems. The problem with this heuristic is that the analogy may not be valid.
  - **Representativeness:** is rooted tendency to generalize from a small sample or even a single vivid

anecdote. This bias violates the statistical law of large numbers, which says that it is inappropriate to generalize from a small sample, let alone from a single case.

- **Illusion of control:** the tendency to over-estimate one's ability to control events. They tend to be overconfident about their ability to succeed. According to Richard Roll, such overconfidence leads to what he has termed as the hubris hypothesis of takeover.

Techniques for Improving Decision Making

Devil's advocacy

It requires the generation of a plan, and a critical analysis of that plan. One member of the decision-making group acts as the devil's advocate, emphasizing all the reasons that might make the proposal unacceptable. In this way, decision makers can become aware of the possible perils of recommended courses of action.

Dialectic inquiry

It is more complex because it requires the generation of a plan (a thesis) and a counter-plan (an antithesis) that reflect plausible but conflicting courses of action. Strategic managers listen to a debate between advocates of the plan and counter-plan and then decide which plan will lead to higher performance. The purpose of the debate is to reveal the problems with the definitions, recommended courses of action, and assumptions of both plans. As a result of this exercise, strategic managers are able to form a new and more encompassing conceptualization of the problem, which then becomes the final plan (a synthesis). Dialectic inquiry can promote strategic thinking

The outside view

It requires planners to identify a reference class of analogous past strategic initiatives, determine whether those initiatives succeeded or failed, and evaluate the project at hand against those prior initiatives.

Source: Hill, Jones and Schilling (2015)

Group Think

- Concept was given by psychologist Irvin Janis.
- It occurs when a group of decision makers embarks upon a course of action without questioning underlying assumptions.
- Typically, a group coalesces (unites) around a person or policy.
- It ignores or filter out information that can be used to question the policy and develops after the fact rationalizations for its decision.
- Commitment to the mission or goals becomes based on an emotional rather than an objective assessment of the correct course of action.
- The consequences can be poor decisions.

Exercise

A. Theoretical Questions:

⊙ Multiple Choice Questions

1. This ________ provides the broad ‘data’ from which to identify key drivers of change.
   a. SWOT analysis
   b. BCG matrix
   c. PESTEL analysis
   d. Critical Success Factors
2. Environment is ________.
   a. complex
   b. dynamic
   c. Multi-faceted
   d. All of the above
3. ____________are the growth rate of the economy, interest rates, currency exchange rates, and inflation (or deflation) rates.
   a. Macro-economic forces
   b. Demographic forces
   c. Technological forces
   d. Political forces
4. ___________ are outcomes of changes in the characteristics of a population.
   a. Macro-economic forces
   b. Demographic forces
   c. Technological forces
   d. Political forces
5. What describes the categories of activities within and around an organisation, which together create a product or service?
   a. SWOT analysis
   b. BCG framework
   c. Value Chain
   d. Brain storming
6. _______________transform these inputs into the final product or service.
   a. Operations
   b. Inbound logistics
   c. Outbound logistics
   d. Service

7. _______includes those activities that enhance or maintain the value of product or service, such as installation, repair, training and spares.

   a. Operations

   b. Inbound logistics

   c. Outbound logistics

   d. Service

8. _________are companies that are not currently competing in an industry, but have the capability to do so if they choose.

   a. Established companies

   b. Potential competitors

   c. Rivals

   d. Competitors

9. Absolute cost advantages arise from

   a. superior production operations and processes

   b. control of particular inputs required for production

   c. access to cheaper funds

   d. all of the above

10. A __________is a business unit in a growing market, but not yet with high market share.

    a. cash cow

    b. dog

    c. question mark

    d. star

11. What does a "star" represent in the BCG Matrix?

    a) Products with high market share in a high-growth market

    b) Products with low market share in a low-growth market

    c) Products with high market share in a low-growth market

    d) Products with low market share in a high-growth market

12. What is the strategic implication for products categorized as "cash cows" in the BCG Matrix?

    a) Invest heavily to maintain or increase market share

    b) Harvest profits to invest in other business units

    c) Explore opportunities for market expansion

    d) Phase out the product from the market

13. The threat of new entrants is high when:

    a) There are high switching costs for customers

    b) Existing companies have established brand loyalty

    c) There are low barriers to entry

    d) Customer demand is low

14. How does Porter's Value Chain framework help in strategic management?

    a) By analyzing macroeconomic factors impacting the industry

    b) By identifying areas where the company can gain a competitive advantage through cost leadership or differentiation

    c) By focusing solely on financial performance metrics

    d) By monitoring customer satisfaction levels

15. Which of the following activities involves receiving, storing, and distributing inputs to the production process?

    a) Operations

    b) Outbound logistics

    c) Inbound logistics

    d) Marketing and sales

16. How does the PESTEL analysis framework assist in strategic planning?

    a) By focusing solely on internal factors of a business

    b) By evaluating external factors that may impact business operations

    c) By assessing customer preferences and buying behaviours

    d) By determining financial performance metrics

17. What does the McKinsey 7S Framework consider to be the "Hard S's"?

    a) Strategy, Structure, and Staff

    b) Strategy, Structure, and Systems

    c) Systems, Staff, and Skills

    d) Skills, Structure, and Systems

Answer:

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
c	d	a	b	c	a	d	b	d	c	a	b	c	b	c	b	b

- **State True or False**

1. Entry barriers are economic, strategic, and emotional factors that prevent companies from leaving an industry.
2. Value chain puts corporate headquarters into the role of an internal banker.
3. Decentralised planning involves formulating plans that are based upon “what-if” scenarios about the future.
4. Critical success Factors are those product features that are particularly valued by an organisation.
5. Escalating commitment is rooted tendency to generalize from a small sample or even a single vivid anecdote.
6. Group Think concept was given by psychologist Daniel Goleman.
7. Growing demand tends to increase rivalry.
8. Companies in fragmented industries sometimes seek to reduce threat by following the prices set by the dominant company in the industry.
9. A fragmented industry consists of a large number of small or medium-sized companies, each is in a position to determine industry price.
10. When switching costs are low, customers can be locked in to the product offerings of established companies.
11. Established companies are companies that are not currently competing in an industry, but have the capability to do so if they choose.
12. Social influences refer to innovations such as artificial intelligence, internet, nano-technology, or the rise of new composite materials.

Answer:

1	2	3	4	5	6	7	8	9	10	11	12
F	F	F	F	F	F	F	F	F	F	F	F

3. **Fill in the Blanks**

1. An ______is a group of firms producing the same principal product or service.
2. _________activities are directly concerned with the creation or delivery of a product or service.
3. ________logistics are activities concerned with receiving; storing and distributing inputs to the product or service.
4. Service includes those activities that ______or _________the value of product or service.
5. ________helps to identify the sources of competition in an industry or sector.
6. ________competitors are companies that are not currently competing in an industry, but have the capability to do so if they choose.
7. _________companies are those which are already operating in an industry.
8. _________exists when consumers have a preference for the products of established companies.

9. Rivalry refers to the _________struggle between companies within an industry to gain market share from each other.

10. A __________industry consists of a large number of small or medium-sized companies, none of which is in a position to determine industry price.

11. A ______industry is dominated by a small number of large companies (an oligopoly) or, in extreme cases, by just one company (a monopoly), and companies often are in a position to determine industry prices

Answer:

1	industry	**2**	Primary
3	Inbound	**4**	enhance, maintain
5	Porter's Five Forces framework	**6**	Potential
7	Established	**8**	Brand loyalty
9	competitive	**10**	fragmented
11	consolidated		

Short Essay Type Questions

1. What do you understand by the term 'business environment'?
2. Mention the differences between industry and sector.
3. What is value chain?
4. When according to Porter the buyers have greater bargaining power?
5. According to Porter's Five forces Framework, when the suppliers enjoy a greater bargaining power?
6. What are the steps for conducting SWOT analysis?
7. What do you understand by the term 'complementors'?
8. Explain portfolio analysis.
9. What are the objectives of portfolio analysis?
10. What are the benefits of BCG matrix?
11. What is scenario planning?

Essay Type Questions

1. Explain the different layers of 'business environment'?
2. What are the different characteristic features of 'business environment'?
3. Give a detailed explanation of the PESTEL framework.
4. What are the activities involved in value chain of an organisation?

5. Write a short note on ‘risk of entry by potential competitors’ as given by Porter in his Five Forces Framework.
6. What are the factors that determine the rivalry among established firms according to Porter’s Five Forces Framework?
7. What are the limitations of SWOT analysis?
8. What are the advantages and limitations of portfolio analysis?
9. Explain the four sorts of business as given in the BCG matrix.
10. Identify the limitations of BCG matrix.
11. Write a short note on the steps in a formal strategic planning process.
12. What are the techniques that can help to improve decision making?
13. What do you understand by the term Critical Success Factors? What are the sources of Critical Success Factors?

Formulation and Implementation of Strategy

10

This Module Includes

Formulation and Implementation of Strategy

SLOB Mapped against the Module

To develop the ability to identify, understand, assimilate, and use innovative strategies to create and sustain competitive advantage.

Module Learning Objectives:

After studying this module, the students will be able to:

Students should understand that successful strategy formulation does not guarantee successful strategy implementation. The complexities in the task of implementation arise from a number of organisational adjustments that are required over an extended period of time and the need to match them all to the strategy. In fact the very essence of strategic success lies at the operational level. No matter how good a strategy has been developed, if it is not properly executed then the strategy is not likely to give the desired results. This chapter will enable students to understand the importance of the following areas in formulation and implementation of strategy:

- Formulation of strategy with respect to the functional areas (Production, Supply, Marketing and Human Resource).
- Structuring organisations for strategy implementation.
- Identification of an organisation's SBUs.
- Restructuring business to cut costs and return to profitability (Business Process Reengineering).
- Understand the concept and approaches to management control, operational control and task control.

Introduction

10

Successful strategy formulation does not guarantee successful strategy implementation. The complexities in the task of implementation arise from a number of organisational adjustments that are required over an extended period of time and the need to match them all to the strategy. Key people need to added or reassigned, resource have to be mobilised and allocated, functional strategies and policies are to be designed, organisational structures may have to be changed, a strategy- supportive culture may have to be developed, rewards and incentive plans are to be revised and if necessary, restructuring, re-engineering and redesigning becomes imperative. In short the difficulties in affecting the organisational adjustments arise from the tasks associated with change. The success of strategic implementation to a large extent, therefore, depends on the way the task of change management is carried out. Implementation of strategy involves a number of interrelated decisions, choices, and a broad range of activities. It requires an integration of people, structures, processes etc

Strategy Formulation - Production Strategy, Supply Chain Strategy, Marketing Strategy, Human Resource Strategy

10.1

The possession of resources (including people) does not guarantee strategic success. Strategic capability is concerned with how these resources are deployed, managed and controlled to create competences in those activities and business processes needed to run the business. The formulation of strategy with respect to the functional areas namely production, supply chain, marketing and human resource is discussed hereunder:

Production Strategy

- The production system is concerned with the capacity, location, layout, product or service design, work systems, degree of automation, extent of vertical integration and such factors.
- Plans and policies related to production system are significant as they deal with vital issues affecting the capability of the organisation to achieve its objectives.
- Strategy implementation would have to take into account the production system factors. It should be noted that any decision on production system factors would have a long lasting influence on the operations capability of an organisation and its ability to implement strategies and achieve objectives.
- Production strategy determines how and where a product or service manufactured, the level of vertical integration in the production processes, the deployment of physical resources, and relationships with suppliers.
- It should also deal with the optimum level of technology that the firm should use in its operations processes.
- A firm's production strategy is often affected by a product's life cycle. As the sales of the product increase, there will be an increase in the production volume ranging from lot sizes as low as one in a job shop through connected line batch flow to lot sizes as high as 100000 or more per year for flexible manufacturing systems and dedicated transfer lines.
- According to the concept, the product becomes standardised in to a commodity over time in conjunction with increasing demand. Flexibility thus gives way to efficiency.
- Increasing competitive intensity in many industries has forced companies to switch from traditional mass production using dedicated transfer lines to a continuous improvement production strategy.
- A mass production system was an excellent method to produce large number of low cost, standard goods and services.
    - Under this system the workers were expected to learn what was assigned to them and learning how to do better was the sole prerogative of the management.
    - Quality often tended to be fairly low as the employees worked on narrowly defined, repetitious tasks under the close supervision in a bureaucratic and hierarchal structure.

- Under the continuous improvement system developed by Edwards Deming and perfected by Japanese firms, companies empowered cross-functional teams to continuously strive to improve production processes.
- Mangers role have been more of a coach than as a boss. This resulted in not only standard good and services at low cost bit of superior quality.
- The key to continuous improvement is the acknowledgement that workers' experience and knowledge can help managers solve production problems and contribute to tightening variances and reducing errors.

The automobile industry is currently experimenting with the strategy of modular manufacturing in which preassembled subassemblies are delivered as they are needed (JIT) to a company's assembly line workers, who quickly piece the modules together into a finished product.

It may be mentioned that it is not only the manufacturing organisations who are concerned about the production system they adopt. Service organisations, such as the resort company club Mahindra, too look to customisations as a means to identify a distinct market segment to serve. In case, the company customises the vacations offered. This is based on the unique needs of its customer, who are young metropolitans looking for a change from the routine jobs and sedentary life style with much time spent in air conditioned environment to indulge in energetic activities in open spaces. Club Mahindra has a separate division called Zest to look after this customer group.

The issue of sustainability is cause of concern for most of the manufacturing companies throughout the world as the availability of resources needed to operate a modern factory is increasingly becoming scarce and costly. One of the resources that have been major cause of concern is the increasing cost of oil that has led to drastically boosting cost of production. Although some of the costs can be passed on the customers, however, in the fiercely competitive environment maintaining cots at the optimum level is the key to success. This is an important challenge for most of the organisations. The likelihood that fresh water will become an equally scarce resource is causing many companies to rethink water- intensive manufacturing processes. The issue of reducing global warming and carbon emissions have become major agenda of all the countries. The uses of eco friendly technologies have become the focused area of the manufacturing sector. The increasing government regulations towards cleaner and eco friendly technologies have increased costs on research and development.

Supply Chain Strategy

- The term supply chain management refers to the task of managing the flow of inputs and components from suppliers into the company's production processes to minimize inventory holding and maximize inventory turnover.
- The contribution of materials management (logistics) to boosting the efficiency of a company can be just as dramatic as the contribution of production and marketing.
- Materials management encompasses the activities necessary to get inputs and components to a production facility (including the costs of purchasing inputs), through the production process, and out through a distribution system to the end-user. Because there are so many sources of cost in this process, the potential for reducing costs through more efficient materials management strategies is enormous. For a typical manufacturing company, materials and transportation costs account for 50 to 70% of its revenues, so even a small reduction in these costs can have a substantial impact on profitability.
- In a typical competitive market, reducing materials costs by 3% is usually much easier than increasing sales revenues by 30%.
- Improving the efficiency of the materials-management function typically requires the adoption of a just-in-time (JIT) inventory system, which is designed to economize on inventory holding costs by scheduling components

to arrive at a manufacturing plant just in time to enter the production process, or to have goods arrive at a retail store only when stock is almost depleted.

- The major cost saving comes from increasing inventory turnover, which reduces inventory holding costs, such as warehousing and storage costs, and the company's need for working capital.
- Wal-Mart can replenish the stock in its stores at least twice a week; many stores receive daily deliveries if they are needed through efficient logistics. The typical competitor replenishes its stock every 2 weeks, so it must carry a much higher inventory, which requires more working capital per dollar of sales. Compared to its competitors, Wal-Mart can maintain the same service levels with a lower investment in inventory, a major source of its lower cost structure. Thus, faster inventory turnover has helped Wal-Mart achieve an efficiency-based competitive advantage in the retailing industry.
- Source: Hill, C.W. L., Jones, G. R. and Schilling, M. A. (2015). Strategic Management Theory. 11th edition. Cengage Learning. Stamford City, pg158
- More generally, in terms of the profitability model developed, JIT inventory systems reduce the need for working capital (because there is less inventory to finance) and the need for fixed capital to finance storage space (because there is less to store), which reduces capital needs, increases capital turnover, and, by extension, boosts the return on invested capital.

Limitations of JIT

The drawback of JIT systems is that they leave a company without a buffer stock of inventory. Although buffer stocks are expensive to store, they can help a company prepare for shortages on inputs brought about by disruption among suppliers (for instance, a labour dispute at a key supplier), and can help a company respond quickly to increases in demand.

Overcoming limitations of JIT

However, there are ways around these limitations.

- In order to reduce the risks linked to dependence on just one supplier for an important input, a company might decide to source inputs from multiple suppliers.
- Plans and policies related to operations planning and control are concerned with aggregate production planning; materials supply; inventory, cost and quality management; and maintenance of plant and equipment. Here, the aim of strategy implementation is to see how efficiently resources are utilised and in what manner the day-to-day operations can be managed in the light of long-term objectives.
- Operations planning and control provides an example of an organisational activity that is aimed at translating the objectives into reality.

Marketing Strategy

- The marketing strategy that a company adopts can have a major impact on efficiency and cost structure.
- Marketing strategy refers to the position that a company takes with regard to market segmentation, pricing, promotion, advertising, product design, and distribution.
- Some of the steps leading to greater efficiency are fairly obvious. For example, moving down the experience curve to achieve a lower cost structure can be facilitated by aggressive pricing, promotions and advertising all of which are the task of the marketing function.
- Other aspects of marketing strategy have a less obvious but no less important impact on efficiency. One important aspect is the relationship of customer defection rates, cost structure, and unit costs.

- Customer defections (or 'churn rates') are the percentage of a company's customers who defect every year to competitors.
- Defection rates are determined by customer loyalty, which in turn is a function of the ability of a company to satisfy its customers.
- Because acquiring a new customer often entails one-time fixed costs, there is a direct relationship between defection rates and costs. For example, when a wireless service company signs up a new subscriber, it has to bear the administrative costs of opening up a new account and the cost of a subsidy that it pays to the manufacturer of the handset the new subscriber decides to use.
- There are also the costs of advertising and promotions designed to attract new subscribers.
- The longer a company retains a customer, the greater the volume of customer generated unit sales that can be set against these fixed costs, and the lower the average unit cost of each sale.
- Thus, lowering customer defection rates allows a company to achieve a lower cost structure
- Because of the relatively high fixed costs of acquiring new customers, serving customers who stay with the company only for a short time before switching to competitors often leads to a loss on the investment made to acquire those customers.
- The longer a customer stays with the company, the more the fixed costs of acquiring that customer can be distributed over repeat purchases, boosting the profit per customer.
- Thus, there is a positive relationship between the length of time that a customer stays with a company and profit per customer.
- If a company can reduce customer defection rates, it can make a much better return on its investment in acquiring customers, and thereby boost its profitability.
- Another economic benefit of long-time customer loyalty is the free advertising that customers provide for a company.
- Loyal customers can dramatically increase the volume of business through referrals.

The key message, then, is that reducing customer defection rates and building customer loyalty can be major sources of a lower cost structure. A central component of developing a strategy to reduce defection rates is to identify customers who have defected, find out why they defected, and act on that information so that other customers do not defect for similar reasons in the future. To take these measures, the marketing function must have information systems capable of tracking customer defections.

Human Resource Strategy

Employee productivity is one of the key determinants of an enterprise's efficiency, cost structure, and profitability. Productive manufacturing employees can lower the cost of goods sold as a percentage of revenues, a productive sales force can increase sales revenues for a given level of expenses, and productive employees in the company's R&D function can boost the percentage of revenues generated from new products for a given level of R&D expenses. Thus, productive employees lower the costs of generating revenues, increase the return on sales, and, by extension, boost the company's return on invested capital. The challenge for a company's human resource function is to devise ways to increase employee productivity. Among its choices are using certain hiring strategies, training employees, organizing the workforce into self-managing teams, and linking pay to performance.

- ⦿ Hiring Strategy: Many companies that are well known for their productive employees devote considerable attention to hiring. Organisations hire people who have a positive attitude and who work well in teams because it believes that people who have a positive attitude will work hard and interact well with customers, therefore helping to create customer loyalty. It is important to be sure that the hiring strategy of the company is consistent with its own internal organization, culture, and strategic priorities. The people a company hires should have attributes that match the strategic objectives of the company. Employee Training Employees are a major input into the production process. Those who are highly skilled can perform tasks faster and more accurately, and are more likely to learn the complex tasks associated with many modern production methods than individuals with lesser skills. Training upgrades employee skill levels, bringing the company productivity related efficiency gains from learning and experimentation.

⦿ **Self-Managing Teams:**

- The use of self-managing teams, whose members coordinate their own activities and make their own hiring, training, work, and reward decisions, has been spreading rapidly.
- The typical team comprises 5 to 15 employees who produce an entire product or undertake an entire task.
- Team members learn all team tasks and rotate from job to job.
- Because a more flexible workforce is one result, team members can fill in for absent co workers and take over managerial duties such as scheduling work and vacation, ordering materials, and hiring new members.
- The greater responsibility thrust on team members and the empowerment it implies are seen as motivators. (Empowerment is the process of giving lower-level employees decision-making power.)
- People often respond well to being given greater autonomy and responsibility.
- Performance bonuses linked to team production and quality targets work as an additional motivator.
- The effect of introducing self-managing teams is reportedly an increase in productivity of 30% or more and a substantial increase in product quality.
- Further cost savings arise from eliminating supervisors and creating a flatter organizational hierarchy, which also lowers the cost structure of the company.
- In manufacturing companies, perhaps the most potent way to lower the cost structure is to combine self-managing teams with flexible manufacturing cells.
- Still, teams are no panacea; in manufacturing companies, self-managing teams may fail to live up to their potential unless they are integrated with flexible manufacturing technology.
- Also, teams place a lot of management responsibilities upon team members, and helping team members to cope with these responsibilities often requires substantial training a fact that many companies often forget in their rush to drive down costs.
- Haste can result in teams that don’t work out as well as planned.
- Pay for Performance: It is hardly surprising that linking pay to performance can help increase employee productivity, but the issue is not quite so simple as just introducing incentive pay systems. It is also important to define what kind of job performance is to be rewarded and how. Some of the most efficient companies in the world, mindful that cooperation among employees is necessary to realize productivity gains, link pay to group or team (rather than individual) performance. This link creates a strong incentive for individuals to cooperate with each other in pursuit of team goals; that is, it facilitates teamwork.

The knowledge and experience of people can be the key factors influencing the success of strategies. So people-related issues should be a central concern and responsibility of most managers in organisations and are not confined to a specialist HR function. Creating a climate where people strive to achieve success is also a crucial role of any manager. Although formal HR systems and structures may be vitally important in supporting successful strategies, it is quite possible that they may hinder strategy if they are not tailored to the types of strategies being pursued. There are three possible related issues about the people dimension of strategy namely, people as a resource, people and behaviour and the need to organise people.

People as a resource

The importance of human resource cannot be undermined. The management of this resource is not similar to the other resources of the organisation. There a lot of issues with respect to managing human resource. Some are called the 'harder' issues and the others 'softer' ones.

The harder issues are the traditional HR activities that can help underpin successful strategies in the following ways:

- Audits to assess HR requirements to support strategies and/or identify people based core competences on which future strategies might be built.
- Goal-setting and performance assessment of individuals and teams. Most organisations will expect line managers to undertake these tasks, usually within a centrally designed appraisal scheme. This improves the chances of appraisals being linked to strategy. Also, there has been a move towards so-called 360° appraisals. These assess an individual's performance from multiple perspectives not just from the line manager but also from other parts of the organisation on which the work of the individual and/or his or her team impacts and even from external stakeholders. This is an attempt to assess the full impact of an employee's work on the success of strategy.
- In many organisations the planning of rewards has had to take on board the reality of more team working in delivering strategy. Highly geared individual incentives (often found in sales forces) may undermine this teamwork.
- Recruitment and retention are key ways of improving strategic capability. For example, many public sector organisations have needed to recruit and retain people with marketing and IT skills as they try to get closer to their customers and exploit IT. As organisations face faster changes, succession planning has had to be refocused away from preparing people for particular jobs to simply ensuring that a sufficiently large pool of talented individuals exists to meet future leadership requirements. In some cases an organisation's strategy may require uniquely competent individuals, such as a top surgeon in a hospital, a criminal lawyer or a leading academic in a university. In contrast, some strategies might require redeployment and redundancy planning.
- Many training and development plans have reduced the use of formal programmes in favour of more coaching and mentoring to support self-development. In order to put in place and execute HR strategies in all these areas,
- managers and HR professionals need to be familiar with the organisation's strategies, how these might be changing in the future and the implication to people's competences.
- Many companies might attempt this alignment through formalised approaches to performance management assisted by IT-based systems. However; it is not enough simply to adjust the performance management processes to support changing strategies.
- Managers need to be able and willing to envisage a future where the strategies and performance of the organisation are transformed by exploiting the performance management capabilities of the organisation better than their competitors. For example, a capability in mentoring and coaching could provide an environment

that will attract creative people who like to be challenged and to learn. In turn, this creates a workforce that is much more able than competitors to 'think out of the box' and to produce innovative product features and new ways of competing in the market. This will require organisation structures and processes to support these behaviours.

People and behaviour

People are not like other resources. They influence strategy both through their competence and through their collective behaviour (culture). It may be emphasised that many of the problems of managing change result from a failure to understand, address and change culture. This 'soft' side of HR management is concerned with the behaviour of people – both individually and collectively. The softer issues include the following:

- Understanding how they may need to change the paradigm of the organisation. This is particularly important when the business environment is changing quickly.
- Seeing their own role as people-oriented 'shapers of context' and not just as 'business analysts'. This will require an understanding of how these 'softer' aspects of strategy help or hinder strategic success.
- Understanding the relationship between behaviours and strategic choices. This is crucial if managers are properly to prioritise their efforts in managing organisational behaviours. For example, there may be some strategies where an organisation's current culture gives unique advantage over other organisations. Culture is a core competence.
- Being realistic about the difficulty and time-scales in achieving behaviour changes. Culture change is a long process of changing behaviours. The hard change tools (structures and systems) if used alone are unlikely to deliver.
- Being able to vary their style of managing change with different circumstances. So a manager's relationship and leadership skills with both internal and external stakeholders are important. Also, teams in organisations must be capable of operating different styles simultaneously. Therefore, a manager's ability to build and maintain teams of different personality types is just as important as the mix of competences in those teams.

Organising People

Organising people is important for an organisation to be competitively superior. With the changing environment and complexities arising from both within and outside the organisation the issues relating to organising people needs to be addressed carefully. Organising people may be broadly discussed into the following three areas namely HR function, Line managers and structure and processes.

The HR function

There are a number of important considerations concerning the HR function in organisations. The most challenging question is whether a specialist HR function is needed at all, or at least whether its traditional scale and functions are appropriate. In principle (and in practice in many organisations), people can be managed strategically without a specialist HR function. This may make sense for some HR issues for example, the dismantling of across-company grades and pay scales as organisations globalise to reflect the much greater diversity in the labour markets. But for other aspects the reverse might be true. For example, a major problem of highly devolved organisations is that managers at 'lower' levels are unfamiliar with corporate-level strategies, are extremely busy and may not have the professional HR knowledge. If an HR function is felt to be valuable then the expectations as to its role must be clear and consistent with the discussion above. There are four broad roles that an HR function could fulfil in contributing to successful business strategies:

- As a service provider (for example, undertaking recruitment or arranging training) to line managers who are carrying the strategic responsibility for the HR issues.

- As a regulator 'setting the rules' within which line managers operate, for example on pay and promotions.
- As an advisor on issues of HR strategy to line managers (ensuring that HR policies and practice are in line with the 'best practice').
- As a change agent moving the organisation forward. The determinants of the most appropriate role for an HR function are the organisation's context. The type of staff, the nature of the strategy and the broad structural arrangements in the organisation are all important. Of course it may prove difficult for the same HR specialists to operate in all of these roles simultaneously. For example, they may feel a conflict between their role as a regulator whilst trying to advise or change a group of people in the organisation.

Middle (line) managers

It has been mentioned above that there has been a significant move towards line managers being centrally involved in managing people issues themselves. This has the clear advantage of more ownership and a better chance of blending people related issues with business strategies. But there are also worries and research confirms the concerns as to whether the circumstances in which line managers operate are conducive to their doing a good job on people management issues:

- Whether it is realistic to expect line managers to be competent HR professionals. Handled badly, this could be a formula for mediocrity. This same concern could equally be applied to other areas such as information management.
- The short-term pressures to meet targets do not help line managers in taking a more strategic view of people-related issues. Downsizing and de-layering have left the remaining managers too busy.
- Trade unions and professional associations have tended to resist a dispersion of responsibility for HR strategies. From a union's point of view it is much easier to deal with a single, centralised authority. Professional bodies may take a similar view.
- Managers may lack the incentive to take on more of the formal HR activities, either directly in their pay or grade or indirectly in their judgement as to which competences make them more marketable outside the company. Despite these concerns it is important to recognise the crucial influence of middle managers on the day-to-day performance and behaviour of people in their organisation. The implication for top managers is not to bypass middle managers in the strategy development process; otherwise the changes may not stick with the people in the organisation.

Structures and processes

People may be held back from contributing to strategic success because the traditional structures and roles do not match future strategies. Also, as circumstances and strategies change, organisations may need to change the processes and relationships. Another challenge is whether some HR issues (for example, recruitment, training, etc.) should reside in the organisation or be bought in from specialist suppliers (for example, consultants). External agencies will have the advantage of a wider experience and knowledge of best practice but the disadvantage of being unfamiliar with the detailed circumstances of specific organisations. [Johnson, Scholes and Whittington, R. (2008)]

Structuring of Organisation for Implementation of Strategy

10.2

Managers often describe their organisation by drawing an organisation chart, mapping out its formal structure. These structural charts define the 'levels' and roles in an organisation. They are important to managers because they describe who is responsible for what. But formal structures matter in at least two more ways.

- First, structural reporting lines shape patterns of communication and knowledge exchange: people tend not to talk much to people much higher or lower in the hierarchy, or in different parts of the organisation.
- Second, the kinds of structural positions at the top suggest the kinds of skills required to move up the organisation: a structure with functional specialists such as marketing or production at the top indicates the importance to success of specialised functional disciplines rather than general business experience.

In short, formal structures can reveal a great deal about the role of knowledge and skills in an organisation.

The five basic structural types: are functional, multidivisional, matrix, transnational and project. Broadly, the first two of these tend to emphasise one structural dimension over another, either functional specialism or business units. The three that follow tend to mix structural dimensions more evenly, for instance trying to give product and geographical units equal weight. However, none of these structures is a universal solution to the challenges of organising. Rather, the right structure depends on the particular kinds of challenges each organisation faces.

- **The Functional Structure**

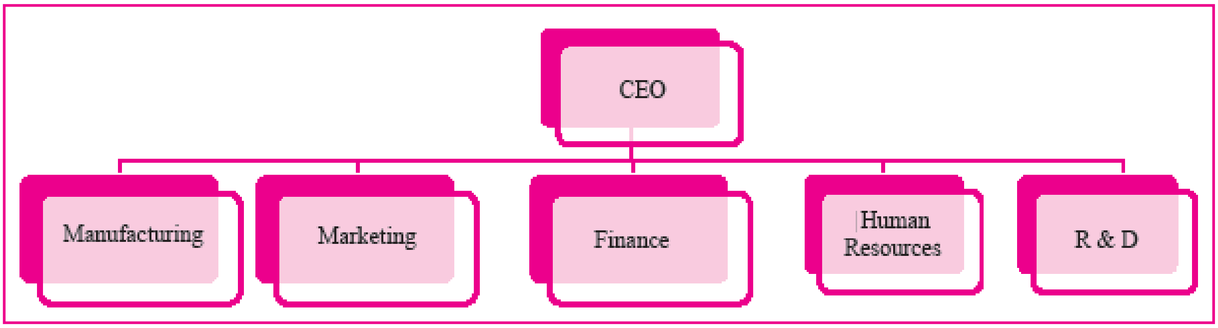


Figure 10.1: Functional Structure

A functional structure is based on the primary activities that have to be undertaken by an organisation such as production, finance and accounting, marketing, human resources and research and development. This structure is usually found in smaller companies, or those with narrow, rather than diverse, product ranges. Also, within a multidivisional structure the divisions themselves may be split up into functional departments. The potential advantages of a functional structure include

- It gives senior managers direct hands-on involvement in operations and allows greater operational control from the top.
- The functional structure provides a clear definition of roles and tasks, increasing accountability.
- Functional departments also provide concentrations of expertise, thus fostering knowledge development in areas of functional specialism.
- Centralised decision making and more efficient use of managerial and technical talent.

However, there are disadvantages, particularly as organisations become larger or more diverse.

- Perhaps the major concern in a fast-moving world is that senior managers focus on their functional responsibilities, becoming overburdened with routine operations and too concerned with narrow functional interests. As a result, they find it hard either to take a strategic view of the organisation as a whole or to manage coordinated responses quickly. Thus functional organisations can be inflexible.
- Separate functional departments tend also to be inward looking – so-called 'functional silos' – making it difficult to integrate the knowledge of different functional specialists.
- Finally, because they are centralised around particular functions, functional structures are not good at coping with product or geographical diversity. For example, a central marketing department may try to impose a uniform approach to advertising regardless of the diverse needs of the organisation's various SBUs around the world.
- Overburdens the top management, as functional conflicts are pushed up.
- Line staff conflicts and difficult to establish uniform standards across the organisation.

Electrolux Home Products Europe

Functional Structures can help in bringing uniformity and simplicity into a business.

Solved Case 1

In January 2001, Electrolux Home Products Europe completely redesigned its structure as part of its competitive strategy in Europe. The Swedish multinational company manufactured a range of consumer durables - such as cookers and fridges - and had grown through several decades of acquisitions to become a dominant player in Europe. But the market in Europe was fiercely competitive and the company needed to find a way to capitalise on its size - both to reduce costs and also to improve product and service standards. Their solution was to introduce a Europe-wide functional structure to replace the geographical structure (resulting from its acquisitions).

The management explained the rationale for the restructuring: 'the realignment of EHP Europe is a part of a programme to ensure profitable growth as the organisation drives more simplicity into its business, while reducing the number of organisational hand-offs, and creating more focus on areas where increased effort is required to meet the tougher challenges of the market-place'. The functional departments would operate as follows:

Purchasing, Production and Product Development was the manufacturing arm of the business. It also included product development and purchasing to provide a seamless flow from suppliers to finished products. This was felt to be essential to maintaining a stream of innovative and cost effective products.

Supply Chain Management and Logistics was responsible for getting products to the customer and was the link between sales forecasts and factory production.

Product Businesses, Brand Management and Key Account Management was responsible for the marketing activities to support products and brands. It also included key account management service and spare parts.

Sales clusters were the sales divisions and were grouped geographically into seven clusters. The first three divisions were managed as cost centres whilst the sales clusters were focused on sales revenue.

Source: Johnson and Scholes (2006), Exploring Corporate Strategy-Text and Cases, sixth edition, Pearson education, pg 462

- **The Multidivisional Structure**

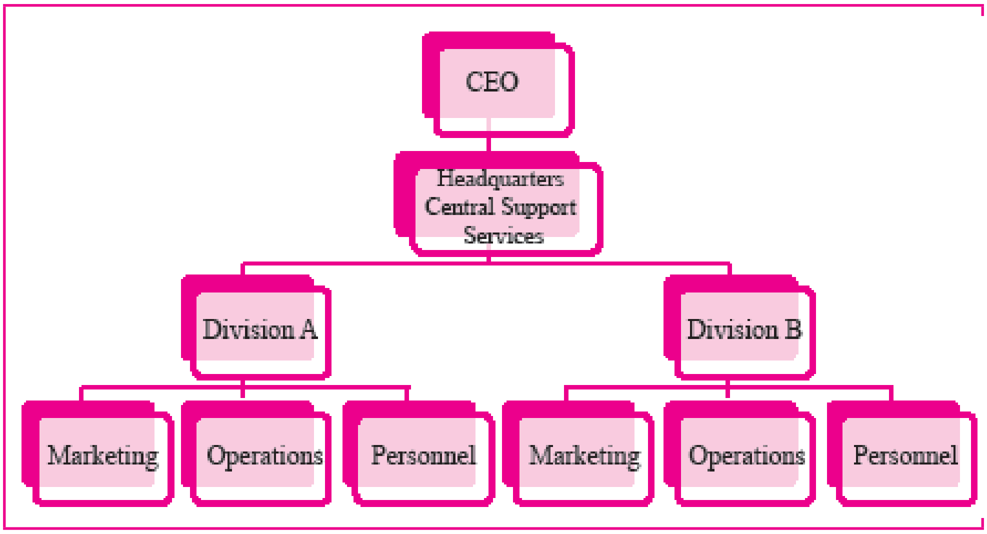


Figure 10.2: Multidivisional Structure

A multidivisional structure is built up of separate divisions on the basis of products, services or geographical areas. Divisionalisation often comes about as an attempt to overcome the problems that functional structures have in dealing with the diversity mentioned above. Each division can respond to the specific requirements of its product/ market strategy, using its own set of functional departments.

A similar situation exists in many public services, where the organisation is structured around service departments such as recreation, social services and education.

There are several potential advantages to divisional structures.

- They are flexible in the sense that organisations can add, close or merge divisions as circumstances change.
- As self-standing business units, it is possible to control divisions from a distance by monitoring business performance.
- Divisional managers have greater personal ownership for their own divisional strategies.
- There can be benefits of specialisation within a division, allowing competences to develop with a clearer focus on a particular product group, technology or customer group.
- Management responsibility for a whole divisional business is good training in taking a strategic view for managers expecting to go on to a main board position.
- Conflicts across functional areas can be minimised with increased accountability and focus.

However, divisional structures can also have disadvantages of three main types.

- Divisions can become so self-sufficient that they are de facto independent businesses, but duplicating the functions and costs of the corporate centre of the company. So it may make more sense to split the company into independent businesses, and demergers of this type have been very common.
- Divisionalisation tends to get in the way of cooperation and knowledge sharing between business units: divisions can quite literally divide. Expertise is fragmented and divisional performance targets provide poor incentives to collaborate with other divisions.
- Divisions may become too autonomous, especially where joint ventures and partnership dilute ownership. In these cases, multidivisional degenerate into holding companies, where the corporate centre effectively 'holds' the various businesses in a largely financial sense, exercising little control and adding very little value.
- Differences in image and quality may occur across divisions.
- There are chances of divisions focusing on short term performances with a perspective of dominating the organisation-wide process.

Large and complex multidivisional companies often have a second tier of subdivisions within their main divisions. Treating smaller SBUs as subdivisions within a large division reduces the number of units that the corporate centre has to deal with directly. Subdivisions can also help complex organisations respond to contradictory pressures. For example, an organisation could have geographical subdivisions within a set of global product divisions.

- **The Matrix Structure**

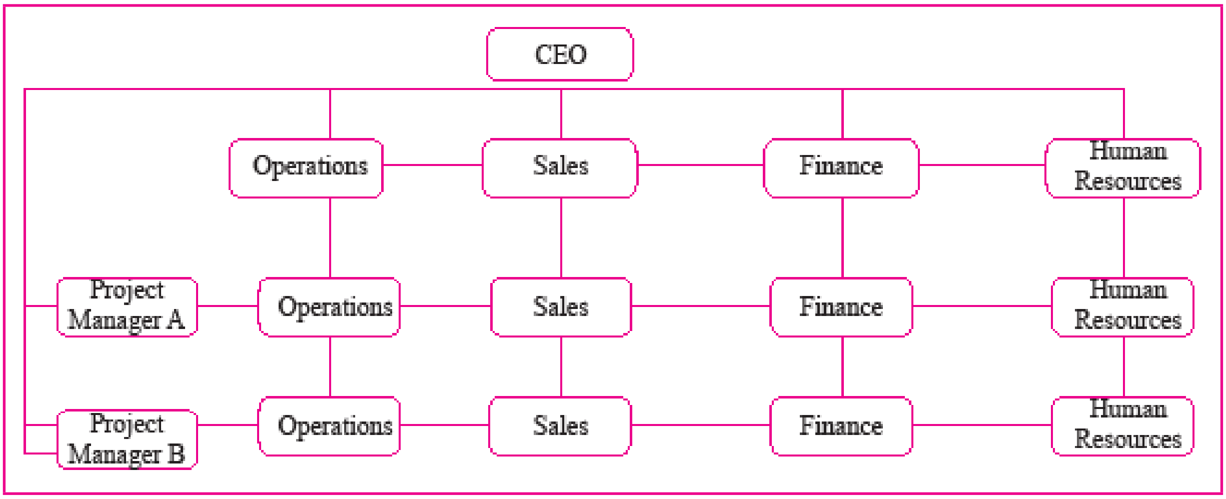


Figure 10.3: Matrix Structure

A matrix structure is a combination of structures which could take the form of product and geographical divisions or functional and divisional structures operating in tandem.

Matrix structures have several advantages.

- They are effective at knowledge management because they allow separate areas of knowledge to be integrated across organisational boundaries. Particularly in professional service organisations, matrix organisation can be helpful in applying particular knowledge specialisms to different market or geographical segments.

- Matrix organisations are flexible, because they allow different dimensions of the organisation to be mixed together. This permits innovation. They are particularly attractive to organisations operating globally, because of the possible mix between local and global dimensions. For example, a global company may prefer geographically defined divisions as the operating units for local marketing (because of their specialist local knowledge of customers). But at the same time it may still want global product divisions responsible for the worldwide coordination of product development and manufacturing, taking advantage of economies of scale and specialisation.
- Firms can use resources more efficiently.
- It provides professionals with broader range of responsibilities.

However, because a matrix structure replaces formal lines of authority with (cross-matrix) relationships, this often brings problems.

- In particular, it will typically take longer to reach decisions because of bargaining between the managers of different dimensions.
- There may also be conflict because staff find themselves responsible to managers from two structural dimensions.
- Matrix organisations are hard to control.
- There may be excessive reliance of group processes and teamwork.
- May erode timely decision making.

As with any structure, but particularly with the matrix structure, the critical issue in practice is the way it actually works (that is, the processes and relationships). The key ingredient in a successful matrix structure can be senior managers good at sustaining collaborative relationships (across the matrix) and coping with the messiness and ambiguity which that can bring.

- **The transnational structure**

A transnational structure combines the local responsiveness of the international subsidiary with the coordination advantages found in global product companies. The transnational structure seeks to obtain the best from the two extreme international strategies, the multi domestic strategy and the global strategy. A global strategy would typically be supported by global product divisions; a multi domestic strategy would be supported by local subsidiaries with a great deal of design, manufacturing and marketing autonomy for all products. The transnational structure, however, attempts to achieve both high local responsiveness and high global coordination. The transnational is like a matrix but has two specific features: first, it responds specifically to the challenge of internationalisation; second, it tends to have more fixed responsibilities within its crosscutting dimensions. The transnational has the following detailed characteristics:

- Each national unit operates independently, but is a source of ideas and capabilities for the whole corporation. For example, in Unilever, the centre for innovation in hair-care products worldwide is in France.
- National units achieve greater scale economies through specialisation on behalf of the whole corporation, or at least large regions. Unilever in Europe has replaced its web of small national food manufacturing units with a few specialised larger factories that export its products to other European countries.
- The corporate centre manages this global network by first establishing the role of each business unit, then sustaining the systems, relationships and culture to make the network of business units operate effectively. Unilever has established a system of ‘forums’ bringing managers together internationally to help them swap experience and coordinate their needs. The success of a transnational corporation is dependent on the ability

simultaneously to achieve global competences, local responsiveness and organisation wide innovation and learning. This requires clarity as to boundaries, relationships and the roles that the various managers need to perform. For example:

- Global business managers have the overriding responsibility to further the company's global competitiveness, which will cross both national and functional boundaries. They must be the product/market strategist, the architect of the business resources and competences, the driver of product innovation and the coordinator of transnational transactions.
- Country or area managers have potentially a dual responsibility to other parts of the transnational. First, they must act as a sensor of local needs and feed these back to those responsible internationally for new products or services. Second, they should seek to build unique competences: that is, becomes a centre of excellence which allows them to be a contributor to the company as a whole, in manufacturing or research and development, for instance.
- Functional managers such as finance or IT have a major responsibility for ensuring worldwide innovation and learning across the various parts of the organisation. This requires the skill to recognise and spread best practice across the organisation. So they must be able to scan the organisation for best practice, cross-pollinate this best practice and be the champion of innovations.
- Corporate (head office) managers integrate these other roles and responsibilities. Not only are they the leaders, but they are also the talent spotters among business, country and functional managers, facilitating the interplay between them. For example, they must foster the processes of innovation and knowledge creation. They are responsible for the development of a strong management centre in the organisation. There are some disadvantages to a transnational structure. It is very demanding of managers in terms of willingness to work not just at their immediate responsibilities but for the good of the transnational as a whole. Diffuse responsibilities also make for similar complexities and control problems to those of the matrix organisation.
- **Project-based structures**

  A project-based structure is one where teams are created, undertake the work and are then dissolved. This can be particularly appropriate for organisations that deliver large and expensive goods or services (civil engineering, information systems, films) or those delivering time-limited events (conferences, sporting events or consulting engagements). The organisation structure is a constantly changing collection of project teams created, steered and glued together loosely by a small corporate group. Many organisations use such teams in a more ad hoc way to complement the 'main' structure. For example, taskforces are set up to make progress on new elements of strategy or to provide momentum where the regular structure of the organisation is not effective.

Advantages of Project-based structures

- The project-based structure can be highly flexible, with projects being set up and dissolved as required.
- Accountability and control are good because project teams should have clear tasks to achieve within a defined life.
- Projects can be effective at knowledge exchange as project team members will typically be drawn from different departments within the firm..
- Projects can also draw members internationally and, because project life spans are typically short, project teams may be more willing to work temporarily around the world.

Disadvantages of Project-based structures

- Without strong programme management providing overarching strategic control, organisations are prone to proliferate projects in an ill-coordinated fashion.
- The constant breaking up of project teams can also hinder the accumulation of knowledge over time or within specialisms.

Overall, project-based structures have been growing in importance because of their inherent flexibility. Such flexibility can be vital in a fast-moving world where individual knowledge and competences need to be redeployed and integrated quickly and in novel ways.

Structural choice depends on the strategic challenges the organisation faces. In reality, few organisations adopt a structure that is just like one of the pure structural types discussed above. Structures often blend different types and have to be tailor-made to the particular mix of challenges facing the organisation. Michael Goold and Andrew Campbell provide nine design tests against which to check specific tailor-made structural solutions. The first four tests stress fit with the key objectives and constraints of the organisation:

- **The Market-Advantage Test.** This test of fit with market strategy is fundamental, following Alfred Chandler's classic principle that 'structure follows strategy'. For example, if coordination between two steps in a production process is important to market advantage, then they should probably be placed in the same structural unit.
- **The Parenting Advantage Test.** The structural design should fit the 'parenting' role of the corporate centre. For example, if the corporate centre aims to add value as a synergy manager, then it should design a structure that places important integrative specialisms, such as marketing or research, at the centre.
- **The People Test.** The structural design must fit the people available. It is dangerous to switch completely from a functional structure to a multidivisional structure if, as is likely, the organisation lacks managers with competence in running decentralised business units.
- **The Feasibility Test.** This is a catch-all category, indicating that the structure must fit legal, stakeholder, trade union or similar constraints. For example, after scandals involving biased research, investment banks are now required by financial regulators to separate their research and analysis departments from their deal-making departments. Goold and Campbell then propose five tests based on good general design principles, as follows:
- **The Specialised Cultures Test.** This test reflects the value of bringing together specialists so that they can develop their expertise in close collaboration with each other. A structure fails if it breaks up important specialist cultures.
- **The Difficult Links Test.** This test asks whether a proposed structure will set up links between parts of the organisations that are important but bound to be strained. For example, extreme decentralisation to profit-accountable business units is likely to strain relationships with a central research and development department. Unless compensating mechanisms are put in place, this kind of structure is likely to fail.
- **The Redundant Hierarchy Test.** Any structural design should be checked in case it has too many layers of management, causing undue blockages and expense. Delayering in response to redundant hierarchies has been an important structural trend in recent years.
- **The Accountability Test.** This test stresses the importance of clear lines of accountability, ensuring the control and commitment of managers throughout the structure. Because of their dual lines of reporting, matrix structures are often accused of lacking clear accountability.

- **The Flexibility Test.** In a fast-moving world, an important test is the extent to which a design will allow for change in the future. For instance, divisional domains should be specified broadly enough to allow divisional managers to follow new opportunities as they emerge.

Goold and Campbell's nine tests provide a rigorous screen for effective structures. But even if the structural design passes these tests, the structure still needs to be matched to the other strands of the organisation's configuration, its processes and relationships. Each strand will have to reinforce the others.

[Johnson, Scholes and Whittington, R. (2008)]

Strategic Business Unit

10.3

- **SBU Structure**

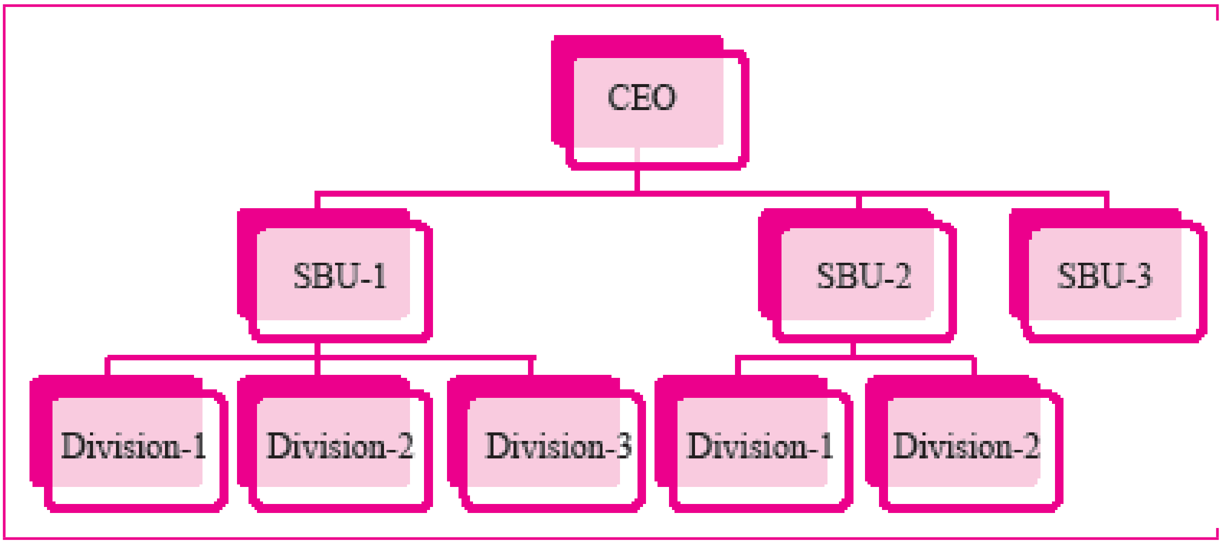


Figure 10.4: SBU Structure

A strategic business unit (SBU) is a part of an organisation for which there is a distinct external market for goods or services that is different from another SBU. The identification of an organisation's SBUs helps the development of business level strategies since these may need to vary from one SBU to another. The identification of SBUs does, however, raise some important areas of concern such as

- As the bases of competitive strategy may need to differ by markets (or market segment) the SBUs considered need to reflect this. However, potentially, managers may subdivide markets into many segments based on different criteria. The result could be unmanageable in terms of identifying compatible bases of competitive strategy. So sensible judgements need to be made about which SBUs are most useful for strategy making purposes.
- Similarly, too many SBUs can create excessive complexity in developing corporate-level strategy.
- An SBU is an organisational unit for strategy-making purposes. An organisation may not actually be structured on the basis of SBUs, so consideration needs to be given to the relationship of SBUs and organisational design.

There are external and internal criteria that can help in identifying appropriate SBUs:

- Market-based criteria. Different parts of an organisation might be regarded as the same SBU if they are targeting the same customer types, through the same sorts of channels and facing similar competitors. For example, a 'unit' tailoring products or services to specific local needs are a different SBU from one that offers standardised products or services globally. So are units that offer the same products to a customer group through significantly different channels (for example, retailing to consumers versus direct selling via the Internet).

- Capabilities-based criteria. Parts of an organisation should only be regarded as the same SBU if they have similar strategic capabilities. So for a food manufacturer branded goods should probably be considered a different SBU from retail 'own-brand' goods even though they are selling to the same end customers through the same channels. [Johnson, Scholes and Whittington (2008)]

Distinction between strategy formulation and strategy implementation

According to David (2005) the following are the differences between the two

Strategy Formulation	Strategy Implementation
It involves positioning forces before the action	It involves managing forces during the action.
The focus is on effectiveness.	The focus is on efficiency.
It is primarily an intellectual process.	It is primarily an operational process.
It requires good intuitive and analytical skills.	It requires motivation and leadership skills.
Requires coordination among few individuals.	Requires coordination among many individuals.

Business Process Re-engineering

10.4

Business Process Engineering may be considered to be a radical redesign of business processes often used by companies to cut costs and return to profitability. During the 1990s, recognition that the re- design of operational processes could achieve substantial efficiency gains stimulated a surge of interest in a new management tool called business process reengineering (BPR). It may be mentioned that BPR is not in itself a type of structure, but it is an effective program to implement a turnaround strategy. Hammer and Champy (1993) defined BPR as 'the fundamental rethinking and radical redesign of business processes to achieve dramatic improvements in critical contemporary measures of performance such as cost, quality, service, and speed'.

There are primarily three important reasons that lead an organisation to undertake re-engineering

- An organisation needs dramatic improvements to sustain itself and is already in deep trouble. High failure rates of products and repetitive customer complaints can be a one of the reasons that can cause huge disruption in the functioning of the organisation.
- The need for re-engineering can be felt by the management keeping in mind the imminent problems that the organisation is expected to face in the future due to some dramatic changes in the environment, both internal and external.
- There can be situations when reengineering can help organisations to be in better position than they are currently in.

BPR recognises that production and commercial processes involve complex interactions among many individuals and evolve over time with little conscious or consistent direction. According to Pates (2003) with information technology, the temptation is to automate existing processes. The key is to detach from the way in which a process is currently organized and to begin with the question: 'If we were starting afresh, how would we design this process?' Hammer and Champy (1993) point to the existence of a set of 'commonalities, recurring themes, or characteristics' that can guide BPR. These include:

- Combining several jobs into one.
- Allowing workers to make decisions.
- Performing the steps of a process in a natural order.
- Recognition that processes have multiple versions and designing processes to take account of different situations.
- Performing processes where it makes the most sense, e.g., if the accounting department needs pencils, it is probably cheaper for such a small order to be purchased directly from the office equipment store along the block than to be ordered via the firm's purchasing department.
- Reducing checks and controls to the point where they make economic sense.

- Minimizing reconciliation.
- Appointing a case manager to provide a single point of contact at the interface between processes.
- Reconciling centralization with decentralization in process design - e.g., via a shared database, decentralized decisions can be made while permitting overall coordination simply through information sharing.

BPR has resulted in major gains in efficiency, quality and speed. The following case study reveals the same.

Process Reengineering at IBM Credit

IBM credit provides credit to customers of IBM for the purchase of IBM hardware and Software. Under the old system, five stages were involved:

- The IBM salesperson telephoned a request for financing. The request was logged on a piece of paper.
- The request was sent to the Credit Department where it was logged onto a computer and the customer's creditworthiness was checked. The results of the credit check were written on a form and passed to the Business Practices Department.
- There the standard loan covenant would be modified to meet the terms of customer loan.
- The request was passed to the pricer who determined the appropriate interest rate.
- The clerical group took all the information and prepared a quote letter, which was sent to the salesperson.

Because the process took an average of six days, it resulted in a number of lost sales and delayed the sales staff in finalizing deals. After many efforts to improve the process, two managers undertook an experiment. They took a financing request and walked it around through all five steps. The process took 90 minutes.

On this basis, a fundamental redesign of the credit approval process was achieved. The change was replacing the specialists (credit checkers, pricers, and so on) with generalists who undertook all five processes. Only where the request was nonstandard or unusually complex were specialists called in. The basic problem was that the system had been designed for the most complex credit requests that IBM received, whereas in the vast majority of cases no specialist judgment was called for- simply clerical work involving looking up credit ratings, plugging numbers into standard formulae, etc.

The result was that credit requests are processed in four hours compared to six days, total employees were reduced slightly, while the total number of deals increased one hundred times.

- Source: Grant, R.M. (2012). Contemporary Strategic Management. 6th edition. Blackwell Publishing. New Delhi, pg 233

Concerns in BPR

In many instances has produced disappointing result.

- One of the major realizations to emerge from BPR is that most business processes are complex. To redesign a process one must first understand it.
- Process mapping exercises reveal that even seemingly simple business processes, such as the procurement of office supplies, involve complex and sophisticated systems of interactions among a number of organizational members.
- Many organizational routines operate without any single person fully understanding the mechanism.
- Hammer and Champy's (1993) recommendation to 'obliterate existing processes and start with a 'clean sheet of paper runs the risk of destroying organizational capabilities that have been nurtured over a long period of time.

Management Control, Operational Control and Task Control

10.5

Managers choose the organizational strategies and structure they hope will allow the organization to use its resources most effectively to pursue its business model and create value and profit. Then they create strategic control systems, tools that allow them to monitor and evaluate whether, in fact, their strategies and structure are working as intended, how they could be improved, and how they should be changed if they are not working. Strategic control systems refer to the mechanism that allows managers to monitor and evaluate whether their business model is working as intended and how it could be improved. Strategic control is not only about monitoring how well an organization and its members are currently performing, or about how well the firm is using its existing resources. It is also about how to create the incentives to keep employees motivated and focused on the important problems that may confront an organization in the future so that the employees work together and find solutions that can help an organization perform better over time. Strategic control helps managers obtain superior efficiency, quality, innovation, and responsiveness to customers.

- **Control and efficiency.** Efficiency is the ratio of the number of units of inputs required to produce a unit of output. It is the task of the managers to be able to accurately measure how many units of inputs (raw materials, human resources, and so on) are being used to produce a unit of output. They must also be able to measure the number of units of outputs (goods and services) they produce. A control system contains the measures or yardsticks that allow managers to assess how efficiently they are producing goods and services. Moreover, if managers experiment to find a more efficient way to produce goods and services, these measures tell managers how successful they have been. Without a control system in place, managers have no idea how well their organizations are performing nor how to perform better in the future—something that is becoming increasingly important in today's highly competitive environment.

- **Control and quality.** Today, competition often revolves around increasing the quality of goods and services. Strategic control is important in determining the quality of goods and services because it gives managers feedback on product quality. If managers consistently measure the number of customers' complaints and the number of new cars returned for repairs, they have a good indication of how much quality they have built into their product.

- **Control and innovation.** Strategic control can help to raise the level of innovation in an organization. Successful innovation takes place when managers create an organizational setting in which employees feel empowered to be creative and in which authority is decentralized to employees so that they feel free to experiment and take risks. Deciding upon the appropriate control systems to encourage risk taking is an important management challenge.

- **Control and responsiveness to customers.** Finally, strategic managers can help make their organizations more responsive to customers if they develop a control system that allows them to evaluate how well employees with customer contact are performing their jobs. Monitoring employees' behaviour can help managers find ways to help increase employees' performance level, perhaps by revealing areas in which skills training can help employees, or by finding new procedures that allow employees to perform their jobs more efficiently.

When employees know their behaviours are being monitored, they may have more incentive to be helpful and consistent in the way they act toward customers.

Strategic control systems are the formal target-setting, measurement, and feedback systems that allow strategic managers to evaluate whether a company is achieving superior efficiency, quality, innovation, and customer responsiveness and implementing its strategy successfully. An effective control system should have three characteristics. It should be flexible enough to allow managers to respond as necessary to unexpected events; it should provide accurate information, thus giving a true picture of organizational performance; and it should supply managers with the information in a timely manner because making decisions on the basis of outdated information is a recipe for failure.

Levels of Strategic Control

Strategic control systems are developed to measure performance at four levels in a company: corporate, divisional, functional, and individual. Managers at all levels must develop the most appropriate set of measures to evaluate corporate, business and functional-level performance. As the balanced scorecard approach suggests, these measures should be tied as closely as possibly to the goals of developing distinctive competencies in efficiency, quality, innovativeness, and responsiveness to customers. Care must be taken, however, to ensure that the standards used at each level do not cause problems at the other levels—for example, that a division's attempts to improve its performance do not conflict with corporate performance. Furthermore, controls at each level should provide the basis upon which managers at lower levels design their control systems.

Types of General Control Systems

The balanced scorecard approach was discussed as a way to ensure that managers complement the use of return on invested capital (ROIC) with other kinds of strategic controls to ensure they are pursuing strategies that maximize long-run profitability. In this chapter, we consider three more types of control systems: personal control, output control, and behaviour control.

Personal Control:

- Personal control is the desire to shape and influence the behaviour of a person in a face-to-face interaction in the pursuit of a company's goals.
- The most obvious kind of personal control is direct supervision from a manager farther up in the hierarchy.
- The personal approach is useful because managers can question subordinates about problems or new issues they are facing to get a better understanding of the situation and to ensure that subordinates are performing their work effectively and that they are not hiding any information that could cause additional problems later.
- Personal control also can come from a group of peers, such as when people work in teams. Once again, personal control at the group level means that there is more possibility for learning to occur and competencies to develop, as well as greater opportunities to prevent free-riding or shirking.

Output Control:

- Output control specifies what is to be accomplished by focusing on the end result.
- It is a system in which strategic managers estimate or forecast appropriate performance goals for each division, department, and employee, and then measure actual performance relative to these goals.
- It is important to understand that these controls are appropriate when specific output measures have been agreed upon.
- Often a company's reward and incentive system is linked to performance on these goals, so output control also provides an incentive structure for motivating employees at all levels in the organization.

- Goals keep managers informed about how well their strategies are creating a competitive advantage and building the distinctive competencies that lead to future success.
- Goals exist at all levels in an organization. Divisional goals state corporate managers' expectations for each division concerning performance on dimensions such as efficiency, quality, innovation, and responsiveness to customers.
- Generally, corporate managers set challenging divisional goals to encourage divisional managers to create more effective strategies and structures in the future. Output control at the functional and individual levels is a continuation of control at the divisional level.
- Divisional managers set goals for functional managers that will allow the division to achieve its goals. As at the divisional level, functional goals are established to encourage the development of generic competencies that provide the company with a competitive advantage, and functional performance is evaluated by how well a function develops a competency.
- In the sales function, for example, goals related to efficiency (such as cost of sales), quality (such as number of returns), and customer responsiveness (such as the time necessary to respond to customer needs) can be established for the whole function.
- Finally, functional managers establish goals that individual employees are expected to achieve to allow the function to meet its goals. Sales personnel, for example, can be given specific goals (related to functional goals) that they are required to achieve. Functions and individuals are then evaluated based on whether or not they are achieving their goals; in sales, compensation is commonly anchored by achievement.
- The achievement of goals is a sign that the company's strategy is working and meeting the organization's wider objectives.
- The inappropriate use of output control can promote conflict among divisions.
- In general, setting across-the-board output targets, such as ROIC targets for divisions, can lead to destructive results if divisions single-mindedly try to maximize divisional ROIC at the expense of corporate ROIC.
- Moreover, to reach output targets, divisions may start to distort the numbers and engage in strategic manipulation of the figures to make their divisions look good—which increases bureaucratic costs.

Behaviour Control: Behaviour control is control achieved through the establishment of a comprehensive system of rules and procedures to direct the actions or behaviour of divisions, functions, and individuals. The intent of behaviour controls is not to specify the goals but to standardize the way or means of reaching them. Rules standardize behaviour and make outcomes predictable. If employees follow the rules, then actions are performed and decisions are handled the same way time and time again. The result is predictability and accuracy, the aim of all control systems. The primary kinds of behaviour controls are operating budgets, standardization, and rules and procedures.

Strategic controls

There are four types of strategic controls:

- **Premise Control:** Strategy is built around several assumptions or predictions, which are called planning premises.
    - Premise control checks systemically and continuously whether the assumptions on which the strategy is based are still valid.
    - If a vital premise is no longer valid, the strategy may have to change. The sooner these invalid assumptions are detected and rejected, the better are the chances of changing the strategy.

  - The premise control is concerned with two types of factors namely environmental factor and industry factors.
  - A firm's performance is affected by changes in environmental factors like the rate of inflation, government regulations, social changes etc. Although the firm has little of no control over environmental factors, these factors have considerable influence over the success of the strategy because strategies are generally based on key assumptions about them.
  - Industry factors also affect the performance of a company. Competitors, suppliers, buyers, substitutes, new entrants, etc. are some of the industry factors about which assumptions are made.
  - If any of these assumptions go wrong, strategy may have to be changed.

- **Strategic Surveillance:** Strategic surveillance is a broad-based vigilance activity in all daily operations both inside and outside the organization. With such vigilance, the events that are likely to threaten the course of a film's strategy can be tracked. Business journals, trade conferences, conversations observations etc. are some of the information sources for strategic surveillance
- **Special Alert Control:** Sudden, unexpected events can drastically alter the course of the firm's strategy. Such events trigger an immediate and intense reconsideration of the firm's strategy. Generally, firms develop contingency plans along with crisis teams to respond to such sudden, unexpected events.
- **Implementation Control:** Strategy implementation takes place as a series of steps, programmes, investments and moves that occur over an extended period. Resources are allocated, essential people are put in place, special programmes are undertaken and functional areas initiate strategy related activities.
  - Implementation control is aimed at assessing whether the plans, programmes and policies are actually guiding the organisation towards the predetermined objectives or not.
  - Implementation control assesses whether the overall strategy should be changed in the light of the results of specific units and individuals involved in implementation of the strategy.
  - Two important methods to achieve implementation control are monitoring strategic thrusts and milestone review.
  - Monitoring Strategic Thrusts are small critical projects that need to be done if the overall strategy is to be accomplished. They are critical success factors in the success of strategy.
  - Milestones are critical events that should be reached during strategy implementation. These milestones may be fixed on the basis of critical events, major resource allocation and time frames. Network controls like PERT/CPM for project implementation are examples of milestone reviews.
  - After doing a milestone review, managers often undertake a full scale reassessment of the strategy to decide whether to continue or refocus the firm's strategy.
  - Implementation control is also done through operational control systems like budgets, schedules, key success factors etc. **[Rao, et.al. (2008)]**

Approaches to Strategic Control

According to Dess, Lumpkin and Taylor (2003), there are two approaches to strategic control namely, Traditional Approach and Contemporary Approach.

Traditional Approach

This approach to strategic control is sequential:

- Strategies are formulated and top management set the goals.
- Strategies are implemented.
- Performance is measured against goals.
- Corrective measures are taken, if there are deviations.

The control is based on a feedback loop from performance measurement to strategy formulation. This type of approach has its own limitations. This process typically involves lengthy time lags and often tied to a firm's annual planning cycle. This approach not being proactive is not sufficient to control a strategy. As strategy involves a long period of time for implementation and to produce results it becomes imperative that there should be continuous evaluation of the planning premises and strategy implementation in order to get the desired results.

Contemporary Approach

Under this approach, adapting to and anticipating both internal and external environment, change is an integral part odd strategic control. This approach addresses the assumptions and premises that provide the foundation for the strategy. The key question addressed here is: do the organisations goals and strategies still fit within the context of the current environment? This involves two key actions:

(a) Managers must continuously scan and monitor the external and internal environment.

(b) Managers must continuously update and challenge the assumptions underlying the strategy.

This may even need changes in the strategic direction of the firm. While strategic control requires the contemporary approach, operational control is generally done through traditional approach.

The Role of Strategic Control

- An important element of strategic control is to design a system that sets ambitious goals and targets for all managers and employees and then develops performance measures that stretch and encourage managers and employees to excel in their quest to raise performance.
- A functional structure promotes this goal because it increases the ability of managers and employees to monitor and make constant improvements to operating procedures.
- The structure also encourages organizational learning because managers working closely with subordinates can mentor them and help develop their technical skills.
- Grouping by function also makes it easier to apply output control.
- Measurement criteria can be developed to suit the needs of each function to encourage members to stretch themselves.
- Each function knows how well it is contributing to overall performance and the part it plays in reducing the cost of goods sold or the gross margin.
- Managers can look closely to see if they are following the principle of the minimum chain of command and whether or not they need several levels of middle managers. Perhaps, instead of using middle managers, they could practice *management by objectives*, a system in which employees are encouraged to help set their own goals so that managers manage by exception, intervening only when they sense something is not going right. Given this increase in control, a functional structure also makes it possible to institute an effective strategic reward system in which pay can be closely linked to performance, and managers can accurately assess the value of each person's contributions.

Guidelines for Proper Control

In designing a control system, top management should remember that controls should follow strategy. Unless controls ensure the use of the proper strategy to achieve objectives, there is a strong likelihood that dysfunctional side effects will completely undermine the implementation of the objectives. The following guidelines are recommended:

- Control should involve only the minimum amount of information needed to give a reliable picture of events: Too many controls create confusion. Focus on the strategic factors by following Pareto's 80/20 rule: Monitor those 20% of the factors determines 80% of the results.
- Control must be reasonable. Frequent reporting and rapid reporting may frustrate control.
- Controls do not work unless they are acceptable to those who apply them.
- Controls should monitor only meaningful activities and results, regardless of measurement difficulty: If cooperation between divisions is important to corporate performance, some form of qualitative or quantitative measure should be established to monitor cooperation.
- Controls must be flexible to take care of changing circumstances.
- Controls should be timely so that corrective action can be taken before it is too late: Steering controls, controls that monitor or measure the factors influencing performance, should be stressed so that advance notice of problems is given.
- Long-term and short-term controls should be used: If only short-term measures are emphasized, a short-term managerial orientation is likely.
- Controls should aim at pinpointing exceptions: Only activities or results that fall out- side a predetermined tolerance range should call for action.
- Emphasize the reward of meeting or exceeding standards rather than punishment for failing to meet standards: Heavy punishment of failure typically results in goal displacement. Managers will fudge reports and lobby for lower standards.

If corporate culture complements and reinforces the strategic orientation of a firm, there is less need for an extensive formal control system.

Operational Control

It provides post action evaluation and control over short periods involve systematic evaluation of performance against predetermined objectives.

In order to have effective operational control systems an organisation must follow four steps as under:

- **Setting of Standards**

The first step in the control process involves setting of standards. Standards are the levels or targets against which the actual performance will be measured. They are broadly classified into quantitative standards and qualitative standards.

Quantitative Standards

They are expressed in precise physical or monetary terms with respect to production, marketing, finance, etc. **They may relate to time standards, cost standards, productivity standards and revenue standards.**

Qualitative Standards

Qualitative criteria are also important in setting standards. Human factors such as high absenteeism and turnover rates, poor production quality or low employee satisfaction can be the underlying causes of declining performance. **So, qualitative standards also need to be established to measure performance.**

Measurement of Performance

The second step in operational control is the measurement of actual performance. Here the actual performance is measured against the standards fixed. Standards of performance act as the benchmark against which the actual performance is to be compared. It is important, however, to understand how the measurement of performance actually takes place. Operationally measuring is done through accounting, reporting and communication systems. A variety of evaluation techniques are used for this purpose. The other important aspects of measurement relates to:

Difficulties in Measurement:

There are several activities for which it is difficult to set standards and measure performance. For example, performance of a worker in terms of units produced in a day, week or month can be easily measured. On the other hand, it is not easy to measure the contribution of a manager or to assess departmental performance. The solution lays in developing verifiable objectives, stated in quantitative and qualitative terms, against which performance can be measured.

- **Timing of Measurement:**

  Timing refers to the point of time at which measurement should take place Delay in measurement or measuring before time can defeat the very purpose of measurement. So measurement should take place at critical points in a task schedule, which could be at the end of a definable activity or the conclusion of a task. For example, in a project implementation schedule there could be several critical points at which measurement would take place.

- **Periodicity in Measurement:**

  Another important issue in measurement is “how often to measure”. Generally, financial statements like budgets, balance-sheets, and profit and loss accounts are prepared every year; But there are certain reports like production reports, sales reports etc. which are done on a daily, weekly, monthly basis.

- **Identifying Deviations**

  The third step in the control process is identifying deviations. The measurement of actual performance and its comparison with standards of performance determines the degree of variation between actual performance and the standard. There can be three situations

  (a) The actual performance matches the standards.

  (b) The actual performance exceeds the standards.

  (c) The actual performance falls short of the standards.

  The first situation is ideal but at times may not be realistic. Generally, a range of tolerance limits coincide within which the results may be accepted satisfactorily, are fixed and deviations from it are considered as variance.

  The second situation is an indication of superior performance. If exceeding the standards is considered unusual, a check needs to be made to test the validity of tests and the measurement system.

  The third type of situation, which indicates shortfall in performance, should be taken seriously and strategists need pinpoint the areas where the performance is below standard and go into the causes of deviation.

  The analysis of variance generally presented in a format called variance chart and submitted to the top management for their evaluation. After noting the deviations it is necessary to find the causes of deviation, which can be ascertained through the following questions:

  (a) Is the cause of deviation internal or external?

(b) Is the cause random or expected?

(c) Is the deviation temporary or permanent?

Analysis of variance leads to a plan for corrective action.

- **Taking Corrective Action**

The last and final step in the operational control process is taking corrective action. Corrective action is initiated by the management to rectify the shortfall in performance. If the performance is consistently low, the strategists have to do an in depth analysis and diagnosis to isolate the factors responsible for such low performance and take appropriate corrective actions.

There are three courses for corrective action:

- **Checking Performance:** Performance can be affected adversely by a large number of factors such as inadequate resource allocation, ineffective structure or systems, faulty programmes, policies, motivational schemes, inefficient leadership styles, etc. Corrective actions may therefore include the change in strategy, systems, structure, compensation practices, training programmes, redesign of jobs, replacement of personnel, re-establishment of standards, budgets etc.
- **Checking Standards:** It is often argued that when there is nothing significantly wrong with performance then the strategist has to check the standards. A manager should not mind revising the standards when the standards set are unreasonably low or high level. Higher standards breed discontentment and frustration. Low standards make employee unproductive. So, standards check may result in lowering of standards if it is concluded that organizational capabilities do not match the performance requirements. It may also lead to elevation of standards if the conditions have improved to allow better performance. For example, better equipment, improved systems, upgraded skills, etc. need modification in existing standards.
- **Reformulating Strategies,** Plans and Objectives: A more radical and infrequent corrective action is to reformulate strategies, plans and objectives. Strategic control, rather than operational control, generally leads to changes in strategic direction, which will take the strategist back to the process of strategy formulation and choice. Techniques like total quality management (TQM) and ISO 9000 standards series are examples of very good control mechanisms.

Task Control

The term task control refers to the process of ensuring that specific tasks are carried out effectively and efficiently. Task control aims primarily at controlling things and performance, and such control may be purely direct, for example, placing an order for purchase of goods if inventory level falls below a point. Task control helps you plan one's day and time without relying too much on others. It increases efficiency and reduces the interdependence of tasks, making it easier to complete one's work. It may be mentioned that low task control makes employees more stressed as they lack control over how and when they perform their tasks as well as lack of control over the pace of work activity.

KRAs, KPAs and KPIs

The term Key Result Areas (KRAs) refers to a short list of overall goals that guide how an individual does their job, or general achievement and progress goals for an organization or one of its divisions. KRAs help define the scope of a job or a department or an organization's goals, and define the optimum outcomes and results of daily work. KRAs are the items that are critical for an organization or employee to be successful.

The Pareto principle says that 80 percent of the consequences or effects of something come from 20 percent of the causes. Applying that principle to how people (or departments and organizations) do their jobs, this means that 80 percent of the value of the work will come from 20 percent of the work. Therefore, it's critical that one understands and identifies the most important 20 percent of the work that will eventually bring the most value to the organization. Key Result Areas will of course differ widely, depending on the role of an employee or the specific goals of a department or an organization. However, there are some primary attributes that are important in the development of any KRA.

- If the KRAs are being developed for a position, they should broadly define that job and give the employee clarity in their role and mission within the organization. The KRAs likely will include a list of functions and activities vital to success.
- KRAs can require certain objectives from an employee only when the employee has the ability within the organization's structure to accomplish that objective.
- Many experts believe that KRAs (for an employee, department or organization) should be SMART (specific, measurable, aligned, relevant, and time-bound). KRAs should be the most important objectives. They seldom should number more than a handful — no more than seven. Crenshaw suggests writing three to five. That number applies to both KRAs for individuals and KRAs for departments or organizations.
- Group tasks that are related to each other together.
- KRAs must be in writing, reviewed by all relevant parties, agreed upon, and signed by people involved — especially when the KRAs involve an employee's role. The written format for KRAs can be relatively simple. For an employee's KRA, It should include the employee's name, the department and supervisor's name, and a description of some of the most important duties of the employee's role and how it serves the organization's strategic objectives. Then, you should include details on several areas of expected performance. Those details should include metrics that can and will be measured to assess the employee's performance in those areas.

Problems in developing KRA's

While developing good KRAs can be straightforward, common hurdles often create problems:

- **Lack of Clarity:** In KRAs that involve an employee's performance, neither the individual nor the supervisor is clear about the primary tasks and results that the employee should focus on — the tasks and results that will help drive an organization's success.
- **Distractions:** People are too often distracted into doing daily tasks that seem important, but that are of limited value to the success of the organization.
- **Top-Down Imposition of KRAs:** Supervisors who impose specific KRAs on employees — without a discussion to get their input — create a system that often fails.

When employees are allowed to explain how their job works and given some voice in setting appropriate goals and objectives for their job, they're "going to buy into it more," says Agile Strategy's Montgomery. If your inclination as a supervisor is to "be too commanding and controlling and dictatorial about it," then you should dispense with any objectives and key results system. "Just tell people what to do," Montgomery advises.

Key Performance Areas

Key Performance Areas (KPAs) describe broad areas of responsibility for which a department or organization or individual employee may be responsible. Unlike KRAs, they aren't necessarily tracked with results or results-focused metrics. KPAs can be many depending on the organization, employee, or industry. Some of the examples of KPAs are improving safety and accident prevention, improving an organization's risk management and regulatory compliance, maintaining good working conditions in a plant, using resources efficiently and effectively, improving business processes, improving an organization's service level agreements, etc.

Important Key Performance Areas

KPAs can cover a wide range of areas, and can vary significantly between organisations within the same industry. However, there are four KPAs that important for any business to identify, understand and pay attention to:

- **Financials:** These include basics like revenue, costs, net profits, and trends that affect all three.
- **Customer Satisfaction: These deals with** customers complain about the business or products, product return rate and the results of customer satisfaction surveys.
- **Market Perception:** This includes how customers and potential customers view the company or its products.
- **Productivity:** These include accomplishing of organisational major goals, meeting the everyday requirements to keep the organisation moving forward and keeping its customers satisfied.

Key Performance Indicator

A key performance indicator (KPI) is any metric that measures whether an organization is meeting certain objectives and goals that are set to help the organization succeed. KPIs might involve sales figures, product performance, return on certain organizational investments or a wide range of other areas. KPIs are often the measurements associated with the general goals outlined in a Key Result Area.

Goal Congruence

10.6

- Goal congruence is the term that is used to describe the situation when the goals of different interest groups coincide.
- The achievement of goal congruence is essential in order to increase the profitability of the organisation and to achieve its goals.
- It is very important that the individual goals are consistent with the organisational goals. It may be said that in a perfect organisation individual goals and organisational goals should correspond perfectly.

However, it is rarely the case as employees have both personal as well as organisational goals.

One way of to achieve goal congruence between shareholders and managers is by carefully designing remuneration packages for managers which would motivate managers to take decisions which were consistent with the objectives of the shareholders.

Agency Theory

- Agency theory views the firm as a nexus of legal contracts. The managerial implication of agency theory relates to the management functions of organization and control.
- Agency theory looks at the problems that can arise in a business relationship when one person delegates decision-making authority to another.
- It offers a way of understanding why managers do not always act in the best interests of stakeholders and why they might sometimes behave unethically, and, perhaps, also illegally.
- According to the Agency theory employees of businesses, including managers, as individuals, has his/her own objectives. There are departmental objectives within a department of a business. When these various objectives lead to the achievement of the objectives of the organisation as a whole, there is said to be goal congruence.
- The firm needs to design work tasks, incentives, and employment contracts and other control mechanisms in ways that minimize opportunism by agents. Such governance mechanisms are used to align incentives between principals and agents.
- These mechanisms need to be designed in such a fashion as to overcome two specific agency problems: adverse selection and moral hazard.
    - Adverse selection is a situation that occurs when information asymmetry increases the likelihood of selecting inferior alternatives.
    - A moral hazard is a situation in which information asymmetry increases the incentive of one party to take undue risks or shirk other responsibilities because the costs incur to the other party

Achieving Goal Congruence

- Goal congruence can be achieved, and at the same time, the agency problem can be dealt with, providing managers with incentives which are related to profits or share price, or other factors such as: An agency problem is a conflict of interest inherent in any relationship where one party is expected to act in the best interest of another.
- Agency problems arise when incentives or motivations present themselves to an agent to not act in the full best interest of a principal.
- Through regulations or by incentivising an agent to act in accordance with the principal's best interests, agency problems can be reduced.

The following are some of the ways by way of which the agency problem can be dealt with:

- Pay or bonuses related to the size of profits termed as profit-related pay.
- Rewarding managers with shares, e.g.: when a private company 'goes public' and managers are invited to subscribe for shares in the company at an attractive offer price.
- Rewarding managers with share options. In a share option scheme, selected employees are given a number of share options, each of which gives the right (after a certain date) to subscribe for shares in the company at a fixed price. The value of an option will increase if the company is successful and its share price goes up.

Such measures might encourage management in the adoption of "creative accounting" methods which will distort the reported performance of the company in the service of the manager's own ends. However, creative accounting methods such as off-balance sheet finance present a temptation to management at all times given that they allow a more favourable picture of the state of the company to be presented than otherwise, to shareholders, potential investors, potential lenders and others. An alternative approach is to attempt to monitor manager's behaviour, for example, by establishing 'Management audit' procedures, to introduce additional reporting requirements, or to seek assurance from managers that shareholders' interests will be foremost in their priorities.

Aspects of Goal Congruence

The following are some of the areas that have the ability to create goal congruence:

a. **Communication and Understanding**

Channels of communication and how goals are perceived are important to achieve goal congruence. Operational managers have a responsibility of being aware as to what actions are desirable and what goals are to be achieved. It should be understood that the communication of different goals can occur through informal channels, which involves meetings and face to face interactions, or through formal channels including budgets or other financial documents. There is a inherent risk that even if the communication is well executed, it might be perceived in different ways. Organisations, therefore, should internalise the goals in a good manner to avoid that employees feel inability to achieve them.

b. **Create direction**

One of the reasons for lack of goal congruence is the absence of direction related to employees' behaviour. Performance management and goals facilitate efficient communication about what managers want their subordinates to focus on. It needs no mention that providing clear information and direction, employees can better understand what is expected from them, how to perform adequately, and how to contribute effectively to the achievement of the organisational goals. There is a need to increase the employees understanding of the strategic objectives as well as the organisation's value drivers.

c. **Motivation**

The problem of motivation can exist even though employees have knowledge about how to perform adequately because employees can act in their own self interest instead of in the organisation's best interest. The employees can make their own performance report better by allocating resources without befitting the organisation as a whole. One of the strongest reasons for demotivation among employees and managers is dislike for the work allocated. The reason for motivation varies among employees. While some employees feel motivated for some recognition and appraisals others may feel motivated because of commitment and responsibility without any required pay off. The more motivated the employees of the organisation the better will be the goal congruence.

d. **Incentives**

In order to increase the likelihood of employees working to achieve their individual goals, organisation's aim to influence motivation by providing incentives. Research suggests that individuals tend to perform better when they are rewarded. Rewards and compensations should create goal congruence between individual goals and organisational goals by stimulating individuals to perform by providing incentives, as rewards are related to increased effort.

e. **Connection**

It is very important to create a connection between goals, performance measures and incentives. In order to align the employees' self interest and overall organisational objectives it is necessary to relate incentives with performance. By linking incentives to certain goals, individuals tend to pay more attention to what is important.

Exercise

A. Theoretical Questions:

⊙ Multiple Choice Questions

1. A __________ is a combination of structures which could take the form of product and geographical divisions or functional and divisional structures operating in tandem.

   a. Functional structure

   b. Matrix Structure

   c. Project based structure

   d. Transnational structure

2. A __________ combines the local responsiveness of the international subsidiary with the coordination advantages found in global product companies.

   a. Functional structure

   b. Matrix Structure

   c. Project based structure

   d. Transnational structure

3. A __________ is one where teams are created, undertake the work and are then dissolved.

   a. Functional structure

   b. Matrix Structure

   c. Project based structure

   d. Transnational structure

4. Which among the following is true?

   a. BPR has resulted in major gains in efficiency.

   b. BPR has resulted in major gains in speed.

   c. BPR has resulted in major gains in quality.

   d. BPR has resulted in major gains in efficiency, quality and speed.

5. __________ specifies what is to be accomplished by focusing on the end result.

   a. Output control

   b. Behaviour control

c. Premise control

d. Implementation control

6. ___________ is control achieved through the establishment of a comprehensive system of rules and procedures to direct the actions of divisions, functions, and individuals.

a. Output control

b. Behaviour control

c. Premise control

d. Implementation control

7. ___________ checks systemically and continuously whether the assumptions on which the strategy is based are still valid.

a. Output control

b. Behaviour control

c. Premise control

d. Implementation control

8. A __________ is based on the primary activities that have to be undertaken by an organisation

a. Functional structure

b. Matrix Structure

c. Project based structure

d. Transnational structure

9. This test is a catch-all category, indicating that the structure must fit legal, stakeholder, trade union or similar constraints.

a. The Feasibility Test

b. The People Test

c. The Parenting Advantage Test

d. The Specialised Cultures Test

10. In a fast-moving world, an important test to determine the extent to which a design will allow for change in the future is called?

a. The Feasibility Test

b. The Flexibility Test

c. cThe Parenting Advantage Test

d. The Specialised Cultures Test

11. Agency theory primarily deals with the relationship between:

    a) Businesses and customers

    b) Shareholders and stakeholders

    c) Principals and agents

    d) Employees and employers

12. Which statement best defines Key Result Areas (KRAs)?

    a) They are specific activities that an employee needs to perform to achieve their objectives.

    b) They are the critical areas where performance must be achieved to fulfil organizational goals.

    c) They are individual tasks outlined in job descriptions.

    d) They are the key outcomes expected from employees' efforts.

13. Which term refers to quantifiable measures used to evaluate the success of an organization or individual in meeting objectives?

    a) Key Result Area (KRA)

    b) Key Performance Indicator (KPI)

    c) Key Performance Area (KPA)

    d) Strategic Objective (SO)

14. In the context of BPR, what does "reengineering" refer to?

    a) Continuously improving existing processes

    b) Completely redesigning and restructuring processes

    c) Outsourcing business operations

    d) Automating manual tasks

15. How does goal congruence contribute to organizational effectiveness?

    a) By encouraging individual employees to pursue personal interests

    b) By fostering a sense of competition among team members

c) By ensuring that individual efforts are directed towards achieving organizational objectives

d) By disregarding the importance of aligning individual and organizational goals

Answer:

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
b	d	c	d	a	b	c	a	a	b	c	d	b	b	c

- **State True or False**

1. The first step in the control process involves measurement of actual performance.
2. The second step in operational control is the setting of standards.
3. Controls work even if they are unacceptable to those who apply them.
4. Monitoring Strategic Thrusts are critical events that should be reached during strategy implementation.
5. Milestones are small critical projects that need to be done if the overall strategy is to be accomplished.
6. A strategic business unit (SBU) is a part of an organisation for which there is a distinct external market for goods or services that is different from another SBU.
7. Special alert control is a broad-based vigilance activity in all daily operations both inside and outside the organization.
8. Behaviour control assesses whether the overall strategy should be changed in the light of the results of specific units and individuals involved in implementation of the strategy.
9. Sudden, expected events can drastically alter the course of the firm's strategy.
10. Strategy Implementation involves positioning forces before the action
11. Matrix organisations are inflexible.

Answer:

1	2	3	4	5	6	7	8	9	10	11
F	F	F	F	F	T	F	F	F	F	F

- **Fill in the blanks:**

1. __________and _________ are key ways of improving strategic capability.
2. ___________ may be broadly discussed into the following three areas namely HR function, Line

managers and structure and processes.

3. ____________have greater personal ownership for their own divisional strategies.

4. Conflicts across functional areas can be minimised with increased ________ and _______.

5. __________is not in itself a type of structure, but it is an effective program to implement a turnaround strategy.

6. _________ is the ratio of the number of units of inputs required to produce a unit of output.

7. ____________ is one where teams are created, undertake the work and are then dissolved.

8. _______________ reflects the value of bringing together specialists so that they can develop their expertise in close collaboration with each other.

9. _____________ asks whether a proposed structure will set up links between parts of the organisations that are important but bound to be strained.

10. ___________ stresses the importance of clear lines of accountability, ensuring the control and commitment of managers throughout the structure.

Answer:

1	Recruitment, retention	**2**	Organising people
3	Divisional managers	**4**	accountability, focus
5	Business Process Re-engineering	**6**	Efficiency
7	A project-based structure	**8**	The Specialised Cultures Test
9	The Difficult Links Test	**10**	The Accountability Test

⊙ Short Essay Type Questions

1. What do you mean by supply chain management?
2. What do you understand by marketing strategy?
3. What do you mean by customer defection rate and how is it determined?
4. What do you understand by the matrix organisational structure?
5. Distinguish between strategy formulation and strategy implementation.
6. What is a Key Performance Indicator?
7. What is goal congruence?

Essay Type Questions

1. What are the potential advantages of divisional structures?
2. What do you understand by Business Process Engineering? What are the important reasons that lead an organisation to undertake re-engineering?
3. Explain people as a resource.
4. What are the guidelines a strategic manger should keep in mind while implementing proper control?
5. What do you understand by task control?
6. Explain Key Result Areas.
7. What are the primary attributes that are important in the development of any KRA?
8. What are the problems in developing KRA's?
9. Explain Key Performance Areas (KPAs).
10. What are the important Key Performance Areas that organisations should be careful?
11. What are the different aspects of goal congruence?
12. What is premise control?
13. Write short notes on Strategic Surveillance and Special Alert control.
14. What do you understand by implementation control? Explain the different method of implantation control.

Digital Strategy

11

This Module Includes

Digital Strategy

SLOB Mapped against the Module

To develop the ability to identify, understand, assimilate, and use innovative strategies to create and sustain with competitive advantages.

Module Learning Objectives:

After studying this module, the students will be able to:

A digital strategy, sometimes called a digital media strategy, is a plan for maximizing the business benefits of data assets and technology-focused initiatives. The chapter has been designed to provide an overview of the latest trends in business environment and includes the following areas:

- Digital transformation vis-a vis digital strategy.
- Completive advantage through digital transformation.
- Steps to be taken by towards digital transformation by an organisation.
- Layers of Digital Transformation.
- Emerging trends in Digital (AI, Blockchain, Fintech, etc.) and Social marketing strategies (Social Media Marketing Platforms, Influencer Marketing, Email Marketing, Content Marketing, etc.)

Introduction

11.1

Digital technologies include electronic tools, systems, devices and resources that generate store or process data. In scientific terms, digital technology is a technology in which information is represented in digital form, i.e., as 0s and 1s. Some of the examples of digital technologies are online games, multimedia, social media and mobile phones.

The invention of transistor in the year 1947 is often credited with the beginning of digital technology era. The Digital Revolution began between the late 1950's and 1970's with the transition of technology from mechanical and analog to digital. Governments across the world were using computers and by 1970s and many household had personal computers. This was the time when digital computers and digital record keeping became the norm and dramatically changed the way humans communicate. The introduction of digital technology has led to job creation. This paved the way to the Information Age.

While some experts are of the opinion that the world has moved out of the Digital Revolution and into the Information Age, others believe that the Digital Revolution has only just begun. The technological advancements have actually increased manufacturing output with robots replacing humans. The Digital Revolution has impacted the medical industry as well with the use of genetic information for personalized treatment plans. The Digital Revolution is allowing us to overcome many limitations rapidly and opening up new frontiers with unprecedented speed.

A digital strategy, sometimes called a digital media strategy, is a plan for maximizing the business benefits of data assets and technology-focused initiatives. A successful digital strategy requires a cross-functional team with executive leadership, marketing and information technology (IT) members. It involves breaking down the silo between information technology leaders and those of other customer-facing departments to deliver a consistent digital customer experience. In today's organization, there are many ideas of what constitutes a digital strategy. A marketing executive will see a digital strategy as social media and web channels. An IT person would see a digital strategy as cloud. An operations executive will see it as data analytics. An R&D executive would see it as online products. A financial person will see it as online revenue channels.

While traditional information technology strategies tend to focus on long-term road maps and budget forecasts that extend years into the future, digital strategies tend to rely on short-term, month-to-month road maps that are tied to actionable items and measurable business objectives. To be successful, the strategy should place focus on where the company value chain is vulnerable to disruption and could be made stronger and more economically viable from a digital reboot. One of the challenges for establishing a digital strategy is to figure out which services should be done in-house, which services should be outsourced to a third-party provider and which services require customization in order to be effective.

There is a tendency to talk about digital transformation interchangeably with digital strategy. The two terms are closely related, but differ in scope.

- Digital transformation drives change in three areas: customer experience, operational processes and business models. The process of digital transformation requires coordination across the entire organization, and involves business culture changes.

- Digital strategy, on the other hand, focuses on technology, not culture. Digital strategy is most relevant to changes in business models, and uses technology to create the capabilities a company needs to become a digital business. Setting down a strategy is a key component of the transformation process, and ensures that technology is being implemented in a way that supports the business objectives.

The five following questions become relevant for an organisation's digital transformation:

- Does digital technology change the businesses you should be in?
- How could digital technology improve the way you add value to the businesses you are in?
- Could digital technology change your target customer?
- Does digital technology affect the value proposition to your target customer?
- How can digital technology enhance the enterprise capabilities that differentiate you from your competition?

To some companies, these questions will have obvious answers, especially those that have already experienced disruption or competition from new digital players. The intention is to identify how digital changes what you do, and then refine your understanding from broad industry trends to specific values that will form the foundation of your strategy. By beginning with a clear understanding of your company's purpose, you can avoid wasting time and resources implementing technology that doesn't enable new competitive advantages.

- According to Basu (2021) in the present Industry 4.0 era, almost all large business entities across industry sectors have embarked upon the journey of digital transformation.
- They have reinforced, further automated and weaponised their operating and financial policies, processes, and ICT systems with the help of technologies to stay ahead of and/or relevant with competitive advantages.
- Micro, small, and medium entities are also gradually joining them in this journey. Many startups are helping these entities with digital solutions built with 'innoventive' applications of eight deep digital technologies.
- Many of such solutions are of 'destruptive' and 'bizruptive' nature. The former means destructively disruptive solutions. These have either destroyed certain conventional for manufacturing, marketing, and supply chain operations or replaced traditional products by combining many functional capabilities in one device. For example, robotic process automation has brought in a new era of man-machine collaboration and smart phones have almost killed traditional/amateur cameras and torches.
- Bizruptive solutions are unique strategy driven innovations for P2P, B2C and B2B networking, as well as time and cost-efficient processes for service deliveries with safety, speed and quality.

"A strategy is an integrated set of choices for actions which positions a firm in an industry so as to generate superior financial returns over the long run." Here 'integrated set of choices' denotes plans for activities to be initiated from internal environment and 'over the long run' signifies dynamics of competitive advantages for sustainable growth and prosperity. At this stage none should forget the axiomatic advice of Sun Tzu which every strategist must always remember "Strategy without tactics is a slow path to uncertain success. Tactics without strategy is the noise before defeat." These words of advice are equally apt and relevant even after twenty-six centuries.

Digital Transformation for Competitive Advantages

11.2

- When an organisation embarks on a transformation journey, embracing digital technologies, two of their main objectives are to out manoeuvre competitors and attain sustainable competitive advantages or growth and prosperity. Basu (2021)
- When 'trans-created' solutions are offered by an entity to solve customers' problems, meet their latent demands, and/or simplify operating processes, that business entity starts operating in a strategically created 'blue ocean' market space in that traditional sector. The phrase 'trans-created' means creation of a new versatile product and/or related business model transforming a traditional one run by legacy systems.
- Innovative applications of digital technologies help them to implement the strategic plan and enjoy first mover's advantages. Such interplays of strategies and technologies can be termed as 'innovention', which is a combination of three tasks. viz., innovation, invention, and creation driven by distinctively formulated strategies.
- The objective is to generate and share values. Here value also includes value for time, quality, greener technology, and minimised risks, in addition to additions to organisations' profit measurable in monetary terms.
- Basu (2021) mentions that according to Bharadwaj et.al. , the emerging idea on digital business strategies may be categorized under four major groups viz, scope, scale, agility, and sources of value creation.
- These would be the influencing factors for scoping digital strategies for those business entities which want to leverage digital technologies for value creation by integration of operating business processes.

Research scholars Chanias and Hess in their seminal work concluded that "Digital transformation strategies are predominantly shaped by a diversity of emergent strategizing activities of separate organisational sub communities through a bottom-up process and prior to the initiation of a holistic digital transformation strategy by top management. As a result, top management's deliberate strategies seek to accomplish the subsequent alignment of pre-existing emergent strategy contents with their intentions and to simultaneously increase the share of deliberate contents." These two researchers have graphically explained the process of interplay of business strategy formulation and technology through the following diagram.

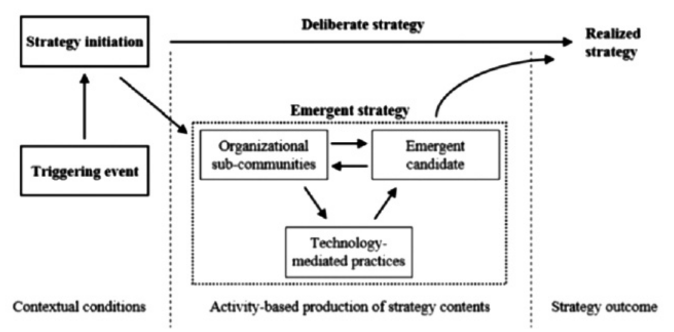


Figure 1. *The activity-based process model (adapted from Henfridsson and Lind (2014)).*

Figure 11.1

Source: Basu,(2021). Management Accountant, November, pg 78

- The triggering event for the entire process of interplay between strategy and digital technologies is identification of the emergent need(s), problem(s) and risks of customers, solution for which was a long persisting latent demand of governmental and/ or societal ecosystem.
- Such a process of identifying an opportunity for an entirely new business and revenue model can also be prompted by digital transformation while business strategies are infused into technology and vice versa.
- A business entity generates loads of data while conducting transactions at the physical marketplace. Particularly a bank generates billions of transactional data conducted with millions of customers. Such data can further be collated for transaction types, time duration, repeats for errors, geographical regions, age group, gender, range values, language, time of the day, etc. once captured.
- Cognitive tools from the stables of Artificial Intelligence, Machine Learning and Big Data Analytics, can now be used for further processing of such data.
- When done, the processed information can enable Chief Experience Officers (CXOs) to draw many inferences in the context of business that has been done and/or can be done.
- Further reflection on such information can trigger innovative thoughts to craft out new business designs that can be offered to customers through digital solutions, mode, and media. These can then be taken to the physical customers' marketplace for implementation and revenue generation. This is called the PDP Loop.

Therefore, the process of interplay starts even before formulation of strategy and/or while formulating the same.

Common elements of Digital Strategy

- **Choose a Leader** -This is arguably the most important part of creating a digital strategy, but choosing the right person will depend on company culture, structure and priorities. Whether companies place leadership with the CEO or an appointed Chief Digital Officer, the leader's influence will need to match the scope of digital strategy; otherwise, it will be difficult to create the full buy-in from each department necessary to make effective changes.
- **Attack vs. Defend**- McKinsey & Company emphasizes that companies would do well to categorize their potential threats and opportunities in digital business, then compare these against their own purpose. This clarifies whether a proactive or defensive stance needs to guide new initiatives.
- **Take a Measured Approach** - Digital strategy often incorporates a process for assessing whether new

technology will really complement or grow the current business. If you fear that your company is already behind on digital, it can be tempting to rush into a project without looking at how it fits your current strategy. By taking a measured approach, you can avoid wasting resources on initiatives that don't align with your business's needs and priorities.

- **Future Proof** - The goal of digital transformation is to create an appropriate foundation for digital business. This means creating an organization that can continue to reinvent itself as necessary to keep up with changes in technology and customer expectations. Digital strategy should be visionary enough to carry companies through changes in the digital economy, in a way that continues to bring a digital edge to the business.

(https://www.liferay.com/resources/l/digital-strategy#:~:text=Digital%20strategy%20focuses%20on%20using,use%20to%20achieve%20these%20changes.)

Innovations and Disruptive Business Models

11.3

The clarion call of present time is to first learn surfing for revival and survival, and then grow. One of the most critical tasks for saving the entity from drowning is implementation of digital transformation (DT) befitting the emerging way of living and operating in the new world order. This is a journey and not a destination to be reached just for once. Any organisation can lay the foundation of digital transformation on 4Ds, viz., Discover, Design, Deliver and De-risk as suggested by McKinsey; 2 Ps, i.e., People and Process and 1 T, i.e., Tools. Basu (2020)

The following measures can be listed for orchestrated planning and execution across hierarchical levels, length and breadth of the organisation:

- Integration of digital technologies with functional areas that will bring metamorphosis in the process of conducting business operations with the ultimate objective of improving stakeholders' relationship and experience management.
- Challenging the status quo of policies and standard operating practices for driving towards the inevitable metamorphosis.
- Training of existing human capital with different capabilities and redeployment for dealing with digital tools consciously being mindful of the requirement of cultural change and removing fear of unknown to embrace the new.
- Conducting experiments with digital technologies to assess suitability vis-à-vis the specificities of the needs of business and its stakeholders with the ultimate objective of incremental contributions for profit and profitability.
- Approaching the long-drawn task with a mindset of creative destruction of long-standing business policies and processes in favour of relatively new digitally driven practices that are still being defined, adopted, and stabilised.
- Providing the DT team, a free environment with committed assistance for innovative applications of various digital tools, if not 'innoventing' new tools, and establishing collaboration with man and digitally operated machines, which are artificially intelligent.
- Ensuring data privacy, cyber security, and information safety as an integral part of the entity's policy and processes for risk-enabled performance management.
- Permitting implementation team to make mistakes andnot penalising them for the same. Instead incentivise every attempt irrespective of success or failure so that the environment is congenial for innovating and delivering the best.
- Unwavering commitment of funds and other resources, as well as extending help and support to the dedicated DT team by every single functional area of the organisation.

Therefore, digital transformation is an orchestrated combination of people, process and technology for discovering, designing, and delivering with risk enabled process management what the stakeholders want. Through deductive logic one can explore out of the above narratives five essential elements of digital transformation, viz., stakeholders' relationship and experience, operational agility, culture and leadership, workforce enablement and integration of digital technologies for revival and sustainable growth with prosperity. The author reiterates that DT should be considered as a journey and not a destination because it is a task in eternity.

Basu (2020) comments that diffusion of digitization and digitalization is at the core of the tasks in this era of DT. Making meaning out of data and drawing inferences for strategic planning and deciding tactics for execution are the two critical drivers for attaining competitive advantages.

- Innovation: There is a need to come out from the aura of this buzz word. Conducting exploratory analysis for identifying hitherto unattended/unresolved problems and latent demands of society from the perspective of the business domain and beyond become imperative. Applying ground-breaking thoughts to determine cost-effective ways for meeting those demands and solving problems with a win-win approach for both customers and the business entity have become the need of the hour. This may cause disruptions to existing players.
- Digitization: All analogue data needs to be converted and generated by operating machinery and legacy systems, devices, physical documents, etc. into digital data and records. Taking steps to ensure that all data to be used in the process of business transformation are relevant, generated from first-hand sources and trustworthy is important.
- Digitalization: The need to use digital technologies befitting the needs for changing business, operating and revenue models with the objective to generate more turnover and achieving maximisation of value creation as well as minimisation of value destruction needs to be implemented. For example, brick and mortar business models is added with and /or replaced by virtual marketplace for e-Commerce.
- Digital Transformation: One has to embark upon the journey with strategically planned tasks for managing changes and applying digital technology to stay ahead of competition with an agile mindset. Taking all possible measures for training/ upskilling of workforce and inculcating digital agility.

It is evident from the above that two major tasks for digital transformation are Digitization and Digitalization as opined by Antonio Grasso. A simple example for this can be drawn from manufacturing industries. Lots of analogue data are generated in industrial units by various counters, flow meters, etc. to count/measure throughputs, output generations, and consumption of utilities like steam, power, chilled water, etc. Voluminous data are also generated in physical records maintained by workmen/supervisors including for maintenance of machines, consumption of spare parts and deployment of technicians. However, such data are not digitised with the help of IoTs and APIs, and stored for conducting analytical studies that may provide meaningful help in planning, monitoring, controlling, deriving trends and patterns, etc., and drawing inferences by cross functional data analyses. All these when done can help in making strategic decisions and execution there of which may in turn help in maximisation of value generation and minimisation of value creation.

New York Times Digital Transformation

In 2013, the New York Times implemented a carefully designed paywall and subscription model for their online content that allowed the company to continue to deliver the same type of high-quality journalism and content their readers expect while continuing to earn revenue.

This method appears to be working. According to their January 2017 report, "The Times brought in almost $500 million in purely digital revenue, which is far more than the digital revenues reported by many other leading publications (including BuzzFeed, The Guardian and The Washington Post) -combined.

Source: https://www.getsmarter.com/blog/career-advice/4-examples-successful-digital-strategies-can-learn/

Layers of Digital Transformation

- The following seven layers simplify the task of DT
- Data aggregation - Aggregation of business relevant data from reliable sources, including conversion of analogue data to digital form and store for easy retrieval.
- Data management - Categorising and organising the digitised data and making it ready for application of further processes.
- Workflow automation - Application of algorithms and utilising the data for the business process to be envisioned.
- Process component - Application of algorithms and start utilising the data for the business process.
- Platform interface integration - Integrating the digital system with the core systems for smoother operations.
- End to end processing - Conducting end to end processing and ensure error free transformation.
- Front end software - Integrating with the front end of stakeholders' devices so that she/he can get seamless services in a technologically collaborated mode.

Source: Basu (2019)

These seven points are to be revisited every time there is a change in business ecosystem, if not at least annually coinciding with the timing for formulating every annual business plan for the organisation. Basu (2019)

Disruptive technologies in the literature refer to technologies that have the potential to introduce new product attributes, which could become a source of competitive advantage. Recent researches indicate a rising interest in big data, cloud computing and closed-loop systems in the circular economy. These new enabling technologies allow firms to apply new business models in support of sustainability issues. The growing intelligence of goods generates novel business models which rely on the intelligence of ecosystems within the activities for resources, by shaping closed-loop systems. Firms are also engaging more in frugal innovations, allowing them to carry out resource-constrained innovations for emerging markets. There is a strong focus on shared platforms or "platfirms".

- **Big Data**
    - **Big data** is a collection of data that is huge in volume and is growing exponentially with time.
    - It is a data with so large size and complexity that none of traditional data management tools can store it or process it efficiently.
    - Big data is also a data but with huge size. Examples of Big Data include s**tock exchange, social networking site, jet engine, etc.**
    - There are three types of Big Data namely, structured, unstructured and semi-structured.
        - A 'structured data' is any data that can be stored, accessed and processed in the form of fixed format. A lot of success has been achieved over a period of time in developing techniques for working with such kind of data (where the format is well known in advance) and also deriving value out of it.
        - An unstructured data is one with unknown form or structure. In addition to the size being huge, un-structured data poses multiple challenges in terms of its processing for deriving value out of it.
        - A semi-structured data can contain both the forms of data. Example of semi-structured data is a data represented in an XML file.

Big Data can be described by the following characteristics:

- **Volume** – Size of data plays a very crucial role in determining value out of data. Also, whether a particular data can actually be considered as a Big Data or not, is dependent upon the volume of data. The name Big Data itself is related to a size which is enormous. Hence, 'Volume' is one characteristic which needs to be considered while dealing with Big Data solutions.
- **Variety** – Variety refers to heterogeneous sources and the nature of data, both structured, unstructured and semi structured. During earlier days, spreadsheets and databases were the only sources of data considered by most of the applications however, in recent period data can be in the form of emails, photos, videos, monitoring devices, PDFs, audio, etc.. These data also need to be analysed.
- **Velocity** – The term 'velocity' refers to the speed of generation of data and processing of data to be responsive to the needs of the customers. Big Data velocity deals with the speed at which data flows in from sources like business processes, application logs, networks, and social media sites, sensors, mobile devices, etc. The flow of data is massive and continuous.
- **Variability** – This refers to the inconsistency which can be shown by the data at times, thus hampering the process of being able to handle and manage the data effectively.

The following are some of the benefits of Big Data Processing

- Businesses can utilize outside intelligence while taking decisions.
- Improved customer service.
- Early identification of risk to the product/services, if any.
- Better operational efficiency.
  - Cloud Computing
    - Cloud computing is a general term for anything that involves delivering hosted services over the internet.
    - These services are divided into three main categories or types of cloud computing: infrastructure as a service (IaaS), platform as a service (PaaS) and software as a service (SaaS).
      - IaaS providers, such as Amazon Web Services (AWS), supply a virtual server instance and storage, as well as application programming interfaces (APIs) that let users migrate workloads to a virtual machine (VM). Users have an allocated storage capacity and can start, stop, access and configure the VM and storage as desired.
      - In the PaaS model, cloud providers host development tools on their infrastructures. Users access these tools over the internet using APIs, web portals or gateway software. PaaS is used for general software development, and many PaaS providers host the software after it's developed.
      - SaaS is a distribution model that delivers software applications over the internet; these applications are often called *web services*. Users can access SaaS applications and services from any location using a computer or mobile device that has internet access. In the SaaS model, users gain access to application software and databases.
    - A cloud can be private or public.
      - A public cloud sells services to anyone on the internet.
      - A private cloud is a proprietary network or a data center that supplies hosted services to a limited number of people, with certain access and permissions settings.

- Private or public, the goal of cloud computing is to provide easy, scalable access to computing resources and IT services. Examples of cloud computing include **Google Docs, Microsoft 365, Email services, Google Calendar, Skype, Wats App, Zoom, etc.**

Cloud computing benefits to modern businesses including the following:

- Cost management: Cloud infrastructure can reduce capital costs, as organisations don't have to spend massive amounts of money buying and maintaining equipment. Moreover, companies don't need large IT teams to handle cloud data center operations because they can rely on the expertise of their cloud providers' teams. Cloud computing also cuts costs related to downtime
- Data and workload mobility: Cloud computing allows users to access data from anywhere with any device with just an internet connection. That means users don't have to carry around USB drives, an external hard drive or multiple CDs to access their data. Users can access corporate data through smart phones and other mobile devices, enabling remote employees to stay up to date with co-workers and customers. End users can easily process, store, retrieve and recover resources in the cloud. In addition, cloud vendors provide all the upgrades and updates automatically, saving time and effort.
- Business continuity and disaster recovery (BCDR): The biggest worry for organisations in the present digital landscape is data loss. Storing data in the cloud guarantees that users can always access their data even if their devices, e.g., laptops or smart phones, are inoperable. With cloud-based services, organisations can quickly recover their data in the event of emergencies, such as natural disasters or power outages. This benefits BCDR and helps ensure that workloads and data are available even if the business suffers damage or disruption.

The demerits of cloud computing

In spite of the fact that cloud computing has huge benefits yet, it has its own causes of concern as follows:

- **Cloud security:** There is a clear lack of transparency regarding how and where sensitive information entrusted to the cloud provider is handled. When relying on the cloud, organisations risk data breaches, hacking of APIs and interfaces, compromised credentials and authentication issues.
- **Cost unpredictability:** The concept Pay-as-you-go subscription plans for cloud use, along with scaling resources to accommodate fluctuating workload demands, can make it tough to define and predict final costs.
- **Lack of capability and expertise:** With cloud-supporting technologies rapidly advancing, organisations are struggling to keep up with the growing demand for tools and employees with the proper skill sets and knowledge needed to architect, deploy, and manage workloads and data in a cloud.
- **IT governance:** The emphasis on do-it-yourself capability in cloud computing can make IT governance difficult, as there is no control over provisioning, de provisioning and management of infrastructure operations.
- **Compliance with industry laws:** When transferring data from on-premises local storage into cloud storage, it can be difficult to manage compliance with industry regulations through a third party.
- **Management of multiple clouds:** Every cloud is different, so multi-cloud deployments can disjoint efforts to address more general cloud computing challenges.
- **Cloud performance:** Network and provider outages can interfere with productivity and disrupt business processes if organisations are not prepared with contingency plans.
- **Building a private cloud:** Architecting, building and managing private clouds whether for its own purpose or for a hybrid cloud goal can be a daunting task for IT departments and staff.
- **Cloud migration:** The process of moving applications and other data to a cloud infrastructure often causes complications. Migration projects frequently take longer than anticipated and go over budget.

- **Vendor lock-in:** Switching between cloud providers can cause significant issues. This includes technical incompatibilities, legal and regulatory limitations and substantial costs incurred from sizable data migrations.

[https://www.techtarget.com/searchcloudcomputing/definition/cloud-computing]

Solved Case 1

Adobe's move to Creative Cloud

Instead of holding steadfast in their existing business model, Adobe proactively moved their entire product-base online in 2013 and it truly paid off. According to their 2018 financials, the company achieved record quarterly revenue of $2.20 billion in its second fiscal quarter, representing 24% growth year-on-year. The move to the cloud also brings with it a reduction in the occurrence of software piracy. The reality is that a large number of Adobe's core product users tend not to pay for their products. In fact, Adobe products consistently top the list of the most frequently pirated software in the world, accounting for 10 out of the top 20 downloaded software products on illegal torrenting sites. But this isn't the case with cloud-delivered software, as all their functionality is hosted and controlled online.

While some of Adobe's performance can be put down to the sheer volume of content being created across the creative industries, the solutions they provide respond to a very key need in the marketplace. Essentially, Adobe is assisting and empowering creative businesses to embrace digital transformation.

On this point, their success came largely from understanding people, and how they work with their products on a day-to-day basis. When Adobe decided to make the transition from physical software to a cloud-based model, it knew it needed to shift its employees' focus towards the needs of the customer. To achieve this, it created a staff Experience-a-thon, where employees could test and provide feedback on Adobe products as if they were users. This encouraged employee engagement and helped change the culture in the midst of a massive technical upheaval.

Source: https://www.getsmarter.com/blog/career-advice/4-examples-successful-digital-strategies-can-learn/

Emerging Trends in Digital and Social Marketing Strategies

11.4

- **Artificial Intelligence:**
  - Artificial intelligence (AI) is intelligence exhibited by machines and systems, with machines imitating functions which are mostly related with human cognition.
  - There are three levels of AI namely; Narrow AI, General AI/human-level and Super AI.
  - Narrow AI refers to the current state-of-the-art with existing software that automates a traditionally human activity and often outperforms humans in efficiency and endurance in one specialized area, e.g., forecasting the weather, autonomous driving, etc.
  - General AI/human-level AI describes the capacity of machines to understand their environment and reason and act accordingly, just as a human would in all activities across all dimensions, including scientific creativity, general knowledge, and social skills.
  - Super AI, the highest level of AI, is reached when AI becomes much smarter than the best human brains in practically every field.
  - Super AI systems can make deductions about unknown environments.
  - Machine learning (ML) describes automated learning of implicit properties of, or underlying rules for data. It is a major component for implementing
  - AI since its output is used as the basis for recommendations, decisions, and feedback mechanisms with regards to a previously unknown situation.
  - ML is an approach to creating AI. As most AI systems today are ML-based, the terms are often used interchangeably-particularly in a business context.
  - ML involves training algorithms on sample input data to optimize its performance on a specific task so that the machine gains a new capability.
  - Deep learning is a branch of AI. It mainly deals with neural networks that consist of many layers, hence the name "deep." In the last years, deep neural networks have been the most successful AI approach in many areas.
  - AI is required for analyzing previously unavailable or indecipherable data (e.g., video or sound which previously could only be interpreted by humans), in order to detect quality issues.
  - AI also has the ability to help detection and analysis mechanisms, improve its own accuracy by continuously learning from the issues detected, and optimize manufacturing processes by incorporating feedback and adjusting the control parameters accordingly.
  - It is amazing to note how much friendly a technology AI is emerging to help people in quest for solving problems for society.

According to Basu (2019) versatility of AI is transcending all areas of solution building. The most encouraging is that AI is emerging as a friend of all for keeping cyber criminals away. It is also acquiring self-propelling energies.

More and more corporates, who were observing peers attaining competitive advantage using digital technologies, are now plunging into the act of digital transformation, particularly using AI with IoTs and Blockchain.

Solved Case 2

AI in Alibaba

One successful example of AI is the Chinese e-commerce giant Alibaba. They are making huge gains in AI thanks to the support, investment, and commitment of the Chinese government. With hopes to build a $1 trillion AI industry by 2030, China is on a path to overtake the United States as the world's leader in technology. Alibaba's application of AI and machine learning in their 'smart' warehouse was borne out of necessity. Having completed over $248 billion in transactions (more than eBay and Amazon combined), the sheer volume of products they need to move makes it practically impossible for employees to keep up. This willingness to commit to new technologies has allowed them to stay competitive by packaging and shipping out more products, more efficiently. Alibaba is also harnessing AI technology through features such as smart product search and recommendation, customer-service chatbots, and image matching. This has allowed them to create tailor-made shopping experiences for consumers and better optimise the shopping process for them by anticipating what they might be seeking out at any given time. And they are only scratching the surface of their plans for AI. As they continue to research and understand the potential that machine learning holds, so Alibaba plans to harness the technology is a myriad of ways, from financing to facial recognition.

Source: https://www.getsmarter.com/blog/career-advice/4-examples-successful-digital-strategies-can-learn/

Solved Case 3

Fintech

The term FinTech (financial technology) includes software, mobile applications, and other technologies that are created to improve and automate traditional forms of finance both for businesses and consumers. FinTech can include everything from straightforward mobile payment apps to complex blockchain networks housing encrypted transactions. The term "fintech company" describes any business that uses technology to modify, enhance, or automate financial services for businesses or consumers. Some examples include mobile banking, peer-to-peer payment services (e.g., Venmo, CashApp, Paysend, etc.), automated portfolio managers (e.g., Wealthfront, Betterment, FundsIndia.com), or trading platforms such as (Robinhood, Upstox Pro Mobile, Zerodha Kite, etc,). It can also apply to the development and trading of crypto currencies (e.g., Bitcoin, Dogecoin, Ether, etc.). It may be mentioned that FinTech simplifies financial transactions for consumers or businesses, making them more accessible and generally more affordable. It can also apply to companies and services utilizing Artificial intelligence (AI), big data, and encrypted blockchain technology to facilitate highly secure transactions amongst an internal network. According to Basu (2019) People's Bank of China (PBoC), as reported by its Dy. Director Mu Changchun, is ready with its prototype for 'China's Digital Currency' on a two-tier platform. Its layer one will be operated by PBoC and layer two by commercial banks. One should keenly watch this development keeping in view the USA's political groups criticizing facebook's initiative for cryptocurrency Libra.

Solved Case 4

Razorpay

Razorpay is a payment solution in India that helps companies with its suite of products to receive, process, and disburse payments. It gives you access to all payment modes, including JioMoney, Mobikwik, Airtel Money, FreeCharge, Ola Money, and PayZapp, including credit card, debit card, net banking, UPI, and common wallets. It was started by Harshil Mathur and Shashank Kumar in 2014. Businesses can handle the marketplace, simplify money transactions, receive regular fees, exchange client invoices, and take advantage of working capital loans from a single platform.

Source: https://www.goodreturns.in/classroom/10-indian-fintech-startups-making-waves-in-finance-sector-2021/articlecontent-pf17590-1207512.html

Solved Case 5

Shiksha Finance

Siksha Finance is India's leading lending in an education finance firm. They also offer loans to educational institutions to develop buildings, buy properties and working capital. The mission of this institution is to fund parents for school fees, thereby reducing school drop-out rates. The debt ranges from Rs 10,000 to Rs 30,050 which must be returned within 6 to 10 months. Student loans may be used by parents to pay school tuition, books, uniforms, shoes, luggage, etc.

https://www.goodreturns.in/classroom/10-indian-fintech-startups-making-waves-in-finance-sector-2021/articlecontent-pf17594-1207512.html

- **Blockchain:** Blockchain is a shared, immutable ledger that facilitates the process of recording transactions and tracking assets in a business network. An *asset* can be tangible (house, car, cash, land, etc.) or intangible (intellectual property, patents, copyrights, branding). Virtually anything of value can be tracked and traded on a blockchain network, reducing risk and cutting costs for all involved. The importance of block chain network stems from the fact that business runs on information. The information should be accurate and received fast. Blockchain is ideal for delivering that information because it provides immediate, shared and completely transparent information stored on an immutable ledger that can be accessed only by permissioned network members. A blockchain network can track orders, payments, accounts, production and much more. As members share a single view of the truth, one can see all details of a transaction end to end, giving greater confidence, as well as new efficiencies and opportunities.

The important components of a block chain includes

Distributed ledger technology

All network participants have access to the distributed ledger and its immutable record of transactions. With this shared ledger, transactions are recorded only once, eliminating the duplication of effort that's typical of traditional business networks.

Immutable records

No participant can change or tamper with a transaction after it's been recorded to the shared ledger. If a transaction record includes an error, a new transaction must be added to reverse the error, and both transactions are then visible.

Smart contracts

A smart contract is stored on the blockchain and executed automatically. A smart contract can define conditions for corporate bond transfers; include terms for travel insurance to be paid and much more. A smart contract acts a set of rules and allows fastest transactions.

- The benefits of blockchain network

Increased trust

As block chain is used by only the members who are within a defined network. This assures the members that the data being received by them is accurate and timely data. Moreover, the confidential blockchain records will be shared only with network members to whom one has specifically granted access.

Greater security

The increase security in blockchain network arises from the fact that consensus on data accuracy is required from all network members, and all validated transactions are immutable because they are recorded permanently. No one, not even a system administrator, can delete a transaction.

Increased efficiencies

With a distributed ledger that is shared among members of a network, time-wasting record reconciliations are eliminated. The smart contract enables automated transactions thereby saving on time.

Solved Case 6

Blockchain to solve phone spamming:

All telecommunication companies in India have been instructed by the Telecom Regulatory Authority of India to adopt blockchain technology. This will enable only registered users to engage in telemarketing activities. This proposal will be put into effect come December. This process does not guarantee the complete elimination of phone 'spamming' problem but will see to it that the people/organisations responsible are held accountable. Blockchain will allow appropriate agencies to track and locate the perpetrators. Rajan Matthews, director general at the Cellular Operations Authority of India, said that the technology is in place, the steps that ensue require the public to be educated on concepts such as setting their DnD (Do not Disturb) preferences, etc. Telcos are happy with blockchain developments and they hope that AI coupled with Blockchain will rectify all the flaws in telecommunications.

Source: https://analyticsindiamag.com/top-7-blockchain-developments-in-india-2019/

Solved Case 7

Tea Board of India to use blockchain:

Tea Board of India, through an expression of interest (EoI), made clear its intention of adopting end-to-end technology to promote transparency and improve traceability of products and trade operations. The quality of tea has been on the decline due to adulteration, therefore, making it difficult to distinguish between good quality tea leaves against bad quality ones. The tea board, plantation owner, manufacturers, etc. have been forced to devalue their product which will run them out of business sooner or later. In a bid to revitalise the stagnating industry, Tea Board of India looks to implement various technologies, one of which is blockchain. Blockchain technology will record all the details pertaining to procurement, manufacturing and delivery of the end product. The Tea Board of India is also looking into the digitisation of the tea trade. Blockchain will enable customers to trace the origin of tea back to the plantation and record any cases of adulteration if any. Blockchain in agricultural, food and other related industries is projected to hit $ 430 million (approx.) by 2023. The impetus of all these industries will be on traceability and tracking, secure payments, data retention and accessibility, risk complaint management, etc. – all of which is greatly enabled through blockchain.

Source: https://analyticsindiamag.com/top-7-blockchain-developments-in-india-2019/

According to Basu (2019) giant MNCs like Uniliver, Kellog, Pfizer, AT&T have become anchor brands for IBM's pilot consortium called 'IBM Mediaocean Blockchain'. This platform will bring transparency, trust, cost reduction and facilitate the process of reconciliation in their complex tasks of advertisements through digital media. Blockchain will create the trust verified chain from every dollar spent to the end user. It will have potentials to cut out several inefficiencies in marketplace. In a recent use case, a large HR hiring agency will deploy a blockchain enabled hiring platform to streamline internal processes such as secure uploading of job seekers' profiles and their distribution among various platforms. Efforts are multiplying for gainfully applying Blockchain to agriculture and environment management.

- **Robotic Process Automation**: Robotic Process Automation (RPA) is a form of business process automation that allows anyone to define a set of instructions for a robot or 'bot' to perform. RPA bots are capable of mimicking most human-computer interactions to carry out a ton of error-free tasks, at high volume and speed. Robotic process automation is not a physical or mechanical robot. RPA is the process by which a software bot uses a combination of automation, computer vision, and machine learning to automate repetitive, high-volume tasks that are rule-based and trigger-driven. Robotic process automation tools are best suited for processes with repeatable, predictable interactions with IT applications. These processes typically lack the scale or value to warrant automation via IT transformation. RPA tools can improve the efficiency of these processes and the effectiveness of services without fundamental process redesign. Robotic process automation software "robots" perform routine business processes by mimicking the way that people interact with applications through a user interface and following simple rules to make decisions. Entire end-to-end processes can be performed by software robots with very little human interaction, typically to manage exceptions.

- The benefits of RPA solutions not only reduce cost but also include:
  - Decreased cycle times
  - Flexibility and scalability
  - Improved accuracy
  - Improved employee morale
  - Detailed data capture

Basu (2019) mentions that the next Russian Soyuz spacecraft will be navigated by a humanoid Skybot sitting in commander's chair. It is one of the latest versions of Russia's FEDOR series robots serving as all-purpose stand-in for humans in everything from rescue work to driving cars and now, flying into space. Such robots will be artificially intelligent and have cognitive skills almost like of a human astronaut. Artificially intelligent robots will soon be able to identify wrongdoers through face and outfit recognition ability and take actions, including killing if need be. This group of robots will eventually be of help to security forces for surveillance and dealing with strategy execution in battlefields and curbing terrorism. Robotists have successfully brought out the next genre of Robots called Cobots by applying DevOps concept. These are designed to interact and collaborate with human beings at a shared workspace. Cobots will ensure delivery with higher speed, quality and cost optimisation, yet will not cause much reduction in workforce.

- **Digitalisation of Sports:** Technology is playing a larger role than ever in the lives of diehard fans and followers, opening the way for sports organisations to create new, innovative customer experiences. Partnering with broadcasters and new distribution platforms can give fans the experiences they want, and capture viewership across multiple devices, including mobile. Sports organisations need to strategically leverage digital media to build direct connections with fans. One way is to partner with broadcasters to master content across multiple channels, which also allows for a wealth of real-time marketing opportunities. Ultimately, digital optimization of content across platforms will help broaden content reach for sports organisation. Many sports fans are no longer interested in the game alone–they crave the kind of exclusive and shareable experiences that can be amplified by technology. Sports organisations could grow stadium attendance by using immersive technologies such as augmented and virtual reality to create an intensely exciting viewing experience. They can also increase engagement by leveraging loyalty and customer relationship management data to tailor experiences to individual fan preferences. [https://www2.deloitte.com/us/en/pages/ technology- media-and-telecommunications/articles/ digital- transformation-and-future-changes-in-sports-industry.html]. According to Basu (2019) the cricket enthusiast will be happy to learn that a Smart Chip, planted in a ball, can now bring amazing advancements for umpires taking more accurate decisions and help trainers in training players more effectively.

- **Internet of Things:** The internet of things (IoT) is a system of interrelated computing devices, mechanical and digital machines, objects, animals or people that are provided with unique identifiers and the ability to transfer data over a network without requiring human-to-human or human-to-computer interaction. A thing in the internet of things can be anything from a person with a heart monitor implant, a farm animal with a biochip transponder, an automobile that has built-in sensors to alert the driver when tire pressure is low or any other natural or man-made object that can be assigned an Internet Protocol (IP) address and is able to transfer data over a network. Increasingly, organisations in a variety of industries are using IoT to operate more efficiently, better understand customers to deliver enhanced customer service, improve decision-making and increase the value of the business. In IoT ecosystem consists of web-enabled smart devices that use embedded systems, such as processors, sensors and communication hardware, to collect, send and act on data they acquire from their environments. IoT devices share the sensor data they collect by connecting to an IoT gateway or other edge device where data is either sent to the cloud to be analyzed or analysed locally. Sometimes, these devices communicate with other related devices and act on the information they get from one another. The devices do most of the work without human intervention, although people can interact with the devices-for instance, to set them up, give them instructions or access the data. [https://www.techtarget.com/iotagenda/definition/Internet-of-Things-IoT].

Although the idea of IoT has been in existence for a long time, a collection of recent advances in a number of different technologies has made it practical. These technologies include:

- **Access to low-cost, low-power sensor technology:** Affordable and reliable sensors are making IoT technology possible for more manufacturers.
- **Connectivity:** A host of network protocols for the internet has made it easy to connect sensors to the cloud and to other "things" for efficient data transfer.
- **Cloud computing platforms:** The increase in the availability of cloud platforms enables both businesses and consumers to access the infrastructure they need to scale up without actually having to manage it all.
- **Machine learning and analytics:** With advances in machine learning and analytics, along with access to varied and vast amounts of data stored in the cloud, businesses can gather insights faster and more easily. The emergence of these allied technologies continues to push the boundaries of IoT and the data produced by IoT also feeds these technologies.
- **Conversational artificial intelligence (AI):** Advances in neural networks have brought natural-language processing (NLP) to IoT devices (such as digital personal assistants Alexa, Cortana, and Siri) and made them appealing, affordable, and viable for home use.

Smart Lighting

This is another one of the Internet of Things examples that have gradually been coming into common usage. Bulbs and battens connected to Wifi can be turned on and off remotely. Schedule for usage can be set for these devices along with their brightnesses controlled and their power consumption monitored. Using other IoT devices, smart lighting devices can also be turned on and off by voice alone. The power consumption of these devices can also be easily monitored using IoT.

Smart Parking

It is hard to regulate the occupancy and parking coverage in large multi-story car parking facilities. Among the many Internet of Things examples is the use of IoT in such facilities for counting the number of cars that have driven into the facility and the number that have driven out. Specific devices can also give you the exact location where you have parked your car so you are not lost.

Medical Fridges

Medical fridges are a grand entry to the Internet of Things examples list and can be used for regulatory compliance and safety purposes. Vials of vaccines and medicines can often be spoiled if they are not kept at the correct temperatures. Medical refrigerators cannot be monitored throughout the day, especially in person. Having IoT sensors inside medical fridges can enable them to be monitored remotely, and their temperature changed as per requirement.

Source: https://www.jigsawacademy.com/5-best-examples-iot-applications-real-world/

The different types of digital marketing strategies are as follows:

- **Social Media Marketing Platforms**

  Todays' consumers are highly reliant on social media platforms such as Instagram, Facebook, LinkedIn, and Snapchat. This is why it is essential that brands are active across accounts. Social media platforms allow marketers to reach their prospects in a myriad of ways. First, marketing teams can use these channels to distribute paid ads and sponsored content. Each platform has a way for marketing teams to create paid ad campaigns and segment users so these ads appear on the feeds of target audience members. While each platform is different, most have capabilities that allow marketing teams to place ads based on location, job title, interests, age, etc. Social media is also a great way to promote products or resources organically to your followers, and engage with consumers. Chances are, people that follow your brand on social media have likely purchased from you in the past. Interacting with them on social media or answering customer service-oriented questions is a great way to ensure continued engagement with the brand and cultivate positive experiences and customer loyalty.

- **Influencer Marketing**

  Another effective way to harness digital channels to reach target audiences is with influencer marketing. Brands can partner with celebrities, sites, or others that are considered experts in their field, that share similar values. Brands can then reach these influencers' followers with branded content and offers.

- **Email Marketing**

  Email marketing campaigns allow organizations to stay connected with prospects and customers, sending them customized newsletters or offers based on past shopping history or brand engagements. If an individual has interacted with a few of your branded touch points- like an email offer for 10 percent off the items they have been considering, or free shipping - that may be what ultimately brings about a conversion.

- **Content Marketing**

  Content marketing allows marketing teams to be proactive in answering their users' questions. Marketing teams create content, videos, and other assets to answer questions or provide context to consumers throughout the three stages of the buyer's journey:

  i. **The awareness stage:** Buyer realizes they have a need

  ii. **The consideration stage:** Buyer determines a course of action to meet this need

  iii. **The decision stage:** Buyer decides on a product / service to purchase to meet the need

For example, a consumer might realize they need new shoes to wear to the gym. The marketing team for an active wear company may produce a piece about what features you need from a running shoe, as opposed to what you need if you focus on strength training. Looking at this content, the buyer determines they need a pair of running shoes that meets that criterion. Another piece of content might show the most popular running shoes and their price points. Once they are educated on these factors, they decide. The guidance offered by your brand throughout will likely result in them purchasing from you. Content marketing is often less expensive than other forms of marketing, while producing many leads.

- **Search Engine Optimization (SEO) Marketing**

  Search engine optimization often goes hand in hand with content marketing. When the customer from the above example is conducting research for which gym shoes to buy, they will probably click on one of the first three results that appear on Google. With this in mind, the athletic shoes' marketing team wants to ensure their article appears in those top results. This is done by optimizing content for user experience and ensuring the technical elements are in place to enable search engine crawlers to easily find and index this content.

- **Pay-per-click (PPC)**

  Pay-per-click is a form of paid advertising that allows marketing teams to essentially purchase traffic to their website. Marketers place ads on websites or search engines such as Google and Microsoft Bing, and pay a fee each time the ad is clicked on. These ads often appear at the top of the search results page, and are typically determined by bids on specific keywords, while banner ads on websites usually have set prices.

- **Affiliate Marketing**

  Affiliate marketing is similar to referral programs; it involves working with outside individuals or companies under the agreement that they promote your product in exchange for a commission from each sale that can be attributed to their efforts. This is a way to cut down on costs and outsource some of the heavy lifting of promotion; however, you're putting your brand's reputation in someone else's hands, so this type of marketing often requires more extensive monitoring and tracking.

- **Mobile Marketing**

  Mobile marketing initiatives can include many of the digital marketing strategies mentioned above, and typically will leverage a combination of text messages, social media, email, push notifications, and mobile applications. The importance of mobile marketing is rising, as it is expected that by 2024, the number of mobile shoppers will rise to approximately 187.5 million users. With the clear move to mobile, marketers need to think about how they can optimize their current marketing efforts for mobile to be able to deliver a seamless and user-friendly experience.

(https://www.marketingevolution.com/marketing-essentials/what-is-a-digital-marketing-platform-marketing-evolution)

Exercise

A. Theoretical Questions:

⊙ Multiple Choice Questions

1. Digital transformation drives change in
   - a. customer experience
   - b. operational processes
   - c. business models
   - d. all of the above
2. The process of digital transformation requires coordination across the entire organization, and involves business culture changes.
   - a. digital strategy
   - b. digitisation
   - c. digital transformation
   - d. data aggregation
3. Categorising and organising the digitised data and making it ready for application of further processes is called________.
   - a. Data aggregation
   - b. Data management
   - c. Workflow automation
   - d. Process component
4. Which among the following is not a characteristic of Big Data?
   - a. Variety
   - b. Volume
   - c. Velocity
   - d. Invariability
5. Data that can be stored, accessed and processed in the form of fixed format is called__________.
   - a. unstructured data
   - b. semi-structured data
   - c. structured data
   - d. flexible data

6. Which among the following is not a component of a block chain?

   a. Distributed ledger technology

   b. Immutable record

   c. Smart contracts

   d. Increased threat

7. Which among the following alternatives is not suited for Robotic process automation tools?

   a. Repeatable

   b. Predictable interactions with IT applications

   c. Routine

   d. Unpredictable events

8. ___________ is similar to referral programs.

   a. Influencer Marketing

   b. Affiliate marketing

   c. Social Media Marketing Platforms

   d. Content marketing

9. __________is a form of paid advertising that allows marketing teams to essentially purchase traffic to their website.

   a. Influencer Marketing

   b. Affiliate marketing

   c. Pay-per-click

   d. Content marketing

10. Forecasting the weather is an example of

    a. Narrow AI

    b. General AI/human-level

    c. Super AI

    d. Deep- learning

11. Which of the following is NOT a way AI can be used in strategic management?

    a) Predictive analytics for forecasting market trends

    b) Automating all decision-making processes

    c) Natural language processing for analyzing customer feedback

    d) Machine learning algorithms for identifying patterns in data

12. How does affiliate marketing contribute to strategic management?

    a) By reducing the need for traditional marketing efforts

    b) By leveraging partnerships to expand reach and increase sales

    c) By eliminating the need for customer relationship management

    d) By increasing operational costs for the organization

13. Which of the following is a key benefit of mobile marketing in strategic management?

    a) Limited audience reach compared to other marketing channels

    b) Ability to engage with customers in real-time and personalize interactions

    c) Higher costs associated with mobile advertising

    d) Inability to track and measure campaign effectiveness

14. How can affiliate marketing be integrated into a company's strategic management approach?

    a) By solely focusing on traditional advertising methods

    b) By collaborating with influencers and affiliates to promote products or services

    c) By ignoring digital marketing trends

    d) By relying exclusively on organic reach through social media

Answer:

1	2	3	4	5	6	7	8	9	10	11	12	13	14
d	c	b	d	c	d	d	b	c	a	b	b	b	b

- **State True or False.**

1. Digital strategy focuses on technology and culture.
2. A distributed ledger technology acts a set of rules and allows fastest transactions.
3. Email marketing allows marketing teams to be proactive in answering their users' questions.
4. Influencer marketing campaigns allow organizations to stay connected with prospects and customers, sending them customized newsletters or offers based on past shopping history or brand engagements.
5. Deep learning describes automated learning of implicit properties of, or underlying rules for data.
6. Machine learning is a branch of AI which mainly deals with neural networks that consist of many layers.
7. Narrow AI systems can make deductions about unknown environments.
8. Velocity refers to heterogeneous sources and the nature of data, both structured, unstructured and semi structured.
9. Internet of Things allows users to access data from anywhere with any device with just an internet connection.

10. Cloud computing is a system of interrelated computing devices, mechanical and digital machines, objects, animals or people that are provided with unique identifiers and the ability to transfer data over a network without requiring human-to-human or human-to-computer interaction.
11. Distributed ledger technology perform routine business processes by mimicking the way that people interact with applications through a user interface and following simple rules to make decisions.

Answer:

1	2	3	4	5	6	7	8	9	10	11
F	F	F	F	F	F	F	F	F	F	F

⊙ Fill in the Blanks.

1. Affordable and reliable ________ are making IoT technology possible for more manufacturers.
2. ___________ is a form of business process automation that allows anyone to define a set of instructions for a robot or 'bot' to perform.
3. ___________ is a shared, immutable ledger that facilitates the process of recording transactions and tracking assets in a business network.
4. _______ can include everything from straightforward mobile payment apps to complex blockchain networks housing encrypted transactions.
5. ____________ describes automated learning of implicit properties of, or underlying rules for data.
6. A __________ is a proprietary network or a data center that supplies hosted services to a limited number of people, with certain access and permissions settings.
7. A _________ sells services to anyone on the internet.
8. The __________is a system that has the ability to transfer data over a network without requiring human-to-human or human-to-computer interaction.
9. The process of moving applications and other data to a cloud infrastructure is referred to as ___________.
10. A clear lack of transparency regarding how and where sensitive information entrusted to the cloud provider is handled is an issue of ____________.

Answer:

1	sensors	2	Robotic Process Automation
3	Blockchain	4	FinTech
5	Machine learning	6	private cloud
7	public cloud	8	internet of things
9	cloud migration	10	cloud security

Short Essay Type Questions

1. What do you understand by Big Data? Give some examples.
2. What are the benefits of Big Data Analytics?
3. What is Deep Learning?
4. What is the meaning of influencer marketing?
5. What is Conversational artificial intelligence?
6. What do you understand by email marketing campaign?
7. What do you understand by pay per click marketing?
8. What is affiliate marketing?

Essay Type Questions

1. List down the steps that an organisation should take for digital transformation.
2. What is Cloud Computing? Explain the merits and demerits of Cloud Computing.
3. What are the characteristics of Big Data?
4. Explain Artificial Intelligence.
5. What is Machine Learning?
6. Write a short note on Fintech and Block Chain.
7. What are the important components of Block Chain?
8. What are the benefits of block chain network?
9. Explain Robotic Process Automation and list the benefits of RPA.
10. Write a short note on IoT.
11. What is content marketing?