GROUP II / PAPER-9

PRODUCTION PLANNING
QUALITY MANAGEMENT
OPERATIONS
INFORMATION SYSTEMS
ERP

OPERATIONS MANAGEMENT & INFORMATION SYSTEMS

INTERMEDIATE

The Institute of Cost Accountants of India
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INTERMEDIATE : PAPER - 9

OPERATIONS MANAGEMENT & INFORMATION SYSTEM

INTERMEDIATE

STUDY NOTES

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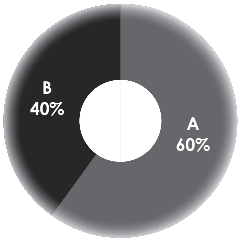
Syllabus

PAPER 9: OPERATION MANAGEMENT & INFORMATION SYSTEMS (OMS)

Syllabus Structure

The syllabus comprises the following topics and study weightage:

A	Operation Management	60%
B	Information Systems	40%



ASSESSMENT STRATEGY

There will be written examination paper of three hours.

OBJECTIVE

To provide an in depth study of the various business process, analyze operations, production planning and information system.

Learning Aims

The syllabus aims to test the student's ability to:

- Understand the business process and analyze the operations
- Identify and evaluate activities for determination of cost centre or activity centre
- Acquire knowledge of production planning and resource management
- Understand and analyze the information system for designing and managing data
- Apply knowledge to develop Management Information System
- Develop basic concepts and operational modalities of Enterprise Resource Planning

Skill Set required

Level B: Requiring the skill levels of knowledge, comprehension, application and analysis.

Section A : Operation Management	**60%**
1. (a) Operations Management (b) Designing and Managing operations	
2. Production Planning	
3. Productivity Management and Total Quality Management	
4. Economics of Maintenance and Spares Management	
Section B : Information Systems	**40%**
5. Information System Analysis and Design	
6. Database management Systems	
7. Management Information System (MIS) and Information Economics	
8. Enterprise Resource Planning (ERP)	
9. Cyber Law, e-commerce	

SECTION A: OPERATIONS MANAGEMENT [60 MARKS]

1.(a) Operations Management – introduction, scope, need, challenges, role in decision-making, operational strategies for competitive advantage

(b) Designing and Managing operations:

(i) Designing of goods and services – selection, product life cycle, generation of new products; product development

(ii) Process strategy , process analysis and design, production process flow, cost flow, costing system with special reference to: - Regulated Industries, Non-regulated Industries and Service Sectors

2. Production Planning

(a) Production planning – introduction, control measures

(b) Economics and optimization – basics, Pareto Optimality condition, price-mechanism and optimum resource allocation, economic batch production

(c) Studies at work place – Time study, Work study, Method study, Activity sampling, Work simplification, Job Evaluation

(d) Forecasting- introduction, features, elements, steps, approaches, techniques (including time series, regression and correlation analysis)

(e) Capacity Management – Planning and Utilization for products and services

(f) Process selection, facility layout, designing work systems, Location Planning and Analysis,

(g) Project Planning – introduction, aspects, Project Life Cycle, scheduling with Gantt Charts, PERT and CPM, Project Risk measurement

(h) Waiting Lines and Simulation – characteristics and measures of waiting lines, performance, queuing models, dispatching, scheduling technique, simulation and line balancing problem

(i) Human Resource Planning and optimization – introduction, job allocation/assignment

(j) Optimum allocation of resources through application of linear programming techniques

(i) For Goods – inputs, processing, outputs JIT and Lean Operations

(ii) For Services

3. Productivity Management and Total Quality Management

(a) Introduction, features, measurement techniques of factors of production, productivity index, productivity of Employee, productivity of materials, productivity of management resources, productivity of other factors

(b) Economics of Research and Development – for improving productivity

(c) Technological Innovation – emerging techniques and its applications for economic decision-making relating to productivity

(d) Methods of improving productivity including quality circles

(e) Total Quality Management (TQM) – basics tools and certification

4. Economics of Maintenance and Spares Management

(a) Breakdown maintenance, preventive maintenance & routine maintenance

(b) Obsolescence, replacement of machinery

(c) Maintenance – Techniques, Organization, problems

(d) Spare parts – Planning, policy and control

(e) Application of Queuing theory in maintenance and spares management

Section B: Information System [40 marks]

5. Information System Analysis and Design

(a) Information System - Systems development life cycle, Structured Systems Analysis and Design, Physical and Logical Data Inflow Diagrams

(b) Requirements Analysis, Design of New Systems. Data Modeling, Data dictionary, entity relationship diagram, structure charts, Transform and Transaction Analysis

6. Database management Systems

(a) File & Data Base Concept, Overview of DBMS, Data Models, Database Administrator, Database User, Schema, Data Independence

(b) Relational Database Management System (RDBMS), some application of RDBMS using Oracle & SQL Server

7. Management Information System (MIS) and Information Economics

(a) Management Information Systems: Definition, scope, planned and unplanned MIS, MIS information time scale, transaction processing

(b) MIS and Levels of Management – operational level, tactical level, strategic level

(c) Business Intelligence - Architecture Analysis

(d) Processing Management Accounting Information

(e) Quality of Information and Value of Information

(f) Desirable properties of Management Accounting Information

(g) Uncertainty and Management Accounting Information

(h) Impact of Information Technology on Management Accounting

(i) MIS in functional areas: Finance & Cost Management, Inventory, Marketing, HRM, Financial modeling

8. Enterprise Resource Planning (ERP)

(a) FICO Module

(b) Basics of other modules of ERP – Production Planning, Plant Maintenance, Quality Management, Materials Management, Sales and Distribution, HR, Logistics

9. Cyber Law, e-commerce

(a) Cyber laws

(b) E-commerce and electronic financial transactions

Content

Study Note 3 : Productivity Management and Total Quality Management

Study Note 4 : Economics of Maintenance and Spares Management

Study Note 5 : Information System Analysis and Design

Study Note 6 : Database Management System

Study Note 7 : Management Information System (MIS) and Information Economics

Study Note 8 : Enterprise Resource Planning

Study Note 9 : Cyber Law, E-commerce

Study Note - 1

OPERATIONS MANAGEMENT & DESIGNING AND MANAGING OPERATIONS

This Study Note includes

1.1 OPERATIONS MANAGEMENT - INTRODUCTION

Operations management is the management of that part of an organization that is responsible for producing goods and/or services. There are examples of these goods and services all around you. Every book you read, every video you watch, every e-mail you send, every telephone conversation you have, and every medical treatment you receive involves the operations function of one or more organizations. So does everything you wear, eat, travel in, sit on, and access the Internet with.

However, in order to have a clear idea of Operations Management, one must have an idea of 'Operating Systems'.

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

Retail organizations, hospitals, bus and taxi services, tailors, hotels and dentists are all examples of operating systems. Any operating system converts inputs, using physical resources, to create outputs, the function of which is to satisfy customers wants. The creation of goods or services involves transforming or converting inputs into outputs. Various inputs such as capital, labour, and information are used to create goods or services using one or more transformation processes (e.g., storing, transporting, and cutting). To ensure that the desired output are obtained, an organization takes measurements at various points in the transformation process (feedback) and then compares with them with previously established standards to determine whether corrective action is needed (control).

It is important to note that goods and services often occur jointly. For example, having the oil changed in your car is a service, but the oil that is delivered is a good. Similarly, house painting is a service, but the paint is a good. The goods-service combination is a continuum. It can range from primarily goods, with little service, to primarily service, with few goods. Because there are relatively few pure goods or pure services, companies usually sell product packages, which are a combination of goods and services. There are elements of both goods production and service delivery in these product packages. This makes managing operations more interesting, and also more challenging.

1.2 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 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 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.

1.3 SCOPE OF OPERATIONS MANAGEMENT

Operations Management concern 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 and Planning Control.
6. Quality Control.
7. Materials Management.
8. Maintenance Management.

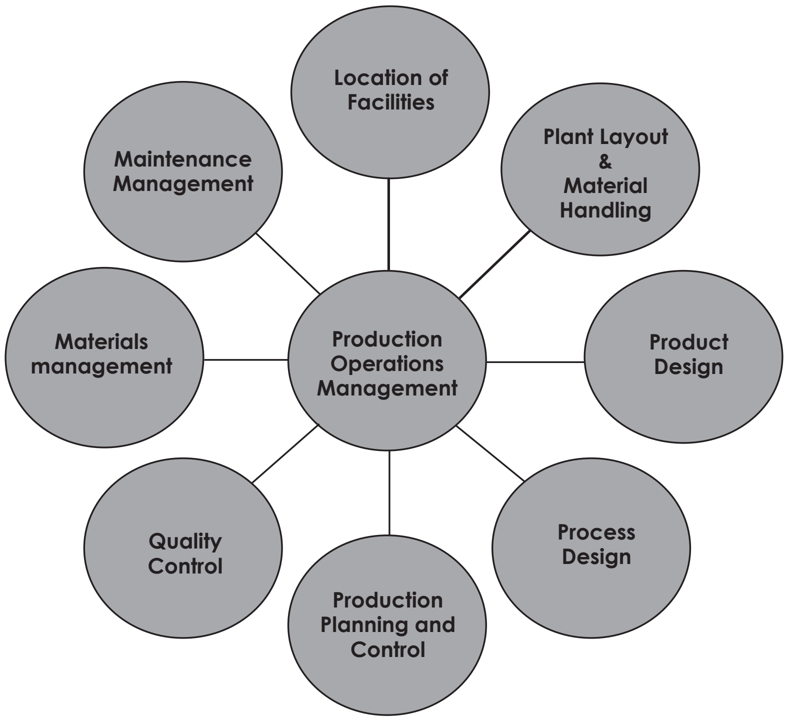


Fig. 1 : Scope of production and operations management

1. Location of Facilities

Location of facilities for operations is a long-term capacity decision, which involves a long-term commitment about the geographically static factors that affect a business organization. It is an important strategic level decision-making for an organization. It deals with the questions such as 'where our main operations should be based?'

The selection of location is a key-decision as large investment is made in building plant and machinery. An improper location of plant may lead to waste of all the investments made in plant and machinery equipments. Hence, location of plant should be based on the company's expansion plan and policy, diversification plan for the products, changing sources of raw materials and many other factors. The purpose of the location study is to find the optimal location that will results in the greatest advantage to the organization.

2. Plant Layout and Material Handling

Plant layout refers to the physical arrangement of facilities. It is the configuration of departments, work centers and equipment in the conversion process. The overall objective of the plant layout is to design a physical arrangement that meets the required output quality and quantity most economically. According to James More Plant layout is of an optimum arrangement of facilities including personnel, operating equipment, storage space, material handling equipments and all other supporting services along with the design of best structure to contain all these facilities.

'Material Handling' refers to the 'moving of materials from the store room to the machine and from one machine to die next during the process of manufacture'. It is also defined as the 'art and science of moving, packing and storing of products in any form'. It is a specialized activity for a modern manufacturing concern, with 50 to 75% of the cost of production. This cost can be reduced by proper section, operation and maintenance of material handling devices. Material handling devices increases the output, improves quality, speeds up the deliveries and decreases the cost of production. Hence, material handling is a prime consideration in the designing new plant and several existing plants.

3. Product Design

Product design deals with conversion of ideas into reality. Every business organizations have to design, develop and introduce new products as a survival and growth strategy. Developing the new products and launching them in the market is the biggest challenge faced by the organizations. The entire process of need identification to physical manufactures of product involves three functions!— Design and Marketing, Product, Development, and manufacturing. Product Development translates the needs of customers given by marketing into technical specifications and designing the various features into the product to these specifications. Manufacturing has the responsibility of selecting the processes by which the product can be manufactured. Product design and development provides link between marketing, customer needs and expectations and the activities required to manufacture the product.

4. Process Design

Process design is a macroscopic decision-making of an overall process route for converting the raw material into finished goods. These decisions encompass the selection of a process, choice of technology, process flow analysis and layout of die facilities. Hence, the important decisions in process design are to analyse die workflow for converting raw material into finished product and to select the workstation for each included in me workflow.

5. Production Planning and Control

Production planning and control can be defined as die process of planning die production in advance, setting die exact route of each item, fixing die starting and finishing dates for each item, to give production orders to shops and to follow-up the progress of products according to orders.

The principle of production planning and control lies in die statement 'First Plan Your Work and then Work on Your Plan'. Main functions of production planning and control include Planning, Routing, Scheduling, Dispatching and Follow-up.

Planning is deciding in advance what to do, how to do it, when to do it and who is to do it. Planning bridges die gap from where we are, to where we want to go. It makes it possible for things to occur which would not otherwise happen.

Routing may be defined as the selection of path, which each part of die product will follow, which being transformed from raw material to finished products. Routing determines die most advantageous path to be followed for department to department and machine to machine till raw material gets its final shape.

Scheduling determines the programme for the operations. Scheduling may be defined as 'the fixation of time and date for each operation' as well as it determines the sequence of operations to be followed.

Dispatching is concerned with the starting the processes. It gives necessary authority so as to start a particular work, which has been already been planned under 'Routing' and 'Scheduling'. Therefore, dispatching is 'Release of orders and instruction for the starting of production for any item in acceptance with the Route sheet and Schedule Charts'.

The function of Follow-up is to report daily the progress of work in each shop in a prescribed proforma and to investigate the causes of deviations from the planned performance.

6. Quality Control (QC)

Quality Control may be defined as 'a system that is used to maintain a desired level of quality in a product or service'. It is a systematic control of various factors that affect the quality of the product. Quality Control aims at prevention of defects at the source, relies on effective feedback system and corrective action procedure.

Quality Control can also be defined as 'that Industrial Management technique by means of which product of uniform acceptable quality is manufactured'. 11 is the entire collection of activities, which ensures that the operation will produce the optimum quality products at minimum cost.

The main objectives of Quality Control are:

(i) To improve the companies income by making the production more acceptable to the customers i.e. by providing longlife, greater usefulness, maintainability, etc.

(ii) To reduce companies cost through reduction of losses due to defects.

(iii) To achieve interchangeability of manufacture in large-scale production.

(iv) To produce optimal quality at reduced price.

(v) To ensure satisfaction of customers with productions or services or high quality level, to build customer good will, confidence and reputation of manufacturer.

(vi) To make inspection prompt to ensure quality control.

(vii) To check the variation during manufacturing.

7. Materials Management

Materials Management is that aspect of management function, which is primarily concerned with the acquisition, control, and use of materials needed and flow of goods and services connected with the production process having some predetermined objectives in view. The main objectives of Material Management are:

(i) To minimize material cost.

(ii) To purchase, receive, transport and store materials efficiently and to reduce the related cost.

(iii) To cut down costs through simplification, standardization, value analysis, import substitution, etc.

(iv) To trace new sources of supply and to develop cordial relations with them in order to ensure continuous supply at reasonable rates.

(v) To reduce investment tied in the inventories for use in other productive purposes and to develop high inventory turnover ratios.

8. Maintenance Management

In modern industry, equipment and machinery are a very important part of the total productive effort. Therefore their idleness or downtime becomes are very expensive. Hence, it is very important that the plant machinery should be properly maintained.

The main objectives of Maintenance Management are:

1. To achieve minimum breakdown and to keep the plant in good working condition at the lowest possible cost.
2. To keep the machines and other facilities in such a condition that permits them to be used at their optimal capacity without interruption.
3. To ensure the availability of the machines, buildings and services required by other sections of the factory for the performance of their functions at optimal return on investment.

1.4 NEEDS AND CHALLENGES OF OPERATIONS RESEARCH TO DECISION MAKING

The use of Operations Research to improve decision-making has become almost universal today. However, this remarkable achievement of Operations Research is not totally free from shortcomings. Certain shortcomings result from lack of awareness on the part of managers about their roles, while others result due to avoidance of the behavioural and organizational issues which are a part of every successful application. A list of various needs and challenges of Operations Research is given below:

Needs

- Operations Research requires business managers to be quite explicit about their objectives, their assumptions and the way of visualizing the constraints. When they define their problem so explicitly, the solution obtained using Operations Research techniques will be very precise.
- Using Operations Research approach the decision maker can determine a solution to his routine or repetitive problem. For obtaining solution of such type of problems, it is necessary to build a model so that future solutions can be obtained using the model thus freeing managers to concentrate on more pressing matters. Only when unusual circumstances arise, they are required to review the situation. In this way, they can achieve better control of their operations and can allocate their time more efficiently.
- While using Operations Research approach, a manager has to consider very carefully all those variables which influence his decisions and the way these variables in a problem interact with each other. He, then selects a decision which is best for the organization as whole.
- Using Operations Research approach a decision-maker can examine a situation from various angles by simulating the model which he has constructed for the real problem. He can change various conditions under which decisions are being made, and examine the effect of these changes through appropriate experiments on the model, to determine the best or optimal solution for the problem under consideration. All these experiments can be carried out without causing any serious damage to the existing system or incurring excessive cost.
- Operations Research approach allows a decision maker to solve a complex problem involving multiple variables much more quickly than if he had to compute them using traditional methods. Sometimes it may not be possible to solve such complex problems without using Operations Research methods.
- Operations Research techniques are gaining acceptance and respect day by day as they improve manager's decision making effectiveness.

Challenges

- Often Operations Research approaches have to simplify the problem or make simplifying assumptions in order to solve the problems.
- There are certain problems which a decision maker may have to solve only once. Constructing a complex Operations Research model for solving such problems is often too expensive when compared with the cost of other less sophisticated approaches available to solve them.
- Sometimes Operations Research specialists become too much enamoured with the model they have built and they forget the fact that their model does not represent the "real world problem" in which decisions have to be made.
- Many Operations Research models are so complex that they cannot be solved without the use of computer. The solutions obtained from these models are difficult to explain to managers a and hence fail to gain their support and confidence.
- Sometimes Operations Research specialists forget to counsel decision makers on the limitations of the model which they build. Sometimes many of the solutions have to be combined with judgment and intuitions for effective use. When the users of the model do not obtain the expected results, they don't appreciate Operations Research approaches.
- When the basic data are subjected to frequent changes, incorporating them into the Operations Research models is a costly affair. Moreover, a fairly good solution at present may be more desirable than a perfect Operations Research solution available after some time.
- Magnitude of computation involved, lack of consideration for non-quantifiable factors and psychological issues involved in implementation are some of the other shortcomings of Operations Research.

- Specialists in Operations Research are not the decision makers themselves: they only provide rational basis for decision making to executives. There is a gap between who provides a solution and who wishes to use it. Due to this gap, management sometimes offers resistance to the use of Operations Research.

1.5 OPERATIONS MANAGEMENT AND DECISION MAKING

The chief role of an operations manager is that of planner and decision maker. In this capacity, the operations manager exerts considerable influence over the degree to which the goals and objectives of the organization are realized. Most decisions involve many possible alternatives that can have quite different impacts on costs or profits. Consequently, it is important to make *informed* decisions.

Operations managers must solve problems in the areas identified above on a regular or 'as required' basis. Not only will it be necessary to decide on the problem-solving procedure, but also in many cases it will be necessary to decide between alternative solutions. We have made a distinction between what have been called the 'principal' or 'characteristic' problems which necessitate the problem-solving procedure being tailored to the particular circumstances, and the 'common' problems which may yield to the same type of problem-solving approach each time they are encountered. Before beginning to discuss the problem-solving strategies, procedures, techniques, etc., we can pull together some of the points made in the previous sections, and develop an overview of the operations manager's decision-making process. This will give a foundation for our discussion where we shall deal with operations management in the business policy context and the relationships between operations management and other functions within the organization.

For the purposes of this discussion we define the operations management decision-making process as 'the formulation of overall strategies for operations, typically involving interrelated areas of responsibility within operations management, and the making of decisions in these areas in pursuit of these strategies within the broader business context'.

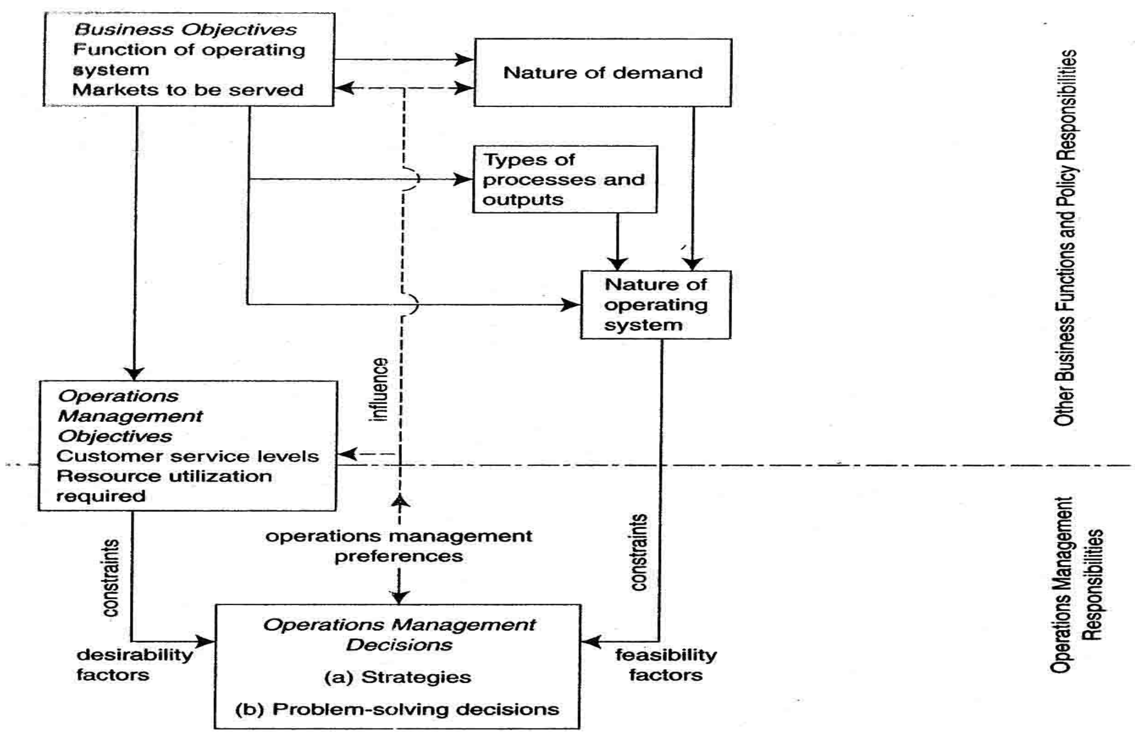


Fig.2 : A model of the operations management decision-making process

Fig. 2 provides a simple model of the operations management decision-making process. It is derived from our discussion above. The figure shows the decision-making process as a 'contingency' model. It suggests that operations managers' decisions about (a) the formulation of strategies for the solution of problems, and (b) particular problem-solving procedures are not free, unconstrained processes. It suggests, naturally, that operations managers' decisions are contingent upon other factors, and, deriving from our discussion above, suggests that the three sets of contingent factors or constraints might be categorized as follows:

(a) Feasibility: The feasibility of choosing a particular course of action in the principal decision-making area of operations management (i.e. capacity management, scheduling and inventory) will be influenced largely by the nature of the operating system, which in turn will be a function of the demand situation, the processes and outputs involved and the system's function.

We have seen that the predictability of the nature of demand (i.e. whether or not it is known what future customers want) will influence the feasibility of the existence of output stocks created in anticipation of demand, and ultimately the use of input stocks of particular resources. For example, an operating system established to satisfy demand which is totally unpredictable in nature will contain neither output stocks nor stocks of specialized input resources, e.g. specialized materials, equipment, etc.

The types of processes and outputs involved may influence the nature of the system. For example, in electrical power generation, even though the nature of future demand is known (i.e. for electricity of a particular voltage, etc.), it will not normally be possible to provide substantial output stocks.

The function of the system will also influence its nature, since the configuration of transport and service systems will differ from that of supply and manufacturing systems, as in both the former cases the customers or some physical item provided by the customers will be a direct input to the process.

Thus the nature of demand, process and outputs, and system function, and their relationship with the customer will influence the nature of the system, which in turn will have a major feasibility influence on the approaches adopted by operations management for the management of such systems.

(b) Desirability: The desirability of pursuing a particular approach in managing the system will be influenced largely by the operations manager's perceptions of desired outcomes, which in turn will be associated with explicit or implicit business objectives. Thus, considering the twin operations management objectives of providing customer service and achieving high resource utilization, an emphasis on the former will possibly encourage the adoption of particular strategies in capacity management, scheduling, etc., while an emphasis on resource utilization may encourage a different approach. For example, given feasibility, an emphasis on customer service will encourage the use of output stocks and possibly the maintenance of excess capacity, while an emphasis on resource utilization may militate against the use of output stocks and lead to a reduction in capacity. Although in general the operations manager's basic strategies may be seen as a function of the given or required balance between customer service and resource utilization, other objectives, e.g. labour policies and pricing policies, will also have some influence. Most of these factors will be beyond the direct and total control of the operations manager. We can consider them to be policy-level decisions to which the operations manager will make some contribution.

(c) Preference: Given feasibility and desirability, we would expect operations managers to have certain preferences. For example, the operations manager may prefer a situation in which his or her activities are in some way 'buffered' or protected from demand uncertainties. This, for example through the use of output inventories, permits the 'core' of the operating system to be in some way protected from uncertainties and thus to be run in a steady and efficient manner. In a labour-intensive situation the operations manager may prefer to minimize the amount, of change in the labour force, hours worked, etc., thus minimizing the risk of labour/industrial relations problems.

Or the operations manager may prefer schedule work in such a way as to avoid the need to schedule each activity against a particular customer's 'requirement' date. All such approaches provide the operations manager with a far greater choice of strategies, etc., but the extent which this approach might be employed is of course a function of both feasibility and desirability.

The operations manager who, for whatever reason, has greater 'power' within the organisatioa is likely to be able to exercise his or her preferences to a greater extent than might otherwise be the case. Such power may be informal or formal. It may have been acquired, have evolved, or simply exist because of the broader circumstances, e.g. the existence of minimum feasibility and desirability constraints. This view associates 'power' with the scope, freedom of action and breadth of choice of I he operations manager given certain feasibility and desirability constraints. This, however, is largely an internal perspective. We must recognize that such power, perhaps rather more broadly defined, may be exercised by the operations manager in seeking to influence both feasibility and desirability constraints which operate on him or her. Thus in certain circumstances the operations manager may be able to Influence product/service design and/or marketing policy in order to make feasible the provision of output stocks of uncommitted goods. Further, he or she may seek 10 retain an overriding commitment to customer service and a tolerance of low resource utilization. Thus the extent to which the operations manager contributes lo and influences these policy-level decisions will at least ensure that such decision-making takes into account the needs, constraints and abilities of the operations function, and at best ensure that constraints are minimized, thus enabling maximization of preference. This mechanism ensures that operations managers who are unable, or unwilling, to influence their policy-level decisions within the organization can be required to operate in highly undesirable situations, seemingly having to meet conflicting objectives while using resources in a diverse range of activities in a continually changing situation. In such circumstances the power of (he operations manager clearly approaches zero: no preference is exercised, and the operations manager's decision-making process is entirely constrained by 'external factors'.

Summarizing, we can view the operations management decision-making process as a constrained process where outcomes are influenced by feasibility, desirability and preference factors. The recognition of these relationships and the adoption of a suitable decision-making process are the prerequisites for effective operations management, and the solution of particular operations management problems must be seen as a subsidiary part of this decision-making process. The operations manager's responsibility within the broader business context must include the recognition of the fact that decisions in other functions will limit his or her own decisions, but, equally important, the operations manager must also" seek to influence those factors which give rise to feasibility and desirability constraints on his or her decisions in the light of, and in order to exercise, his or her particular preferences.

Why Study Operations Management?

If your major field is not operations management, you may be wondering why you need to study operations management. Actually, there are compelling reasons for studying operations management. One is that 50 percent or more of all jobs are in operations management or related fields. Also, recall the image of a business organization as a car, with operations as its engine. In order for that car to function properly, all of the parts must work together. So too, all of the parts of a business organization must work together in order for the organization to function successfully.

Working together successfully means that all members of the organization understand not only their own role, they also understand the roles of others. This is precisely why all business students, regardless of their particular major, are required to take a common core of courses that will enable them to learn about all aspects of business. Because operations management is central to the functioning of all business organizations, it is included in the core of courses business students are required to take. And even though individual courses have a narrow focus (e.g., accounting, marketing), in practice, there is significant interacting and collaboration among the various functional areas, involving exchange of information and cooperative decision making. For example, although the three primary functions in business organizations, perform different activities, many of their decisions impact the other areas of the organization. Consequently, these functions have numerous interactions, as depicted by the overlapping circles shown in **Fig. 3**.

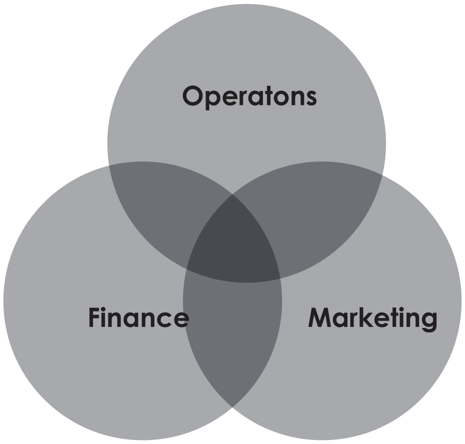


Fig. 3 : The three major functions of business organizations overlap

Finance and Operations management personnel cooperate by exchanging information and expertise in such activities as the following:

1. Budgeting: Budgets must be periodically prepared to plan financial requirements. Budgets must sometimes be adjusted, and performance relative to a budget must be evaluated.
2. Economic analysis of investment proposals: Evaluation of alternative investments in plant and equipment requires inputs from both operations and finance people.
3. Provision of funds: The necessary funding of operations and the amount and timing of funding can be important and even critical when funds are tight. Careful planning can help avoid cash-flow problems.

Lead Time The Time Between Ordering and good or service and receiving it: Marketing's focus is on selling and/or promoting the goods or services of an organization. Marketing is also responsible for assessing customer wants and needs, and for communicating those to operations people (short term) and to design people (long term). That is, operations needs information about demand over the short to intermediate term so that it can plan accordingly (e.g., purchase materials and services and designing new ones. Marketing, design, and production must work closely together to successfully Implement design changes and to develop and produce new products. Marketing can provide valuable insight on what competitors are doing. Marketing also can supply information on consumer preferences so that design will know the kinds of products and features needed; operations can supply information about capacities and judge the manufacturability of designs. Operations will also have advance warning if new equipment or skills will be needed for new products or services. Finance people should be included in these exchanges in order to provide information on what funds might be available (short term) and to learn what funds might be needed for new products or services (intermediate to long term). One important piece of information marketing needs from operations is the manufacturing or service lead time in order to give customers realistic estimates of how long it will take to fill their orders.

Marketing managers have a major influence on the policy decisions, since the marketing function is primarily concerned with decisions on the nature of the 'offering' (i.e. the goods or service(s) to be provided to customers) and the methods by which the 'offering is made. These marketing decisions are usually referred to as the four aspects of the marketing mix, i.e. goods or services, cost, distribution and promotion. Although all business must make decisions on each of these four aspects, different types of businesses will employ different 'mixes'. For example, companies involved in providing consumer goods might emphasize promotion (e.g. advertising), while companies providing a specialist service might emphasize cost or price. Decisions on these four factors, outlined below, may lie considered to be the deliberate market decisions of the organization.

1. **Goods/service,** i.e. goods/service characteristics - the actual item, transport or service provided to the customer, its attributes and characteristics, the features and provisions surrounding it and the essential benefits it provides.
2. **Cost,** i.e. the purchase price of the goods or service and any additional costs or allowances.
3. **Distribution,** i.e. the location of the market, channels of distribution, outlets, territories, etc. involved in the provision of the offering to the customer.
4. **Promotion,** i.e. the publicity, selling and advertising practices employed to bring the goods or services to the notice of the intended customer.

These market decisions influence, but do not determine, the nature of the demand faced by the organization, i.e. the demand felt by the operating system. In addition, other factors only partially influenced by the organization will influence demand, i.e.

(a) **environmental variables** - factors (largely beyond the control of the enterprise) that have broad effects on demand, e.g. the economic situation, public policy and culture;

(b) **competitive variables** - factors under the control of competitors.

1.6 THE OPERATIONS MANAGEMENT STRATEGY DEVELOPMENT PROCESS

Today, many corporations, both large, global conglomerates such as General Electric and small ones such as Mississauga, Ontario-based Cara, consist of several stand-alone businesses that focus on different industries. The conglomerate may have a vision and a mission. For example the vision of Cara (a company founded in 1883, making it older than some provinces) is "To be Canada's leading integrated restaurant company." Its mission is "Enhancing stakeholder value and building leading businesses, by maximizing our resources and living our values and principles." Within this context, corporate strategy defines the specific businesses in which the firm will compete and the way in which resources are acquired and allocated among these various businesses.

The stand-alone businesses within these conglomerates often are referred to as strategic business units (SBUs). SBUs at Cara include, among others, Harvey's and Swiss Chalet in the fast food business, Kelsey's in the restaurant business, Second Cup in specialty coffee, Cara in airline food catering, and Summit in food service distribution. The individual strategy adopted by each SBU, which is referred to as its business strategy, defines the scope and boundaries of the SBU, in terms of how it addresses the specific markets that it serves and the products that it provides.

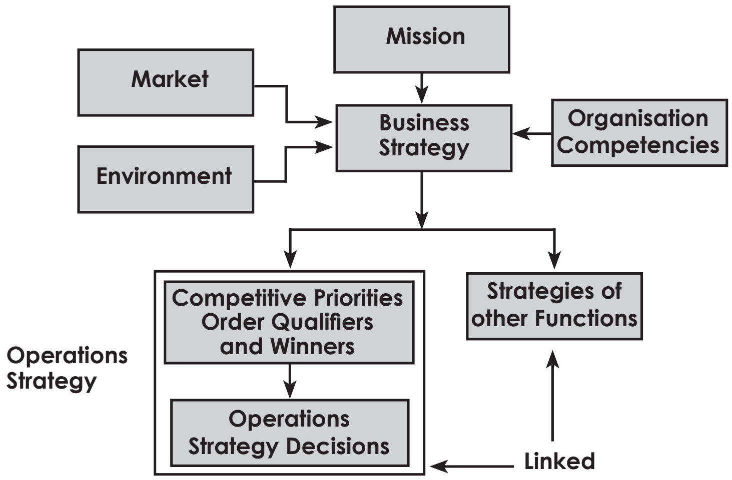


Fig. 4: The Operations Strategy Process

The business strategy depends on the market requirements (such as customer desires and success criteria in the market), the environment (such as competition, technological advances, and government regulations) and the organizational competencies (such as its core capabilities, its culture, and strengths and weaknesses). Each SBU may also have its own vision and mission.

To not only survive but also to prosper in today's fiercely competitive marketplace, an SBU needs to have a successful strategy. In this type of situation, Michael Porter, a professor at the Harvard Business School and perhaps today's leading authority on competitive strategy, believes that there are three generic strategies for succeeding in an industry: cost leadership, differentiation, and market segmentation. Cost leadership implies that the firm has the ability to successfully under price its competition. Differentiation refers to ways in which an organization distinguishes its products and services from its competition. For example a company could offer higher quality products or services than its competitors. Market segmentation refers to the focus of the product or service offering on a segment in the market. An example of focus in the hotel industry would be Toronto-based Four Seasons Hotels, which focuses on the luxury end of the lodging business. Porter believes that to be successful, firms have to trade off among the three. In other words, a company "cannot be all things to all people." Other experts on strategy, such as Henry Mintzberg of McGill University, include cost leadership as a form of differentiation.

Functional strategies (for example, operations, marketing, human resources) are developed to support or align with the established business strategy. For example, Ethan Allen, a retailer who follows a business strategy of providing high quality furniture, cannot pursue an operations strategy of achieving low cost by procuring leather that is not of high quality, nor a human resource strategy of not providing training.

A company or SBU's competitiveness refers to its relative position in the market in terms of how it competes with the other firms in its industry. Operations strategy refers to how the operations management function contributes to a firm's ability to achieve competitive advantage in that marketplace.

Operations strategies are developed from the competitive priorities of an organization, which include (a) low cost, (b) high quality, (c) fast delivery, (d) flexibility, and (e) service. Operations strategies also depend on order qualifiers and winners, which relate to requirements for success in the market place.

Core capabilities are the means by which competitive priorities are achieved. Consequently, core capabilities must align directly with competitive priorities. For example a core capability may relate to research and innovation, such as the ability to design and bring products quickly to market as in the case of Intel, Nortel, or Sony, or effective supply chain management as in the case of Wal-Mart.

Operations strategy decisions can be divided into two major categories: structural elements consisting of facility location, capacity, vertical integration, and choice of process (all are considered to be long term or "strategic" in nature) and infrastructural elements consisting of the workforce (in terms of size and skills), quality issues, procurement, the new-product development process, planning and control, and organizational structure (all of which are often viewed as "tactical" because they can be changed in a relatively short time). The opening vignette on Dofasco highlighted some of these issues. These decisions have to be consistent with strategic decisions of the other functions as in the Ethan Allen example.

In developing an operations strategy, management also needs to take other factors into consideration. These include (a) the level of technology that is or will be available, (b) the required skill levels of the workers, and (c) the degree of vertical integration, in terms of the extent to which outside suppliers are used.

Operations strategy supports the long-range strategy developed at the SBU level. One might say that decisions at the SBU level focus on being effective, that is, "on doing the right things." These decisions are sometimes referred to as strategic planning. Strategic decisions impact intermediate-range decisions, often referred to as tactical planning, which focus on being efficient, that is, "doing things right." Here the emphasis is on when material should be delivered, when products should be made to best meet demand, and what size the workforce should be. Finally, we have planning and control, which deals with the day-to-day procedures for doing work, including scheduling, inventory management, and process management.

Business and operations strategies can, of course, change over time. With Wal-Mart now also stocking groceries in its stores, Canada's second largest grocery chain, Sobeys, is planning to move up-market to leave cost leadership in the industry to organizations such as industry leader Loblaw and the new entrant, Wal-Mart.

1.7 CONTRIBUTION OF OPERATIONS MANAGEMENT TO BUSINESS POLICY DECISIONS

The principal means by which operations management contributes to or influences business policy decisions is through the provision of information on:

(a) the existing operating system structure, objectives and strategies;

(b) the implications for operations management of the goods/service and market/demand characteristics which are proposed or being considered by the business policy makers.

In 'change' situations, both (a) and (b) are relevant, whereas in the establishment of entirely 'new' systems only (b) is appropriate. Change situations may occur when a change or modification of the existing goods or service(s) is under consideration and/or when new markets are being investigated. In such situations an operating system is in existence and changes are being considered which might affect or necessitate a change of system objectives, and strategies. Clearly some knowledge of the nature of the existing system, its characteristics and performance will be of value in making business policy considerations in such circumstances. The alternative is the 'greenfield' situation, in which business policy decisions will lead to the establishment of new operating systems. Here operations management must interpret alternative goods/services and market/demand strategies into implications for operations management, since the nature of the system structure, operations management objectives and strategies required to meet given goods/services and market/demand characteristics will influence the choice between alternatives.

Two factors that tend to have universal strategic operations importance related to quality and time. The following section discusses quality and time strategies.

Quality and Time Strategies

Traditional strategies of business organizations have tended to emphasize cost minimization or product differentiation. While not abandoning those strategies, many organizations have embraced strategies based on quality and/or time.

(i) Quality-based strategy that focuses on quality in all phases of an organization: Quality-based strategies focus on maintaining or improving the quality of an organization's products or services. Quality is generally a factor in both attracting and retaining customers. Quality-based strategies may be motivated by a variety of factors. They may reflect an effort to overcome an image of poor quality, a desire to catch up with the competition, a desire to maintain an existing image of high quality, or some combination of these and other factors. Interestingly enough, quality-based strategies can be part of another strategy such as cost reduction, increased productivity, or time, all of which benefit from higher quality.

Table 3: Strategic operations management decisions

Decision Area	What the Decisions Affect
1. Product and service design	Costs, quality, liability and environmental issues
2. Capacity	Cost structure, flexibility
3. Process selection and layout	Costs, flexibility, skill level needed, capacity
4. Work design	Quality of work life, employee safety, productivity
5. Location	Costs, visibility
6. Quality	Ability to meet or exceed customer expectations

Decision Area	What the Decisions Affect
7. Inventory	Costs, shortages
8. Maintenance	Costs, equipment reliability, productivity
9. Scheduling	Flexibility, efficiency
10. Supply chains	Costs, quality, agility, shortages, vendor relations
11. projects	Costs, new products, services, or operating systems

(ii) Time-based strategy that focuses on reduction of time needed to accomplish tasks:

Time-based strategies focus on reducing the time required to accomplish various activities (e.g., develop new products or services and market them, respond to a change in customer demand, or deliver a product or perform a service). By doing so, organizations seek to improve service to the customer and to gain a competitive advantage over rivals who take more time to accomplish the same tasks.

Time-based strategies focus on reducing the time needed to conduct the various activities in a process. The rationale is that by reducing time, costs are generally less, productivity is higher, quality tends to be higher, product innovations appear on the market sooner, and customer service is improved.

Organizations have achieved time reduction in some of the following:

Planning time: The time needed to react to a competitive threat, to develop strategies and select tactics, to approve proposed changes to facilities, to adopt new technologies, and so on.

Product/service design time: The time needed to develop and market new or redesigned products or services.

Processing time: The time needed to produce goods or provide services. This can involve scheduling repairing equipment, methods used, inventories, quality, training and the like.

Changeover time: The time needed to change from producing one type of product or service to another. This may involve new equipment settings and attachments, different methods, equipment, schedules, or materials.

Delivery time: The time needed to fill orders.

Response time for complaints: These might be customer complaints about quality, timing of deliveries, and incorrect shipments. These might also be complaints from employees about working conditions (e.g., safety, lighting, heat or cold), equipment problems, or quality problems.

Agile operations is a strategic approach for competitive advantage that emphasizes the use of flexibility to adapt and prosper in an environment or change. Agility involves a blending of several distinct competencies such as cost, quality, and reliability along with flexibility. Processing aspects of flexibility include quick equipment changeovers, scheduling, and innovation. Product or service aspects include varying output volumes and product mix.

Successful agile operations requires a careful planning to achieve a system that includes people, flexible equipment, and information technology. Reducing the time needed to perform work is one of the ways an organization can improve a key metric: productivity.

1.8 DESIGNING OF GOODS AND SERVICES

Developing a turbofan engine to power a modern commercial passenger transport requires an investment of $1 billion and takes approximately four years of design and testing.

The investment must begin, along with the engineering effort, before the actual market is developed. As the market unfolds, the aircraft and the engine are modified to insure acceptability and profitability at the time of introduction.

During the initial design period, dialogue must be firmly established between the engineering teams and the manufacturing teams. This dialogue and the resultant team-building not only assures a "design to cost" philosophy but aids the development process when a component must be redesigned for cost, market, or reliability reasons.

Throughout the design and development phase, "real time" data allow the entire team to know the status of drawing releases, hardware promises, required dates, and problem areas. It is only with this knowledge that program management can make the decisions and implement the actions needed for an on-time, on-budget engine development program.

Because of their complexities, the core of engine development programs is team effort; specialists from manufacturing, engineering, test, and marketing join together using a common "real time" database to identify and provide solutions to the problems. This teamwork ensures the product will be accepted in the market and yield an acceptable return on investment.

In planning the conversion system, major decisions are made concerning the design of the product or service as well as the design of conversion process to produce the product or service. We address these decisions by first presenting a traditional model of the design process followed by the design of new products, and then the design of manufacturing processes. After presenting each separately for manufacturing, we consider service product and process design choices together.

Importance of Product Design

Production or operations strategy is directly influenced by product design for the following reasons:

(i) As products are designed, all the detailed characteristics of each product are established.

(ii) Each product characteristic directly affects how the product can be made or produced (i.e., process technology and process design) and

(iii) How the product is made determines the design of the production system (production design) which is the heart of production and operations strategy.

Further, product design directly affects product quality, production costs and customer satisfaction. Hence, the design of product is crucial to success in today's global competition.

A good product design can improve the marketability of a product by making it easier to operate or use, upgrading its quality, improving its appearance, and/or reducing manufacturing costs.

A distinctive design may be the only feature that significantly differentiates a product. An excellent design includes usability, aesthetics, reliability, functionality, innovation and appropriateness. An **excellent design** provides competitive advantage to the manufacturer, by ensuring appropriate quality, reasonable cost and the expected product features. Firms of tomorrow will definitely compete not on price and quality, but on product design.

What Does Product Design Do?

The activities and responsibilities of product design include the following:

(i) Translating customer needs and wants into product and service requirements (marketing).

(ii) Refining existing products (marketing).

(iii) Developing new products (marketing, product design and production).

(iv) Formulating quality goals (quality assurance, production).

(v) Formulating cost targets (accounting).

(vi) Constructing and testing prototype (marketing, production).

(vii) Documenting specifications (product design).

Reasons for Product Design or Redesign

The most obvious reason for product design is to offer new products to remain competitive in the market. The second most important reason is to make the business grow and increase profits. Also, when productivity gains result in reduction of workforce, developing new products can mean adding jobs and retaining surplus workforce instead of downsizing by layoffs/ retrenchment.

Sometimes product design is actually redesign or modification of existing design instead of an entirely new design. The reasons for this include customer complaints, accidents or injuries during product use, excessive warranty claims or low demand. Sometimes product redesign is initiated to achieve cost reductions in labour and material costs.

Objectives of Product Design

(i) The overall objective is profit generation in the long run.

(ii) To achieve the desired product quality.

(iii) To reduce the development time and cost to the minimum.

(iv) To reduce the cost of the product.

(v) To ensure producibility or manufacturability (design for manufacturing and assembly).

Factors Influencing Product Design

(i) Customer requirements: The designers must find out the exact requirements of the customers to ensure that the products suit the convenience of customers for use. The products must be designed to be used in all kinds of conditions.

(ii) Convenience of the operator or user: The industrial products such as machines and tools should be so designed that they are convenient and comfortable to operate or use.

(iii) Trade off between function and form: The design should combine both performance and aesthetics or appearance with a proper balance between the two.

(iv) Types of materials used: Discovery of new and better materials can improve the product design. Designers keep in touch with the latest developments taking place in the field of materials and components and make use of improved materials and components in their product designs.

(v) Work methods and equipments: Designers must keep abreast of improvements in work methods, processes and equipments and design the products to make use of the latest technology and manufacturing processes to achieve reduction in costs.

(vi) Cost/Price ratio: In a competitive market, there is lot of pressure on designers to design products which are cost effective because cost and quality are inbuilt in the design. With a constraint on the upper limit on cost of producing products, the designer must ensure cost effective designs.

(vii) Product quality: The product quality partly depends on quality of design and partly on quality of conformance. The quality policy of the firm provides the necessary guidelines for the designers regarding the extent to which quality should be built in the design stage itself by deciding the appropriate design specifications and tolerances.

(viii) Process capability: The product design should take into consideration the quality of conformance, i.e., the degree to which quality of design is achieved in manufacturing. This depends on the process capability of the machines and equipments. However, the designer should have the knowledge of the capability of the manufacturing facilities and specify tolerances which can be achieved by the available machines and equipments.

(ix) Effect on existing products: New product designs while replacing existing product designs, must take into consideration the use of standard parts and components, existing manufacturing and distribution strategies and blending of new manufacturing technology with the existing one so that the costs of implementing the changes are kept to, the minimum.

(x) Packaging: Packaging is an essential part of a product and packaging design and product design go hand in hand with equal importance. Packaging design must take into account the objectives of packaging such as protection and promotion of the product. Attractive packaging enhances the sales appeal of products in case of consumer products (nondurable).

Characteristics of Good Product Design

A good product design must ensure the following:

(i) Function or performance: The function or performance is what the customer expects the product to do to solve his/her problem or offer certain benefits leading to satisfaction. For example, a customer for a motor bike expects the bike to start with a few kicks on the kick peddle and also expects some other functional aspects such as pick-up, maximum speed, engine power and fuel consumption etc.

(ii) Appearance or aesthetics: This includes the style, colour, look, feel, etc. which appeals to the human sense and adds value to the product.

(iii) Reliability: This refers to the length of time a product can be used before it fails. In other words, reliability is the probability that a product will function for a specific time period without failure.

(iv) Maintainability: Refers to the restoration of a product once it has failed. High degree of maintainability is desired so that the product can be restored (repaired) to be used within a short time after it breaks down. This is also known as serviceability.

(v) Availability: This refers to the continuity of service to the customer. A product is available for use when it is in an operational state. Availability is a combination of reliability and maintainability. High reliability and maintainability ensures high availability.

(vi) Productibility: This refers to the ease of manufacture with minimum cost (economic production). This is ensured in product design by proper specification of tolerances, use of materials that can be easily processed and also use of economical processes and equipments to produce the product quickly and at a cheaper cost.

(vii) Simplification: This refers to the elimination of the complex features so that the intended function is performed with reduced costs, higher quality or more customer satisfaction. A simplified design has fewer parts which can be manufactured and assembled with less time and cost. "

(viii) Standardisation: Refers to the design activity that reduces variety among a group of products or parts. For example, group technology items have standardised design which calls for similar manufacturing process steps to be followed. Standard designs lead to variety reduction and results in economies of scale due to high volume of production of standard products. However, standardised designs may lead to reduced choices for customers.

(ix) Specification: A specification is a detailed description of a material, part or product, including physical measures such as dimensions, volume, weight, surface finish etc. These specifications indicate tolerances on physical measures which provide production department with precise information about the characteristics of products to be produced and the processes and production equipments to be used to achieve the specified tolerances (acceptable variations).

Interchangeability of parts in products produced in large volumes (mass production and flow-line production) is provided by appropriate specification of tolerances to facilitate the desired fit between parts which are assembled together.

(x) Safety: The product must be safe to the user and should not cause any accident while using or should not cause any health hazard to the user. Safety in storage, handling and usage must be ensured by the designer and a proper package has to be provided to avoid damage during transportation and storage of the product. For example, a pharmaceutical product while used by the patient, should not cause some other side effect threatening the user.

New Product Design (Product Development)

(A) The Origin of New Products:

Entrepreneurs frequently form new businesses on the basis of a unique product idea or needed service. As competitors infringe on the market, replicating products and services, or as the useful product life diminishes, firms ordinarily prepare to bring out new products or services. These new product and service ideas come from various sources, including customers, top management, and staff from marketing, research and development, production, and engineering.

Approaches to Product Design

(i) Designing for the Customer

Designing for aesthetics and for the user is generally termed industrial design which is probably the most neglected area by manufacturers. In many products we use, parts are inaccessible, operation is too complicated or there is no logic to setting and controlling the function of the product. Sometimes worst conditions exist, metal edges are sharp and consumers cut their hands trying to reach for adjustment or repairs. Many products have too many features far more than necessary and for instance many electronic products have too many features which the customers cannot fully make use of (operate). One approach to getting the **voice of the customer** into the design specification of a product is **quality function deployment (QFD).** This approach uses interfunctional teams from marketing, design engineering and manufacturing to incorporate the features sought by the customers in the product at the stage of product design. The customer's requirements (with its importance weightage) and the technical characteristics of the product are related to each other in a matrix called **house of quality**. The customers are asked to compare the company's products to the competitor's products. The technical characteristics are then evaluated to support or refute the customer perception of the product. This data is then used to evaluate the strengths and weaknesses of the product in terms of technical characteristics.

(ii) Designing for Manufacture and Assembly (DFMA)

Traditionally the attitude of designers has been "we design it, you build it" which is termed as **"over-the-wall approach",** where the designer is sitting on one side of the wall and throwing the design over the wall to the manufacturing engineers. The manufacturing engineers have to deal with the problems that arise because they were not involved in the design effort. This problem can be overcome by an approach known as **concurrent engineering** (or simultaneous engineering). Concurrent engineering means bringing design and manufacturing people together early in the design phase to simultaneously develop the product and processes for manufacturing the product. Recently this concept has been enlarged to include manufacturing personnel, design personnel, marketing and purchasing personnel in loosely integrated cross-functional teams. In addition, the views of suppliers and customers are also sought frequently. This will result in product designs that will reflect customer wants as well as manufacturing capabilities in the design stage itself. **Design for Manufacturing (DFM)** and **Design for Assembly (DFA)** are related concepts in manufacturing. The term design for manufacturing is used to indicate the designing of products that are compatible with an organisation's capability. Design for assembly focuses on reducing the number of parts in a product or on assembly methods and sequence that will be employed. Designing for manufacture includes the following guidelines:

(a) Designing for minimum number of parts.

(b) Developing modular design.

(c) Designing for minimum part variations (i.e., communisation or using standardised parts) and

(d) Designing parts for ease of fabrication.

(iii) Designing for Ease of Production (or for Producibility or Manufacturafaility)

Manufacturability or **Producibility** is a key concern for manufacturing products. Ease of fabrication and/or assembly is important for cost, productivity and quality. Designing products for ease of production is a key way for manufacturers to be competitive in the world market.

Three concepts which are closely associated to designing for ease of production are: (a) specifications, (b) standardisation and (c) simplification. These concepts are discussed in the following paragraphs:

A **Specification** is a detailed description of a material, part or product, including physical measures such as dimensions, volume, weight etc. These physical measure are given tolerances (acceptable variations). Tolerances are stated minimum and maximum for each dimension of a product. Tight tolerances facilitate interchangeability of parts and allows ease of assembly and effective functioning of the finished products.

Standardisation refers to design activity that reduces variety among a group of products or parts. This will result in higher volume for each product or part model which can lead to lower production costs, higher product quality and lower inventory and higher ease of automation.

Simplification of product design is the elimination of complex features so that the intended function is performed with reduced costs, higher quality and better customer satisfaction. Simplified design provides products to customers which can be easily installed, maintained and used by them. Also production costs can be reduced through easier assembly, less expensive substitute materials and 'less waste or scrap during production.

(iv) Designing for Quality

Building product quality into the product design is the first step in producing products of superior quality. This is known as **"quality of design"** which is followed by **"quality of conformance."** Quality of design refers to the quality specifications incorporated in the design. It consists of quality characteristics such as appearance, life, safety, maintenance and other features of the product. Quality of conformance is the degree to which the product actually conforms to the design specification. Designing products for quality consists of three aspects of design— (a) robust design, (b) design for production and (c) design for reliability which are discussed in the following paragraphs:

(a) Designing for Robustness (or robust design): Customers expect products to perform satisfactorily when used in all kinds of field conditions. Hence it is not enough if the products perform as intended when they are produced and used under ideal conditions. A robust design is one that will perform as intended even if undesirable conditions occur either in production or in the field. Robustness can be designed into products by assuming less than desirable field conditions in terms of heat, cold, humidity, nature of use, vibration and other conditions.

(b) Designing for Production (i.e., for ease of manufacturer and assembly) was discussed in the previous section. This can reduce the sources of error and improve overall product quality. Modular design and designing for automation are two aspects of designing for ease of production.

(i) Modular Design is the creation of products from some combination of basic, prexisting subsystems known as **modules**. In this approach, products are designed in easily segmented components or modules. This design offers flexibility to both production (manufacture and assembly) and marketing. The modular design concept gives consumers a range of product options and offers considerable advantages in manufacturing and product design. Stabilising the designs of the modules makes them easier to build. Even the maintenance or repair of products in case of break down becomes easier because the faulty module can be easily removed and replaced by a spare module,

(ii) **Designing for Automation:** In designing for automation, three broad issues affecting product design efforts come into play. They are:

(i) wasteful or unnecessary processes should not be automated,

(ii) simplify the design before automation,

(iii) the process may be simplified to such an extent that automation may not be needed.

(c) **Designing for Reliability:** Reliability is a measure of the ability of a product, part or system to perform its intended function under a prescribed set of conditions. It is the probability that an item will function as planned over a given time period. Reliability is always specified with respect to normal operating conditions which are taken into consideration while designing the product for reliability. Reliability of a product can be improved by improving the reliability of the components used in the product, by reducing the number of components used and using backups in case certain components fail in operation. These steps will improve the product design (or system design) and improve the product or system reliability. Other methods of improving reliability are improving production, and/or assembly techniques, improving testing methods, improving preventive maintenance procedures, improving user education etc.

(v) Designing for Ergonomics

Poorly designed products may cause work-related accidents resulting in injuries to users. Hence, comfort, safety and ease of use for the users are becoming more important quality dimensions that have to be considered in product design. Human Factor Engineering or Ergonomics applies knowledge of human capabilities and limitations to the design of products and processes.

(vi) Designing for Environmental Protection

This includes designing products which are environmental friendly (e.g., Euro II automobile) known as green designs. Sometimes reaction to a social or environmental concern opens up a set of promising new design options.

A new approach called "universal design" is an example of product design in which an attempt is made to design products that are easily operable by disabled persons.

(vii) Designing for Recycling

This approach to product design focuses on designing products so that raw materials such as plastics can be retrieved once the product has finished its useful life and scrapped. Recycling means recovering materials for further use. Recycling is done to achieve cost savings, and also to meet environmental concerns and regulations. Designing for recycling facilitates the recovery of materials and components in used products for reuse.

(viii) Designing of Disassembly (DFD)

This involves designing products which can be more easily taken apart or disassembled. It includes fewer parts and less material and using snap-fits where possible instead of screws, bolts and nuts.

(ix) Designing for Mass Customisation

It is a strategy of designing standardised products but incorporating some degree of customisation in the final product. **Delayed differentiation** and **modular designs** are two tactics used to make mass customisation possible.

Delayed Differentiation is the process of producing but not quite completing, a product, postponing completion until customer preferences or specifications are known. Modular design is a form of standardisation in which component parts are grouped into modules that are easily replaced or interchanged to produce varieties of the same basic product. One example is a computer system in which a customer can choose a particular configuration depending on the computing, capability desired by the customer. Modular design help mass customisation.

(x) Other issues in product design are **(a) Computer Aided Design (CAD), (b) Value Engineering or Value Analysis** which are discussed below:

(a) Computer Aided Design: Computers are increasingly used for product design. CAD uses computer graphics for product design. The designers can modify an existing design or create a new design on a computer monitor screen by means of a keyboard or a joy stick. The design can be manoeuvred on the screen, it can be rotated to provide the designer different views of the product, it can be split apart to have a view of the inside and a position of the product can be enlarged for closer view. The printed version of the completed design can be taken and also the design can be stored electronically. A number of products such as printed circuit boards, transformers, automobile parts, aircraft parts etc. can be designed using CAD.

CAD increases the productivity of designers from 3 to 10 times and preparing mechanical drawings of product or parts and modifying them frequently becomes easier. Also a data base can be created for manufacturing which can supply required information on product geometry and dimensions, tolerances, material specifications etc. Also, some CAD systems facilitate engineering and cost analyses on proposed designs, for example, calculation of volume and weight and also stress analysis can be done using CAD systems. It is possible to generate a number of alternative designs using computer aided design systems and identify the best alternative which meets the designer's criteria.

(b) Value Engineering/Value Analysis in Product Design: Value engineering or value analysis is concerned with the improvement of design and specifications at various stages such as research, development, design and product development. Benefits of value engineering are:

(i) Cost reduction.

(ii) Less complex products.

(iii) Use of standard parts/components.

(iv) Improvement in functions of the product.

(v) Better job design and job safety.

(vi) Better maintainability and serviceability.

(vii) Robust design.

Value engineering aims at cost reduction at equivalent performance. It can reduce costs to the extent of 15% to 70% without reducing quality. While value engineering focuses on preproduction design improvement, value analysis, a related technique seeks improvements during the production process.

Once launched, even good products have limited lives and, to remain viable, the organization seeks a flow of new product possibilities. Let's examine the product's birth-to-mortality pattern.

(B) Product Life Cycle

Products, like men, are mortal. They flourish for a time, then decline and die. The life cycle of a product has many points of similarity with the human life cycle. A product is born, grows lustily, attains a dynamic maturity, then enters its declining years. Like a human being a product that has not built up its potential during its formative years is likely to be relatively unsuccessful on its maturity. But, there are critical differences between the product and the human life cycle. For instance, every person has an average life expectancy. But the life expected of a product varies widely.

The concept of product failure is applicable both to new products and the existing ones. There may, however, be varying periods of life spans for each product: some failing immediately, other living for a longer period. The product, thus, has “life cycles” just as human beings have. From its birth, a product passes through various stages, until it is finally abandoned, *i*. e.. discontinued from the market. These stages taken together are referred, to as “the product life cycle”. This life cycle of the product comprises four stages: Introduction, Growth, Maturity and Decline. It should be noted that it is purely a theoretical concept.

This may graphically be represented **Fig. 5** in below:

The **introduction stage** is preceded by ‘production planning and development’.This period requires greater investment. This investment should be gradually recouped as the sales pick up. The concept of life cycle would give the management an idea as to the time within which the original investment could be recouped.

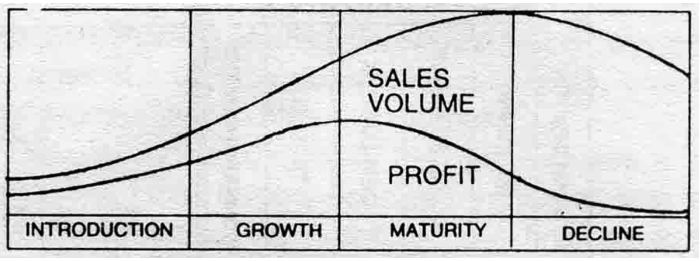


Fig. 5 : **Product life Cycle.**

After testing, a product enters the introduction stage and the product will then become available in the national market. Sales would begin gradually as potential buyers learn of the product through advertising and other selling techniques. But the profits will be low as part of the investment is to be recouped besides heavy expenditure on selling.

In the **growth stage**, both sales and profits will begin to increase. It is here that similar other new products begin to appear in the market as substitutes and offer competition. The management, therefore, should try to change its approach by changing its strategy from “buy my product” to “try my product”. At the end of this stage, the distribution arrangement is likely to get completed and the prices, if necessary, are reduced a little.

The third stage is the **maturity stage**. During this stage the manufacturers introduce new models or adopt methods such as trading-in, etc., to promote the sale of their brands with a view to retaining their position in the market. The number of buyers will continue to grow, but more slowly. In economic terms this is the stage where supply exceeds demand. Some of the promotional efforts may lengthen the span of this stage but they will not offer a permanent solution.

At the final stage of **decline**, profit margins touch a low level, competition becomes severe and customers start using newer and better products. It is here that the story of a product ends-a natrural but hard end.

The above discussion concentrates only on the life cycle of a product, beginning with its introduction into the market *(i.e.,* post-marketing). But a series of processes are to be undertaken by the management prior to the introduction of a product. The diagram given above is presented in an enlarged form to incorporate the pre-introduction (or pre-marketing) stages also.

Product life cycle concept may be used as a managerial tool. Marketing strategies must change as the product goes through the life cycle. If managers understand the cycle concept they are in a better position to forecast the future sales activities and plan marketing strategies. The following points, however, may be kept in mind in using this concept.

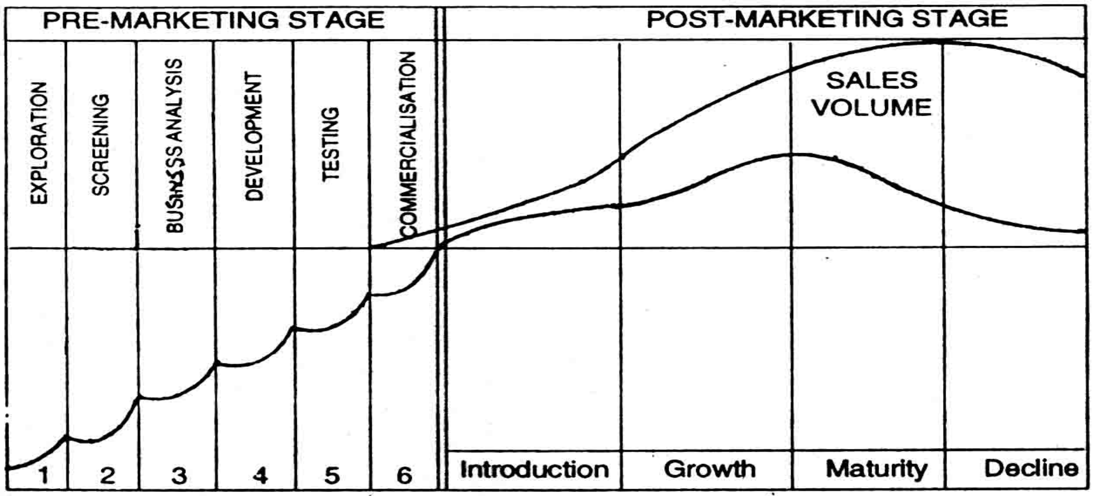


Fig. 6 : The Full Life cycle of a Product from Its Exploration Stage to Decline Stage.

The life cycle is nothing more than the pattern of demand for a product over time.

Not every product goes through every stage. In fact, many products never get past the introduction stage.

The length of time a product spends in any one stage may vary differently.

Some products move through the entire cycle in a very short period. **Repositioning** a product can lead to a new growth cycle. Repositioning is basically changing the image or perceived uses of the product.

The various expenses during the pre-introduction stage are:

1. Research,
2. Engineering and Technical,
3. Post-production,
4. Pre-marketing (Test Marketing, Advertising, etc.),
5. Cost
6. Price.
7. Value,
8. Qualiiy,
9. Service, and
10. Competition

Table 4 : Strategic Consideration in the Product Life Cycle Concept

Effects and Responses	Stages in the product life cycle concept			
	Introduction	**Growth**	**Maturity**	**Decline**
Competition	No importance	Some	Many rivals competing for a small price	Few in number
Overall strategy	Market establishment: persuade early adopters to try the product	Market penetration persuasion of mass market – Brand preferences	Creation of brand loyalty, prevention of competition	Preparation for removal or renewal
Profits	Negligible – high production and marketing cost	Reach peak levels as a result of high prices and growing demand	Increasing competition cuts profit margins	Declining volume pushes costs up and eliminates profits
Retail price	High to recover some excessive cost of launching	High to take advantage of heavy consumer demand	Avoid price war principle: 'what the traffic will bear'	Low
Distribution	Selective	Intensive	Intensive	Selective
Advertising strategies	Aims at the needs of early adopters	Make the mass market aware of brand benefits	Use advertising as vehicle for differentiation among otherwise similar brands.	Emphasize low price
Advertising emphasis	High, to generate awareness and interest among early adopters	Moderate, to let sales rise – 'word of mouth' recommendations.	Moderate, since most buyers are aware of brand characteristics	Minimum expenditure
Consumer sales and promotion expenditures	Heavy, to entice target groups with samples, coupons, etc.	Moderate to create brand preferences – Advertising better suited.	Heavy to encourage brand switching	Minimum

A decline in profit is the first case where one should think of the continuance of a product or not. But before a decision is taken to discontinue a product, the reasons for the fall in its profit must be analysed for the decline in profit may be due to many reasons. If maintaining a currently unprofitable line is thought to be necessary, a time limit should be set on making the item profitable or finding a convenient way to drop it. Similarly, a product should be eliminated when it does not find a proper place in a firm's product line. Many drug manufacturing concerns are forced to delete a product simply because the product does not fit exactly into their product line.

The appearance of substitute products is another instance where a product has to be eliminated. It also happens that certain products may lose their effectiveness in serving the purpose. To quote an example, most of the antibiotics will have no effect after some time, since with the passage of time they become totally useless and non-responsive.

The decision to delete a product normally creates certain problems:

1. The capital invested on a 'to be deleted' product becomes waste.
2. Such deletion should be implemented only after the entire stock is sold out.
3. customers should not suffer on account of the deletion of a product.

For example, when a particular variety of product (say, a car) is dropped from product line, it becomes the duty of the producer to supply spares until the product's life is complete. It is also necessarily that the product elimination should not cause inconvenience to customers. They should be informed about the elimination far in advance so that they can make replacements, if necessary. Similarly, the process of deletion should be properly timed so that it exactly coincides with the end to the selling season. This will also help in clearing out the products by recovering at least the cost of production.

It is to be stressed once again that a proper analysis might reveal that instead of deletion it would be better to bring marginal or substantial changes in the existing product. In the case of most of the consumer durables, the investment cost is high. So it may not be advisable to decide their outright deletion. Product modification would be equally profitable. For example, in the case of refrigerators, washing machines, radios, etc., the product features are modified to attract customers.

Take the case of radios. Originally the product was a simple one working on electricity. Later battery-operated transistor sets were introduced. Stereophonic system came thereafter. The final product to date is the combination of radio, tape recorder and gramophone. (This is called "three-in-one set".) This process of product change is shown in the form of a replacement cycle in **Fig. 7**.

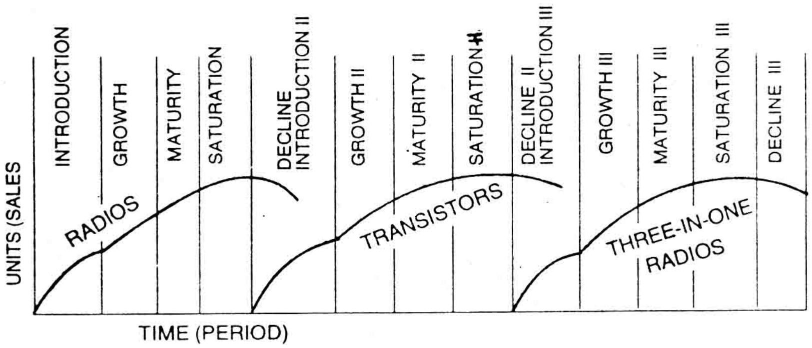


Fig. 7 : Replacement Cycle of Products

This product planning for existing products is a onerous job for the management. Among the product policies, product deletion is one of the most important ones. The more dynamic the business, the more vital the decision on product deletion. The management of such business is required to adopt the policy of reviewing its products continuously. The needs of consumers undergo a change and the appearance of rival products creates the need to modify the existing products. The management cannot wait to introduce a new product only when its former product has reached the decline stage, for the introduction of new products is a lengthy process. This does not mean that the products should be changed constantly. There are some products still selling after a very long time during which period they have undergone no, or very slight changes, e.g., Horlicks, Condensed Milk.

Technical and marketing innovations now occur at an ever-increasing rate of change and five years may be average product life, although in the field of electronics and pharmaceuticals one year to two years may be more accurate. Fundamentally, the time period of each phase of the cycle will vary according to the nature of the product. Rapidly moving consumer products may have regular pattern like a regular movement and it may enable a replacement product to be introduced with a fairly accurate predictability. Industrial products ,however ,may have very irregular patterns over long periods. Product replacement in the industrial field is often a case of changing technology. In short, in practical terms a company cannot permit a product to go too far into decline before it takes action.

As fewer but larger competitors emerge, the form of competition shifts dramatically, requiring commensurate changes in the manufacturing competence. Whereas the life-cycle stages emphasize the product's unique characteristics and quality, later life-cycle stages emphasize price competition and delivery capabilities. Survival in the market depends on producing a stable product with high volume in contrast to the earlier emphasis on a high product variety, low-volume conversion process. The conversion process has changed substantially, including new types of human skills and orientations, equipment and facility revisions, and planning and control systems. What can be done to prepare for and influence these adaptations? Part of the answer is to use research and development (R&D) to create new products and production processes.

1.9 PROCESS PLANNING AND PROCESS DESIGN

At the time of designing and developing a product, due consideration is given for the manufacturability or producibility of the product using the current process technology and the capability of the firm to manufacture the product. If the firm already has the required technology, the facilities (machines and equipments) and the manufacturing processes, and the firm has sufficient capacity or can acquire the needed capacity to manufacture the product, then decision is taken to go ahead with the product design. Otherwise, the design effort may be terminated.

After the final design of the product has been approved and released for production, the production planning and control department takes the responsibility of process planning and process design for converting the product design into a tangible product. As the process plans are firmly established, the processing time required to carry out the production operations on the equipments and machines selected are estimated. These processing times are compared with the available machine and labour capacities and also against the cost of acquiring new machines and equipments required before a final decision is made to manufacture the product completely inhouse or any parts or sub-assemblies must be outsourced.

What is a Process?

A process is a sequence of activities that is intended to achieve some result, typically to create added value for the customers.

A process converts inputs into outputs in a production system. It involves the use of organisation's resources to provide something of value. No product can be made and no service can be provided without a process and no process can exist without a product or service.

Processes underlie all work activities and are found in all organisations and in all functions of an organisation. Deciding what processes to use is an essential issue in the design of a production system. Process decisions involve many different choices in selecting human resources, equipment and machinery, and materials. Process decisions are strategic and can affect an organisation's ability to compete in the long run.

Types of Processes: Basically, processes can be categorised as:

(i) Conversion processes, i.e., converting the raw materials into finished products (for example, converting iron ore into iron and then to steel). The conversion processes could be metallurgical or chemical or manufacturing or construction processes.

(ii) Manufacturing processes can be categorised into (a) Forming processes, (b) Machining processes and (c) Assembly processes.

(iii) Testing processes which involve inspection and testing of products (sometimes considered as part of the manufacturing processes).

Forming processes include foundry processes (to produce castings) and other processes such as forging, stamping, embossing and spinning. These processes change the shape of the raw material (a metal) into the shape of the workpiece without removing or adding material.

Machining processes comprise metal removal operations such as turning, milling, drilling, grinding, shaping, planing, boring etc.

Assembly processes involve joining of parts or components to produce assemblies having specific functions. Examples of assembly processes are welding, brazing, soldering, riveting, fastening with bolts and nuts and joining using adhesives.

Process Planning

Process planning is concerned with planning the conversion processes needed to convert the raw material into finished products. It consists of two parts:

(i) Process design and **(ii) Operations design.**

Process Design is concerned with the overall sequences of operations required to achieve the product specifications. It specifies the type of work stations to be used, the machines and equipments necessary to carry out the operations. The sequence of operations are determined by (a) the nature of the product, (b) the materials used, (c) the quantities to be produced and (d) the existing physical layout of the plant.

Operations Design is concerned with the design of the individual manufacturing operation. It examines the man-machine relationship in the manufacturing process. Operations design must specify how much labour and machine time is required to produce each unit of the product.

Framework for Process Design

The process design is concerned with the following:

(i) Characteristics of the product or service offered to the customers.

(ii) Expected volume of output.

(iii) Kinds of equipments and machines available in the firm.

(iv) Whether equipments and machines should be of special purpose or general purpose.

(v) Cost of equipments and machines needed.

(vi) Kind of labour skills available, amount of labour available and their wage rates.

(vii) Expenditure to be incurred for manufacturing processes.

(viii) Whether the process should be capital-intensive or labour-intensive.

(ix) Make or buy decision.

(x) Method of handling materials economically.

Process Selection

Process selection refers to the way production of goods or services is organised. It is the basis for decisions regarding capacity planning, facilities (or plant) layout, equipments and design of work systems. Process selection is necessary when a firm takes up production of new products or services to be offered to the customers.

Three primary questions to be addressed before deciding on process selection are:

(i) How much variety of products or services will the system need to handle?

(ii) What degree of equipment flexibility will be needed?

(iii) What is the expected volume of output?

Process Strategy

A **process strategy** is an organisation's approach to process selection for the purpose of transforming resource inputs into goods and services (outputs). The objective of a process strategy is to find a way to produce goods and services that meet customer requirement and product specification (i.e., design specifications) within the constraints of cost and other managerial limitations. The process selected will have a long-term effect on efficiency and production as well as flexibility, cost, and quality of the goods produced. Hence it is necessary that a firm has a sound process strategy at the time of selecting the process.

Key aspects in process strategy include:

(i) Make or buy decisions

(ii) Capital intensity and

(iii) Process flexibility

Make or buy decisions refer to the extent to which a firm will produce goods or provide services in-house or go for outsourcing (buying or subcontracting).

Capital intensity refers to the mix of equipment and labour which will be used by the firm.

Process Flexibility refers to the degree to which the system can be adjusted to changes in processing requirements due to such factors as changes in product or service design, changes in volume of products produced and changes in technology.

Three process strategies: Virtually every good or service is made by using some variation of one of three process strategies. They are: **(i) process focus (ii) repetitive focus and (iii) product focus.**

Exhibit 1 illustrates the relationship between the three process strategies and volume and variety of products produced.

Each of these three strategies are discussed below:

(i) **Process Focus:** Majority (about 75 per cent) of global production is devoted to low volume, high variety products in manufacturing facilities called job shops. Such facilities are organised around performing processes. For example, the processes might be welding, grinding or painting carried out in departments devoted to these processes. Such facilities are **process focussed** in terms of equipment, machines, layout and supervision. They provide a high degree of product flexibility as products move intermittently between processes. Each process is designed to perform a wide variety of activities and handle frequent changes. Such processes are called **intermittent processes**. These facilities have high variable costs and low utilisation of facilities.

(ii) **Repetitive Focus:** A repetitive process is a product oriented production process that uses modules. It falls between product focus and process focus. It uses modules which are parts or components prepared often in a continuous or mass production process.

A good example of repetitive process is the **assembly line** which is used for assembling automobiles and household appliances and is less flexible than process-focused facility. Personal computer is an example of a repetitive process using modules in which the modules are assembled to get a custom product with the desired configuration.

(iii) **Product Focus:** It is a facility organised around products, a product oriented, high-volume low-variety process. It is also referred to as **continuous process** because it has very long continuous production run. Examples of product focussed processes are steel, glass, paper, electric bulbs, chemicals and pharmaceutical products, bolts and nuts etc. Product-focussed facilities need standardisation and effective quality control. The specialised nature of the facility requires high fixed cost, but low variable costs reward high facility utilisation.

Exhibit 1 : Process Selected Must Fit with Volume and Variety

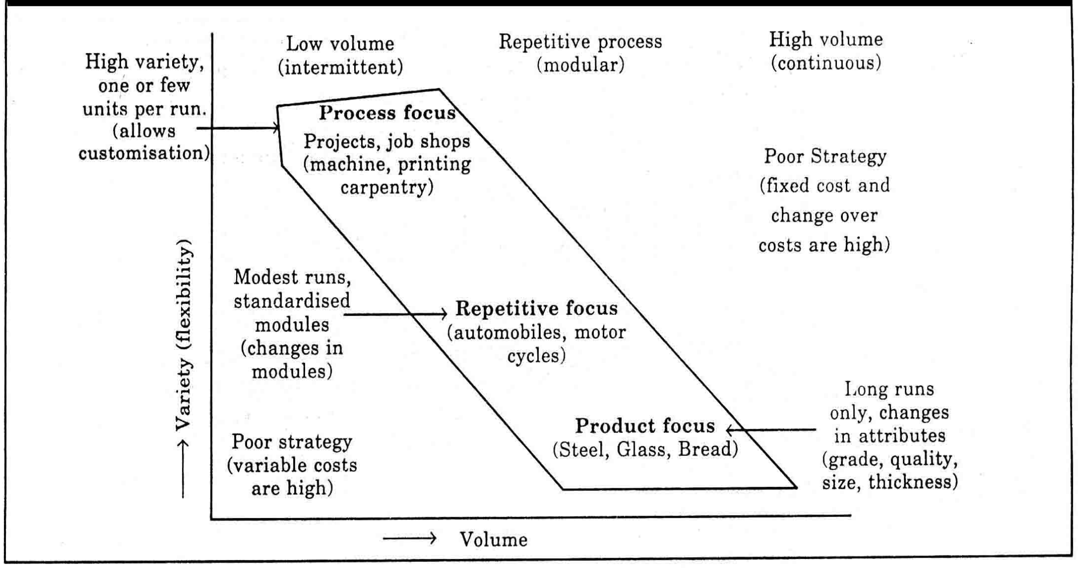


Table 5 gives a comparison of three choices namely process focus, repetitive focus and product focus.

Table 5 : Comparison of the Characteristics of Three Types of Process Strategies

Process Focus (Low Volume-High Variety)	Repetitive Focus (Modular)	Product Focus (High Volume – Low Variety)
1. Small quantity and large variety of products are produced	1. Long runs, usually standardized products with options for customers are produced from modules	1. Large quantity and small variety of products are produced
2. General purpose machines and equipments are used	2. Special equipments used in assembly lines	2. Special purpose machines and equipments are used
3. Broadly skilled operators	3. Modestly trained operators	3. Broadly skilled operators
4. Many job instructions because of job changes	4. Repetitive operations reduce job instructions and training	4. Few job instructions because jobs are standardized
5. High raw material inventory	5. Just-in-time procurement techniques are used	5. Low raw material inventories relative to value of output
6. High work-in-process compared to output	6. Just-in-time production techniques are used	6. Work-in-process inventory is low compared to output
7. Work flow is slow	7. Work flow is slow	7. Fast work flow
8. Finished goods are usually made to order and not stored	8. Finished goods are made to frequent forecasts	8. Finished goods are usually mode to a forecast and stored
9. Production scheduling is complicated, concerned with trade-off between inventory availability, capacity and customer service	9. Production scheduling is based on building various models from a variety of modules to forecasts	9. Simple production scheduling, concerned with establishing a rate of output sufficient to meet demand forecast
10. Low fixed costs and high variable costs	10. Fixed costs are dependent on flexibility of the facility	10. Fixed costs tend to be high and variable costs low.

1.10 PROCESS ANALYSIS AND DESIGN

Process Analysis and Design is a systematic approach to improve our understanding of the business processes of an organization to assist in the realization of tangible benefits such as cost reduction, process efficiency, and effective human resource allocation.

Leading organizations strive for continuous process improvement to create value and optimization in a complex and uncertain environment. Well-planned process analysis and design initiatives deliver sustainable process improvement in key areas such as human resources, finance, payroll, or administrative operations. Process Analysis and Design projects are typically organized into the following phases:

PROCESS ANALYSIS AND DESIGN

Planning	Analysis	Design	Implementation
1. Define how project is important to the organization 2. Define plan for project 3. Development project charter 4. Develop schedule commitments	1. Understand as is state 2. Identify improvements 3. Develop concept for To-Be-state	1. Develop how to realize To-Be state 2. Develop To-Be process design	1. Develop implementation plan 2. Design tests 3. Develop knowledge documentation and training 4. Develop change communication

Fig. 8 : Process Analysis and Design

1.11 PROCESS MANAGEMENT

Process management is concerned with the selection of inputs, operations, work flows and methods that transform inputs into outputs. The starting point of input selection is the make-or-buy decision (i.e., deciding which parts and components are to be produced in-house and which are to be purchased from outside suppliers).

Companies begin the process of organizing operations by setting competitive priorities. That is they must determine which of the following eight priorities are to be emphasized as competitive advantages:

1. Low-cost operations
2. High performance design
3. Consistent quality
4. Fast delivery time
5. On-time delivery
6. Development speed
7. Product customization
8. Volume flexibility

Although all eight are obviously desirable, it is usually not possible for an operation to perform significantly better than the competition in more than one or two.

1.12 PROCESS DECISIONS

It must be made when :

(i) a new or modified product or service is being offered

(ii) quality must be improved

(iii) competitive priorities have changed

(iv) demand for a product or service is changing

(v) cost or availability of materials has changed

(vi) competitors are doing better by using a new technology or a new process.

Major Process Decisions

Five common process decisions considered by production/operations managers are:

(1) Process choice, (2) Vertical integration, (3) Resource flexibility, (4) Customer involvement and (5) Capital intensity.

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.

Provides an overview of the processes discussed in this section.

Table 6: Types of Processes

Description	Job Shop Process	Batch Process	Repetitive (Assembly) Process	Continuous Process	Project Process
Output characteristics goods & services	Customised goods or services	Semi-standardised goods or services	Standardised goods or services	Highly standardised 'goods or services	Highly customised services
Examples of productive systems	Machine shop, tool room	Bakery, class room	Assembly line for automobiles	Steel mill; paper mill	Building bridges and dams
Examples of goods produced	Press tools, moulding tools	Bread, cakes, cookies	Automobiles, Television sets, computers	Steel, paper, sugar, flour	-
Volume	Low	Low to moderate	High	Very high	Very high
Output variety	Very high	Moderate	Low	Very low	Extremely low
Equipment flexibility	Very high	Moderate	Low	Very low	Low to high
Cost Estimation	Difficult	Somewhat routine	Routine	Routine	Complex
Cost per unit	High	Moderate	Low	Low	Very high
Equipment used	General purpose	General purpose	Special purpose	Special purpose	Varied
Fixed costs	Low	Moderate	High	Very high	Varied
Variable costs	High	Moderate	Low	Very low	High
Labour skills	High	Moderate	Low	Low	Low to high
Scheduling	Complex	Moderately complex '	Routine	Routine	Complex, subject to change
Work-in-process inventory	High	High	Low	Low	Varied
Advantages	Able to handle a wide, variety' of work	Flexibility	Low unit cost, high volume efficient	Very efficient, very high volume	Suitable for non-routine time and cost bound work
Disadvantages	Slow, high cost per unit, complex planning and scheduling	Moderate cost per unit, moderate scheduling complexity	Low flexibility high cost of downtime	Very rigid, lack of variety cost to change, very high cost of downtime	Very difficult to plan and control resources cost and time of completion

2. **Vertical Integration: Vertical integration** is the degree to which a firm's own production system handles the entire supply chain starting from procurement of raw materials to distribution of finished goods. Vertical integration is the amount of the production and distribution chain, from

suppliers of components to the delivery of products/services to customers, which is brought under the ownership of a firm. The management decides the level or degree of integration by considering all the activities performed from the acquisition of raw materials to the delivery of finished products to customers. The degree to which a firm decides to be vertically integrated determines how many production processes need to be planned and designed to be carried out in-house and how many by outsourcing. When managers decide to have more vertical integration, there is less outsourcing. The vertical integration is based on **"make-or-buy" decisions**, with **make** decisions meaning more integration and a **buy** decision meaning less integration and more outsourcing. Two directions of vertical integration are (a) **Backward integration** which represents moving upstream toward the sources of raw materials and parts, for example a steel mill going for backward integration by owning iron ore and coal mines and a large fleet of transport vehicles to move these raw materials to the steel plant, (b) **Forward integration** in which the firm acquires the channel of distribution (such as having its own warehouses, and retail outlets).

The advantages of more vertical integration are disadvantages of more outsourcing and similarly, advantages of more outsourcing are disadvantages of more vertical integration.

Advantages of vertical integration are:

(i) Can sometimes increase market share and allow the firm enter foreign markets more easily.

(ii) Can achieve savings in production cost and produce higher quality goods.

(iii) Can achieve more timely delivery.

(iv) Better utilisation of all types of resources.

Disadvantages of vertical integration are:

(i) Not attractive for low volumes.

(ii) High capital investment and operating costs.

(iii) Less ability to react more quickly to changes in customer demands, competitive actions and new techniques.

3. **Resource flexibility: Resource flexibility** is the ease with which equipments and workers can handle a wide variety of products, levels of output, duties and functions. The choices that management makes concerning competitive priorities determine the degree of flexibility required of a firm's resources — its employees, facilities and equipment. Production managers must decide whether to have **flexible workforce** which will provide reliable customer service and avoid capacity bottlenecks. Flexible workforce is useful with flexible flow strategy to even out fluctuating workloads. Also when volume flexibility is required, instead of laying off and hiring workforce to match varying demands, it is better to have certain amount of permanent workforce having multiple skills. This will facilitate movement of surplus workforce from low-load work centres to higher-load work centres.

   When a firm's product has a short life cycle and a high degree of customisation, low production volumes mean that the firm should select flexible general purpose machines and equipments.

4. **Customer-involvement: Customer involvement** refers to the ways in which customers become part of the production process and the extent of their participation. Customer-involvement is the extent to which customers interact with the process. A firm which competes on customisation allows customers to come up with their own product specification or even become involved in the designing process for the product (quality function deployment approach to design for incorporating the voice of the customer).

5. **Capital intensity** is the mix of equipment and human skills in a production process. Capital intensity will be high if the relative cost of equipment is high when compared to the cost of human labour. **Capital intensity** means the predominant resource used in manufacturing, i.e., capital equipments and machines rather than labour. Decision regarding the amount of capital investment needed for equipments and machines is important for the design of a new process or the redesign of an existing one. As the capabilities of technology increase (for example automation), costs also will

increase and managers have to decide about the extent of automation needed. While one advantage of adding capital intensity is significant increase in product quality and productivity, one big disadvantage can be high investment cost for low-volume operations.

It could be argued that some industries produce a tangible product required by a consumer or organization. However, this consumer might just be one individual in the chain. Consider the case of a customer who wants a dining table and chairs. These might be purchased from a retail outlet, which in turn was supplied by a furniture manufacturer.

The products or materials involved in this chain are all tangible in that they exist as artefacts. They are also functional in that they perform some specific function or purpose. The metal used to manufacture the screws and blots will have a strict specification, and be supplied to conform to this, the same applies to the manufacture of the bolts and screws themselves.

It is possible to move on down the spectrum from the tangible towards the intangible. Figure gives some examples of organizations and the products manufactured or the services provided in progressing from the one extreme (tangibility) to the other extreme (intangibility)

TANGIBILITY

FIXING MANUFACTURER
(screws and bolts)
↓
FURNITURE MANUFACTURER
(tables and chairs)
↓
RESTAURANT
(meal out)
↓
HOTEL
(overnight accommodation)
↓
HAIRDRESSER
(hair cut and styles)
↓
COACH SERVICE
(transport from Bradford to London)
↓
COLLEGE
(diploma course)
↓
HOSPITAL
(illness cured)
↓
MANAGEMENT CONSULTANT
(problem solved)

INTANGIBILITY

It is worth pointing out also that as we move down the scale towards intangibility, quantification/measurement of the customer requirements appears to become more difficult. It is possible to prepare a detailed specification for a particular nut and bolt. It is more difficult to know exactly what a client staying overnight at a particular hotel required or expects, and cost inevitably enters into this. Indeed, establishing a service strategy is crucial in indentifying the target market and which aspects of the service experience are valued. A businessman staying at a hotel midweek on business will have different requirements from the same businessman spending the weekend at the hotel with his family.

(B) Service Sector

Let's start the discussion with a small example

Narayana Hrudayalaya (NH) at Bangalore is renowned for giving new hope to 'inoperable' cardiac conditions and has attracted patients not only from different parts of the country, but also from neighbouring countries. Its patron, Dr. Devi Prasad Shetty, has many feats to his credit, most remarkable being the drastic reduction the cost of cardiac surgeries due to remarkable operations management practices adopted by him at NH.

(1) Service are intangible

Products are tangible, i.e., have physical dimensions, allowing customers to touch, see, and examine their features, while making the buying decision. Services, on the other hand, can only be 'felt' by customers after purchasing. Only after having undergone the 'service process', customers can tell if it was 'good' or 'bad' and accordingly, whether they would like to experience it again or not. Otherwise, the decision to buy a service is primarily guided by the 'reputation' of the service provider. For example, lectures of certain professors are so entertaining and enlightening that students willingly attend their classes, while they prefer to spend time in the canteen or library during the classes of other professors.

(2) Services are ideas and concepts; products are things

Service innovations are not patentable and in order to derive maximum benefits of a pioneering service concept, the service provider has to expand its operations rapidly in order to preempt the risk of competitors copying the same concept. Franchising is one route to achieve this daunting task in the minimum possible time. In India, the retailing concept of Big Bazaar is rapidly being imitated by new entrants such as FabMall, Foodworld, etc. Big Bazaar itself was inspired by the retail chain stores in the West. Similarly, the low-cost airline model of Air Deccan is being replicated by new entrants such as GoAir, SpiceJet, Indigo, etc. it may be recalled that the Air Deccan Model of low cost airlines was adapted from Ryanair of Europe and Southwest Airlines of the US.

(3) In a just-in-time (JIT) system

The production and provision of service starts as soon as the customer arrives to avail the service. The customer's involvement in the service process is imperative. This is known as the 'pull' production system in manufacturing and was inspired by the retailing services in the US supermarkets. The production process is initiated only when the customer places the order for the product and the raw material is 'pulled' into the various constituents of the production process according to the quantity of the order placed by the customer. Thus, the 'push' production system prevalent in many manufacturing organizations cannot be applied to service organizations. The 'push' production system results in 'pushing' the raw material in the production system and creation of inventories (work-in-process or finished goods). This is not possible in services, as they cannot be inventories.

(4) Services are more people-centric

Services are more 'people-centric' due to its labour intensive nature and high customer involvement. In most instances, the service providers provide (or are rather forced to do so by the competition) a personalized service to the customer. This complicates the service process manifold. Different customers have varied expectations from a service and employees providing the service have different levels of skill-sets. The interactions between customers and employees may lead to different levels of customer satisfaction or dissatisfaction. The challenge before the operations manager is to try and match customer expectations and develop employees' skill-sets through constant training and development.

Classification of Services

Schmenner (1986) categorized services into four categories in the service process. The four categories are named service factory, service shop, mass service, and professional service. In this matrix, one variable considered is the degree of interaction and customization. The services categorized in service shop and professional service fall in a high degree of interaction and customization. For example, in hospitals every patient has a unique problem and the doctor has to provide a customized prescription for the problem. Similarly, in auto repair shops every vehicle coming for service has unique repair requirements. In professional services provided by lawyers, every lawsuit involves different sections of the law and has its own unique points to be considered.

Table 7: Degree of interaction and Customization

Degrees of labour intensity	**low**	Service Factory • Freight services • Hotels, Inns, Motels • Airline services • Amusement park	Service Shop • Auto/Electronic service centres • Hospital and nursing home
	high	Mass service • Schools and colleges • Retail Shops • Wholesellers • Selling of insurance policies.	Professional Services • Specialist Doctors • Lawyers and tax consultants • Financial consultants • Engineers

On the other hand, the services categorized under service factory and mass service have a low degree of interaction and customization. For example, airlines provide very few options to the passengers – say, the economy class and business class services. The customers are rarely provided with customized services. The menu service onboard has mainly two options – vegetarian and non-vegetarian. Similarly, in schools, every student in a class is given the same standard treatment and education.

The second parameter considered in the serviced process matrix is the degree of labour intensity, measured by the ratio of labour cost to capital cost. Mass service and professional service have a high degree of labour intensity. For example, in case of architects, accountants, etc. the capital cost is low (as there is no costly equipment requirement) compared to the labour cost (there may be a team of professionals of this sort). Thus, the degree of labour intensity is high.

The service factory and service shop categories have a low degree of labour intensity. For example, in airlines the cost of capital required is quite high (as the cost of equipment, i.e., the aircrafts, is airlines, is very high) compared to the labour cost. Similar is the case with hospitals, where the cost of equipment such as X-ray machines, CAT scan machines, pathology labs, etc. is very high compared to the cost of labour.

From the service quality point of view, it is easiest to manage the quality of the service factory category of services (low degree of labour intensity as well as low degree of interaction and customization), while it is most difficult to manage the service quality of the professional service category. On the other hand, for professional services (high degree of labour intensity as well as high degree of interaction and customization) there are no standard ways of measuring and improving the service quality.

For service shop and mass service (low-high combination for the two variables in the matrix), service quality management has moderate level of difficulty).

Comparisons and contrasts

There are a large number of **similarities in terms of the management** of the process as we move along the spectrum from the tangible towards the intangible. The furniture manufacturer needs stocks of wood, screws and so on to allow manufacture and assembly to proceed, the restaurateur needs stocks of vegetables in order to prepare the meals, the hospital requires stocks of appropriate drugs to treat patients. All therefore need to try to predict requirements and to adopt a policy for managing the stocks of materials in order to be able to meet demand in the most cost-effective manner. All organizations need to plan and manage the availability of the human resources: the cooks need to be available to prepare and cook the meals when they are required by the dinners at the restaurant, drivers must be available to drive the coaches according to the timetables (and must satisfy additional restrictions on maximum driving time), lecturers must be available to provide the courses within the college. It is also necessary to manage the physical resources, the kitchen equipment and ovens, the bedrooms in the hotel, the hairdriers in the hairdresser's, the coaches, the lecture room. Many of the topics and concepts covered provided allowance is made for specific constraints imposed.

It is tempting to claim that, as we go further down the path towards intangibility, there are fewer similarities and the concepts have much less to offer because of the idiosyncrasies of the service environment. However, this argument is not valid since it could be argued also that every manufacturing situation is unique, with its own set of constraints. One of the challenges of Production Operation Management (POM) is the adoption of general concepts in a specific situation.

It has to be said, however, that there are some differences between 'pure manufacturing' and 'pure services', and that some of these should be recognized and can be exploited to advantage.

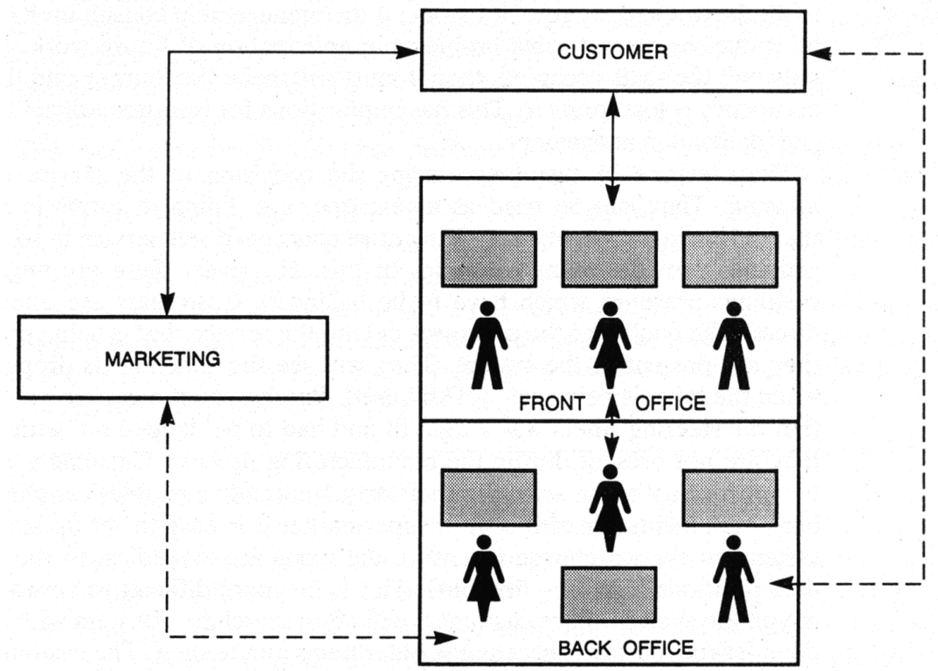


Fig. 9 : Comparison and Contrast

One concept which a number of authors have developed is that of the 'front and back office'. This is illustrated in **Figure 9**. It is a structure which is found frequently in service operations. Specific illustrations are in banking, with counter staff in direct contact with the customers handling their transactions. They are supported by 'behind the-scenes' staff, processing the direct debits, checking account details, ordering and preparing foreign currency and performing other activities independent of the presence of the customer. A similar type of structure exists in building societies, with customer contact concerned with such issues as discussing mortgage requirements and account transactions, and back office activities involving arranging building surveys, checking and preparing documentation and so on. Other illustrations are insurance offices, retailing (e.g. in store stock management and warehouse stock management), health care (e.g. in-store stock management and warehouse stock management), health care (e.g. taking an X-ray and processing it). The presence of the customer is 'accepted' in the front office (in fact required in some environments – try taking an X-ray without the patient!), but this acts as a buffer for the back office where the customer goes or makes contact less frequently. The presence of the customer in the front office is a 'factory', when activities can be more readily planned since it is a more predictable environment, and more amenable to many of the planning-related concepts.

A distinguishing feature of service operations is the general inability to hold stocks 'of the service' (not to be confused with holding stocks of materials required or consumed in producing the service). If the fixing manufacturer has no specific orders to fill, he can make screws for stock; if the management consultant has not clients then he is idle, he cannot solve problems in anticipation of future work. If the coach has only half the seats occupied, then it must still make the journey and the potential seat occupancy is lost forever. This has implications for resource utilization, and capacity and demand management.

The presence of customers during the provision of the service can be a mixed blessing. They can be used as a resource, e.g. filling in forms in a bank, serving themselves in a supermarket. The entire concept of self-service in so many of today's customer presence which have to be balanced. Customers are often able to check directly the quality of the processes behind the service that is being provided, because they are present in the system. They will see the fore that is dropped on the floor while the table is being set, yet still used. Purchasers of a car are not generally aware that the steering wheel was a tight fit and had to be 'helped on' with a hammer since they are not present during the manufacturing process. Customers can also be used to control quality, in selecting their own fruit and vegetables, or checking their own bank statements for errors. In a supermarket it is easy to set up stock management systems in the warehouse to ensure the items are loaded on to the shelves in strict date rotations (first-in-first-out). This is far more difficult to ensure once the items are to the shelves, since customers will often search for the item with the least sell-by date, leaving perfectly acceptable older items on the shelf. The customer also provides a degree of unpredictability which makes resource planning difficult. Will the next customer in the queue at the bank be paying in one cheque (a ten-second transaction) or the whole day's takings in small change from an ice-cream stall (which will occupy several minutes), and will that customer then take the opportunity to resolve some other problems (changing a standing order/direct debit, enquiring about a car loan or mortgage)? In manufacturing it is easier to specify the bound of responsibilities.

1.13 OPERATIONS MANAGEMENT WITHIN MANUFACTURING

The distinction is made above between manufacturing and services. Frequently within services the phrase 'operations management' tends to be used, whereas in manufacturing the phrase 'production management' is adopted to describe the management of the conversion process. However, even within a manufacturing organization, operations management concepts can be used within the non-manufacturing aspects of the operations.

The Processes Strategy, Process Analysis & Design, Process Flow

It is crucial that the way work is recognized is subjected to a systematic study, in order that the correct process for this may be established, the best method for the individual tasks be identified, and satisfactory achievement be monitored.

This section presents and evaluates the various approaches to work organization: job, batch, flow and group working. Work Study/ Organization and Methods is developed as a means for determining the best use to be made of materials, personnel and equipment in performing a task, and also for establishing the 'work content' of that task. The various techniques or Statistical Process Control (SPC) are illustrated as a means for monitoring and controlling quality.

Production/Operating Systems Design

Manufacturing Systems Design

Method Study

Work Measurement

Controlling Quality through Measurement

Controlling Quality through Counting.

Now we shall get an idea of the production process in different industries-regulated and unregulated and also of service industries.

Under the provisions of Cost and Works Accounts Act, 1959 (23 of 1959)

The regulated industries are –

i) Pharmaceutical Industry

ii) Fertilizers Industry

iii) Sugar & Alcohol Industry

iv) Electricity Industry

v) Petroleum Industry

vi) Telecommunication Industry

Amongst these regulated industries, most are manufacturing, except the telecommunication.

(A) Regulated Industries

(1) Sugar & Industrial Alcohol

A section of regulated industries produces sugar (from sugarcane) and Industrial alcohol or ethyl alcohol from raw fruit products such as grains, molasses etc. The largest users of ethyl alcohol are the food, medical & electronic industries. The major carbohydrate sources for ethanol fermentation are sugar from beet and cane. During this process the most important industrial wastes from cane alcohol are stillage and bagasse. The stillage is used mainly as a dried soil fertilizer, as a cattle feed supplement and as a feedstock for methane production. Bagassees is used as a steam-generating fuel. The following diagrams explain the production process right from sugarcane to sugar & further to industrial alcohol.

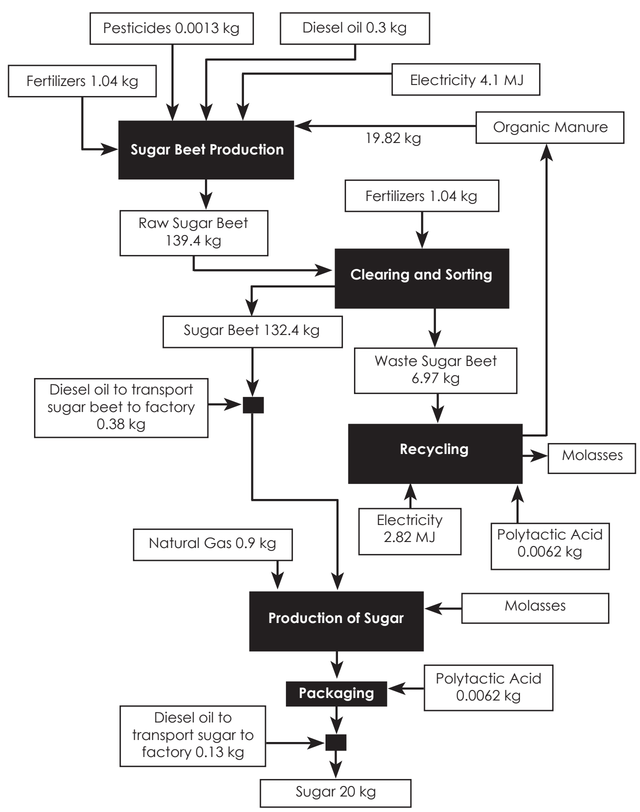


Fig. 10 : Production Process of Sugar and Industrial Alcohol

Industrial Alcohol

A section of the regulated industry produces raw and distilled ethyl alcohol from raw food products, such as grain, potatoes, and molasses. The largest users of ethyl alcohol are the food, medical, and electronics industries. The chief methods of large-scale production of industrial ethyl alcohol are the hydrolysis of non-consumable vegetable matter and various methods of chemical synthesis.

Alcoholic beverages obtained by fermenting sugar and starch substances were known in antiquity. Ethyl alcohol was obtained by distilling grape wine for the first time in Italy in the 11th century. Alcohol production – principally from grain – greatly expanded in Western Europe and Russia in the 14th century.

In India this industry is regulated by Cost Accounting Record Rules (Industrial alcohol) 1997.

Now for the purpose of cost accounting and cost management we need to analyze this whole process on the basis of cost centers. Cost centers are units of activity or areas of responsibility into which an internal service center is divided for accountability purposes, and to which costs are allocated or directly assigned, i.e., the smallest organizational entity where budget & actual cost activities take place, & which has both characteristics pertinent in cost generation & the ability to track & control those costs. Cost centers can be classified into two main groups production cost centers and service cost centers.

Moreover there are overhead costs which are to be allocated to specific cost centers on an appropriate basis. There are also other non cost items which are not to be considered for product costing purpose but are accounted for while calculating the profit of an organization.

Let us consider production of Industrial Alcohol from molasses for example.

Following is a production process flowchart for Industrial Alcohol produced from Molasses witch is actually a byproduct during the producti on of sugar.

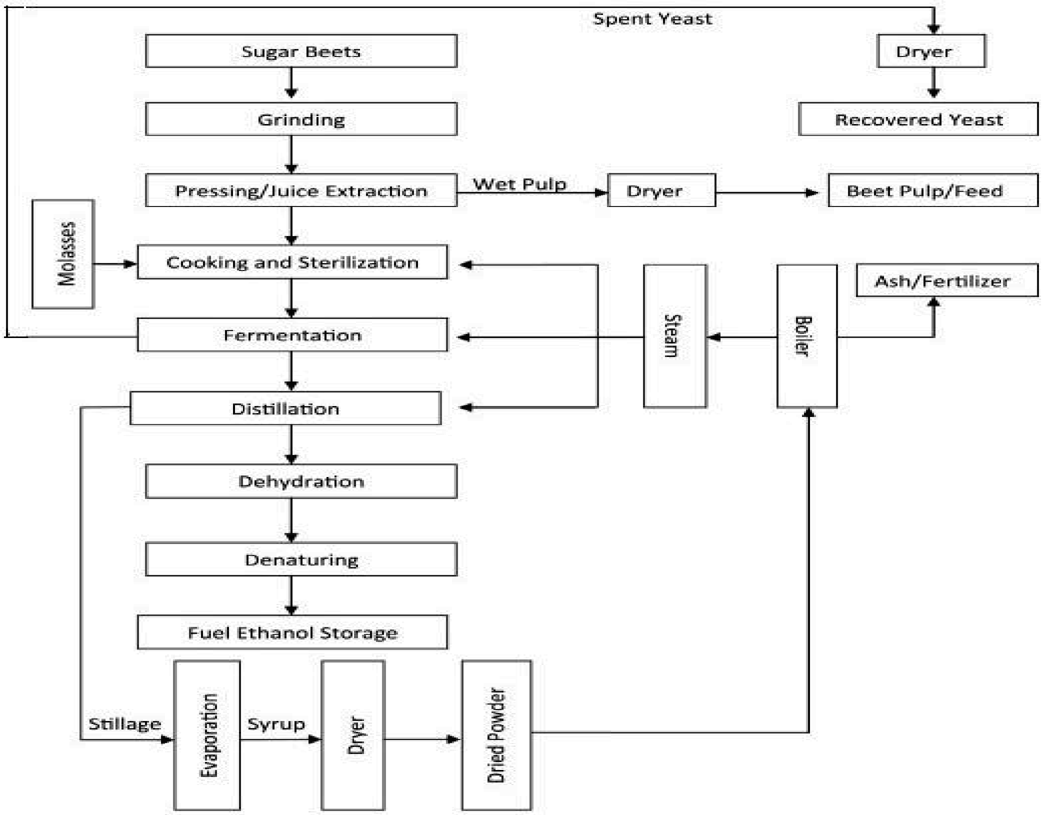


Fig. 11 : Flowchart of Production Process for Industrial Alcohol

(2) Fertilizer industry

Fertilizer Characteristics: Organic compared to mineral fertilizer

Characteristics	Organic fertilizer	Mineral fertilizer
Nutrient source	Crop residues and animal manures	Nitrogen from the air and minerals from the soil

Organic fertilizer contains the same inorganic molecules as mineral fertilizer.

Nitrogen fertilizer value drivers

Cost drivers	**Oil product prices and LNG development**	→	**Gas cost in Europe**
	Manning and maintenance	→	**Fixed Cost**
	Productivity and economies of scale	→	**Unit Cost**

Drivers of demand

The main demand driver for fertilizer is food demand which translates into demand for grains and other farm products.

Fertilizers are essential plant nutrients that are applied to a crop to achieve optimal yield and quality.

There are mainly two types of fertilizes –

Chemical fertilizer

Organic fertilizer.

(i) Chemical Fertilizer

Nutrients of chemical fertilizers are classified into three sub-group based on plant growth needs. There are:

- Macro or primary nutrients: Nitrogen (N), phosphorus (P), potassium (K)
- Major or secondary nutrients: Calcium (Ca), magnesium (Mg), and sulphur (S)
- Micro nutrients or trace elements: chlorine (Cl), Iron (Fe), manganese (Mn), boron (B), selenium (Se), xinc (Zn), copper (Cu), molybdenum (Mo) etc.

Mineral fertilizers can provide an optimal nutrient balance, tailored to the demands of the specific crop, soil and climate conditions, maximizing crop yield and quality whilst also causing bad environmental impacts. There are also organic fertilizers.

Fertilizer Detailed

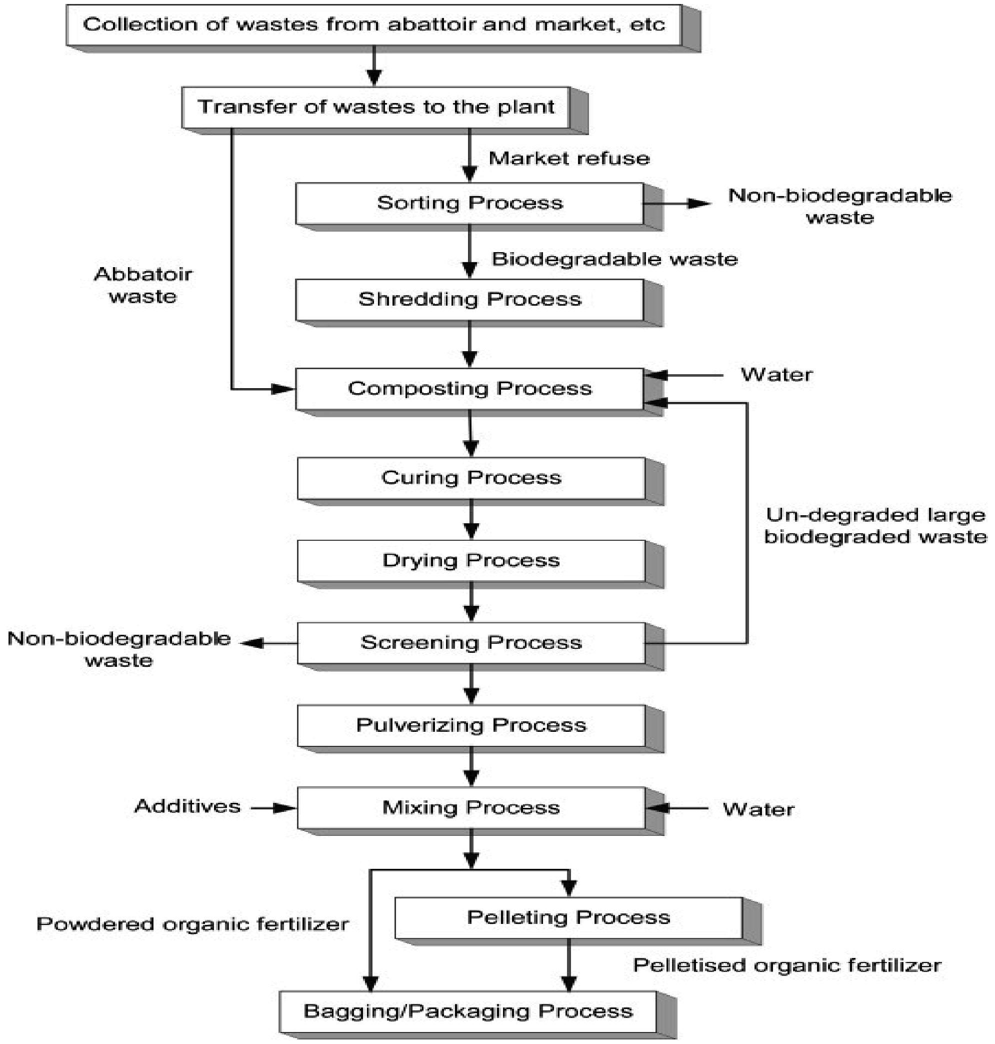


Fig. 12 : Flowchart for Fertilizer

(ii) Organic Fertilizer

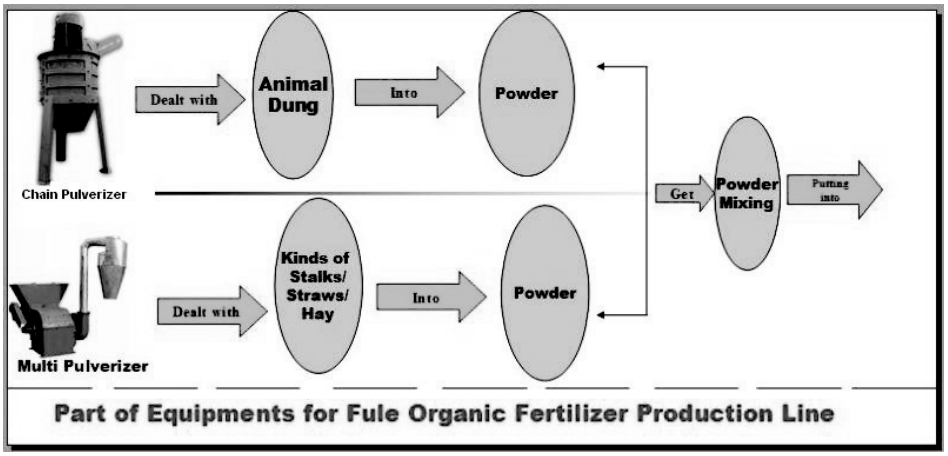


Fig. 13 : Flowchart for Organic Fertilizer

Fertilizer general

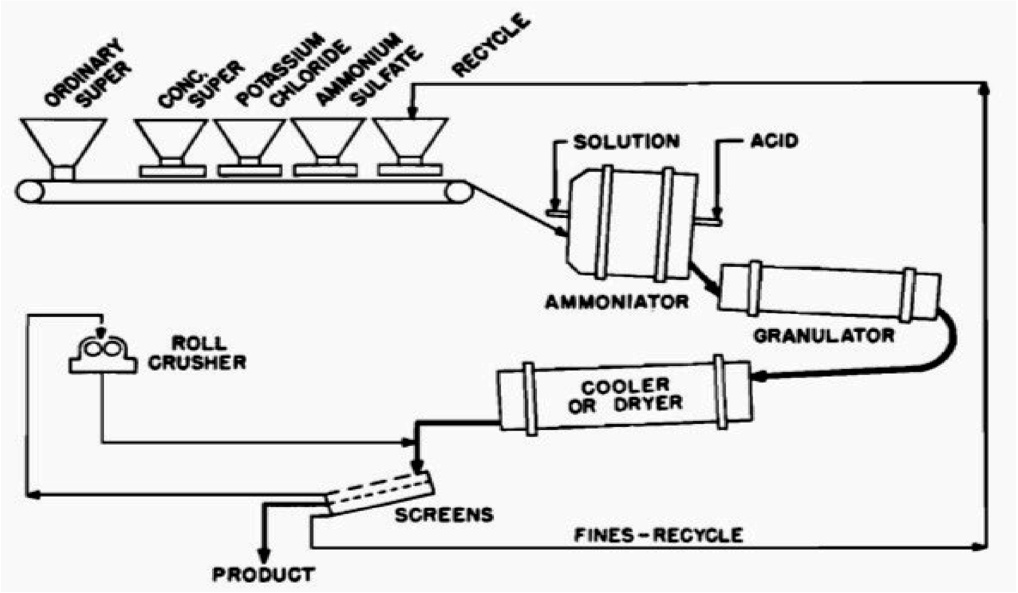


Fig. 14 : Processing of General Fertilizer

(3) Pharmaceutical Industry

Terms used frequently in the pharmaceutical industry:

Bulks are active drug substances used to manufacture dosage – from products, process medicated animal feeds or compound prescription medications.

Drugs are substances with active pharmacological properties in humans and animals. Drugs are compounded with other materials, such as pharmaceutical necessities, to produce a medicinal product.

Pharmacy is the art and science of preparing and dispensing drugs for preventing, diagnosing or treating diseases or disorders in humans and animals.

Many dynamic scientific, social and economic factors affect the pharmaceutical industry. Some pharmaceutical companies operate in both national and multinational markets. Therefore, their activities are subject to legislation, regulation and policies relating to drug development and approval, manufacturing and quality control, marketing and sales.

These complex factors interact to influence the discovery and development, manufacturing, marketing and sales of drugs.

In our country this industry comes under the preview of Cost Accounting Record Rules. The pharmaceutical industry is largely driven by scientific discovery and development in conjunction with toxicological and clinical experience. Major differences exist between large organizations which engage in a broad range of drug discovery and development, manufacturing and quality control, marketing and sales and smaller organizations which focus on a specific aspect based upon local market factors.

Active drug substances are inert materials are combined during pharmaceutical manufacturing to produce dosage forms of medicinal products (e.g., tablets, capsules, liquids, powers, creams and ointments). Drugs may be categorized by their manufacturing process and therapeutic benefits.

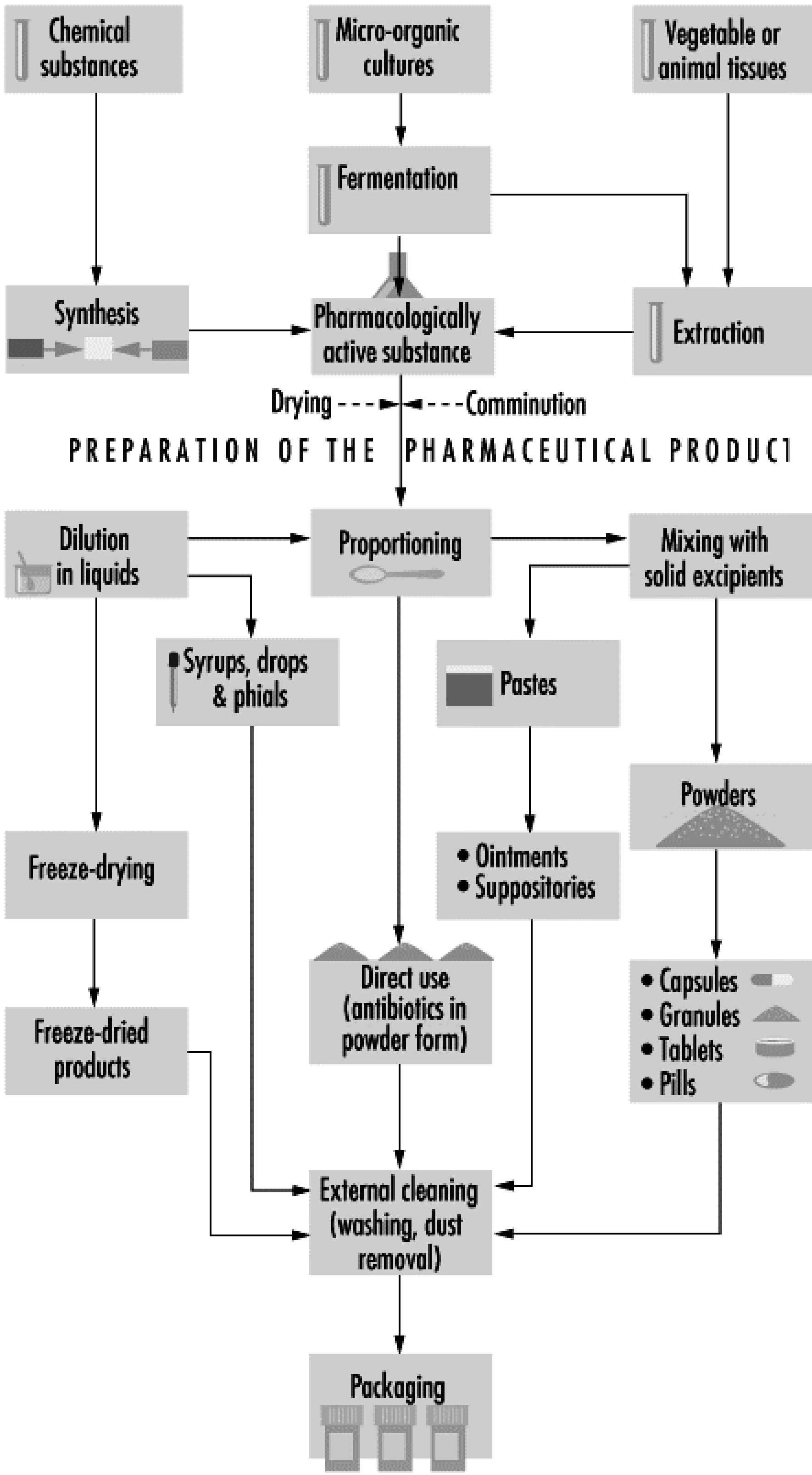


Fig. 15 : Preperation of Pharmaceutical Products

Manufacturing Process in the Pharmaceutical Industry

Basic production of bulk drug substances may employ three major types of processes: fermentation, organic chemical synthesis, and biological and natural extraction (Theodore and McGuinn 1992). These manufacturing operations may be discrete batch, continuous or a combination of these processes.

Pharmaceutical Manufacturing of Dosage Forms

Drug substances are converted into dosage-form products before they are dispenses or administered to humans or animals. Active drug substances are mixed with pharmaceutical necessities, such as binders, fillers, flavouring and bulking agents, preservatives and antioxidants. These ingredients may be dried, milled, blended, compressed and granulated to achieve the desired properties before they are manufactured as a final formulation. Tablets and Capsules are very common oral dosage forms; another common form is sterile liquids for injection or ophthalmic application. Figure illustrates typical unit operations for manufacturing of pharmaceutical dosage-form products.

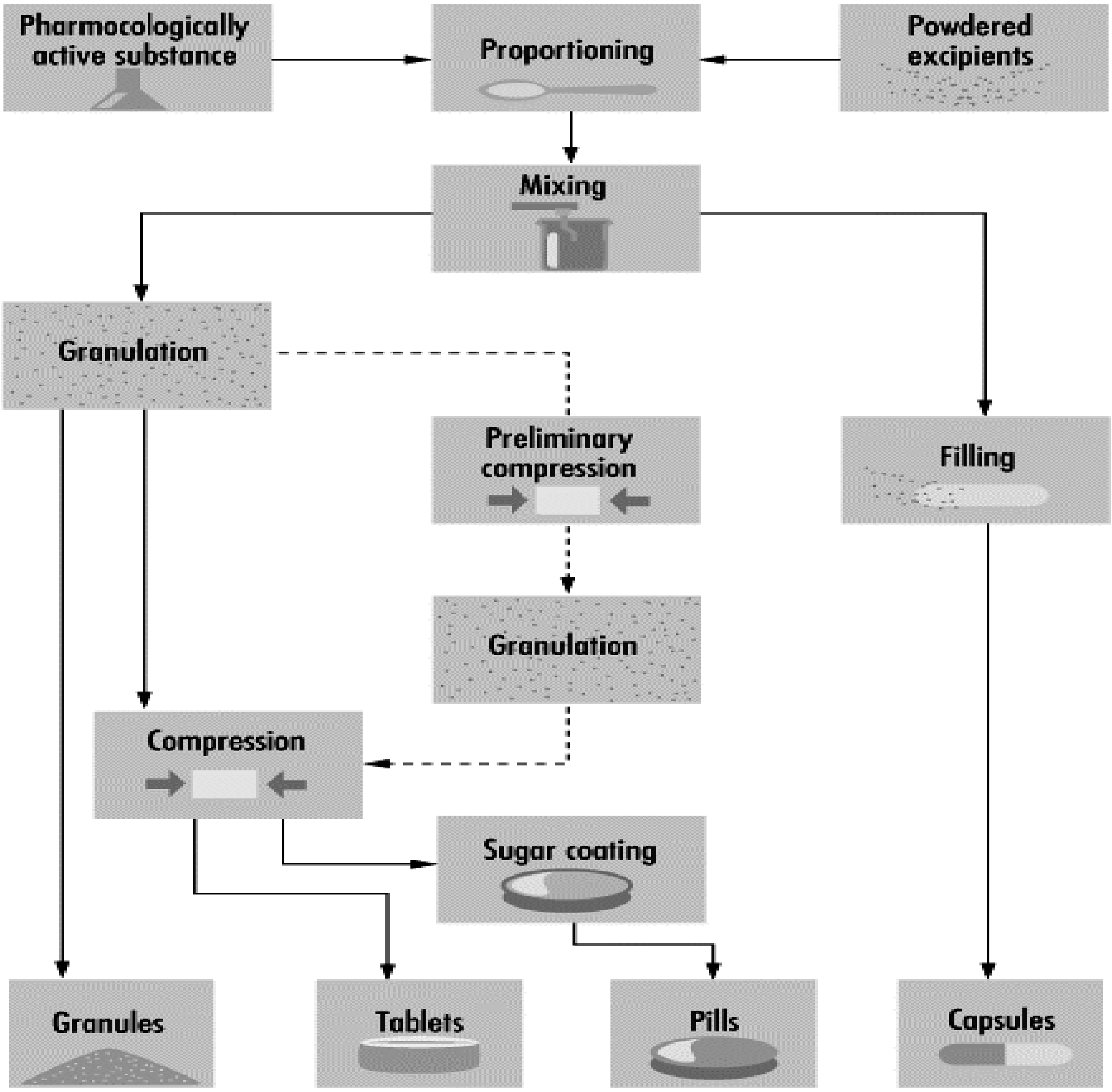


Fig. 16 : Operations for Manufactoring of Pharmactical dosage form Products

(4) Petroleum Industries

The petroleum industry includes the global processes of exploration, extraction, refining, transporting (often by oil tankers and pipelines), and marketing petroleum products. The largest volume products of the industry are fuel oil and gasoline (petrol). Petroleum (oil) is also the raw material for many chemical products, including pharmaceuticals, solvents, fertilizers, pesticides, and plastics.

Petroleum is vital to many industries, and is of importance to the maintenance of industrial civilization in its current configuration, and thus is a critical concern for many nations.

The petroleum industry is one of the largest in the world. It is closely allied with transportation facilities as their primary source of power is derived from petroleum products. Therefore, the location, analysis, and reporting of any portion of the industry are of major importance during time of war. In general, the industry consists of fourmain components: drilling, storing, transporting, and processing.

(1) **Drilling:** One can expect to find oil fields in almost any type of terrain ranging from desert and mountains to the shorelines of large bodies of water, Raising the oil to the surface is accomplished by natural gas and water pressure, if present, and if not, by the installation of a pump. Derricks, pipelines, and storage tanks are the identifying feature of an oil field.

(2) **Transportation:** Transporting the crude oil from the field to the refinery is accomplished by the several means a oil tankers transport a major percentage of the world's oil supply. Amongst other means, there are Oil barges, Pipelines & Railroad tank cars.

(3) **Storage:** Storage tanks located at the oil fields are for the temporary storage of crude oil only. However, tanks which are found at refineries may hold any number of types of petroleum products as well as crude oil.

(4) **Refining:** Crude Petroleum is composed of a great many varied types of chemical compounds. The primary function of a refinery is to separate the crude oil into components having properties of a particular, specified nature. To accomplish this separation, a refinery must employ a great deal of large, complex, and expensive equipment, most of which is designed to take advantage of the effect that application of heat has upon petroleum products.

The flow of production within the refinery is generally as follows but varies with each plant.

(a) **Primary crude oil distillation unit:** The primary distillation unit is the basic unit where it is separated into preliminary fractions.

(b) **Cracking Unit:** The cracking unit is the principal unit is the principal unit from which additional gasoline is obtained. This is done by breaking the heavier petroleum compounds into lighter ones by the application of heat and pressure (thermal cracking), or heat and pressure in the presence of a catalyst (catalytic cracking).

(c) **Vapor recovery area:** The vapor recovery area of a refinery consists of the vapor recovery or "light ends" unit, the polymerization unit, and the alkylation unit. The primary purpose of the vapor recovery area, like that of the cracking unit, it to provide additional high octane gasoline. Instead of obtaining this gasoline by breaking down the very heavy petroleum compounds, the vapor recovery area gathers various gases produced elsewhere in the refinery and combines their very light elements into heavier compounds, primarily gasoline.

(d) **Lube oil unit:** Lubricating oil refining is a group of processes in which some intermediate and heavier fractions from the primary distillation unit are converted into lubricating oils. It involves, mainly, the removal of undesirable constituents from the oil, and the imparting of a proper color to the oil. There are four basic processes involved in a typical example of lube oil refining; deasphalting, solvent extraction, dewaxing, and clay treating.

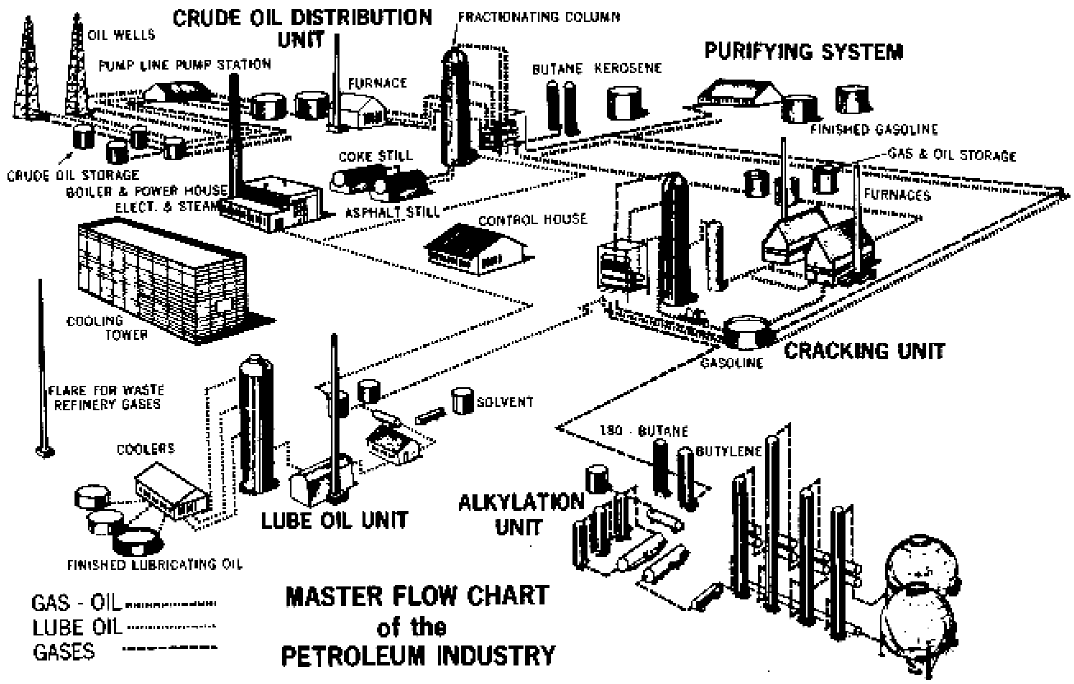


Fig. 17: Flowchart of Petroleum Industry

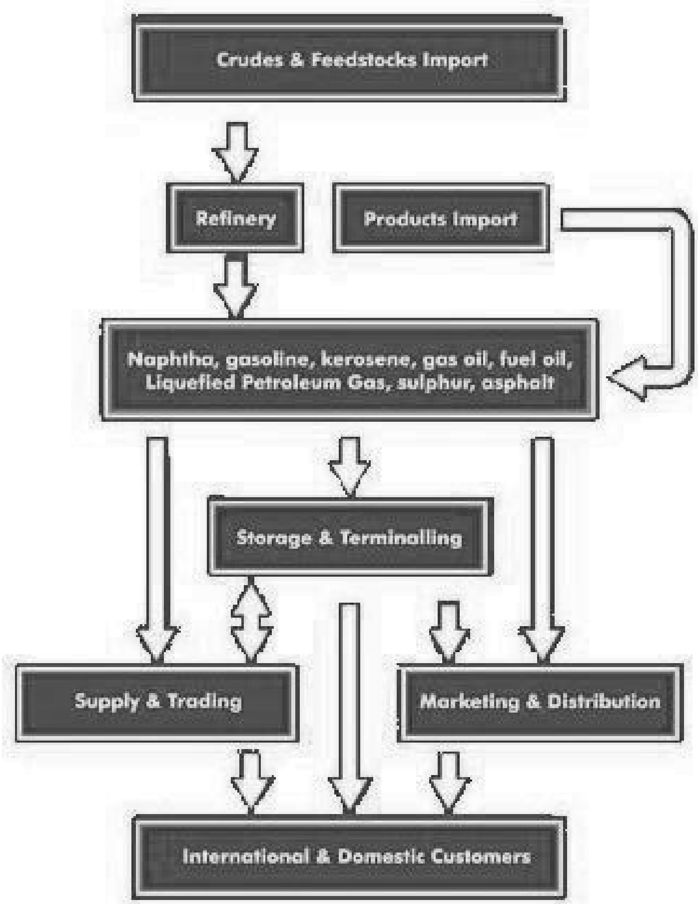


Fig. 18 : Bussines Flowchart of Petrolium Industry

(5) Telecommunication Industries

After getting registered with the Ministry of Communications and Information Technology, a Telecom Company can engage into "Telecom Activities".

"Telecommunication activities" means any act, process, procedure, function, operation, technique, treatment or method employed in relation to telecasting, broadcasting, telecommunicating voice, text, picture, information, data or knowledge through any mode or medium and includes intermediate and allied activities thereof and these activities would, inter alia, include the following Services or activities.

Normally a Telecom or Networking Company earns revenue from following segment:

(i) Basic Telephone Services;

(ii) National Long Distance Services;

(iii) International Long Distance Services;

(iv) Cellular Mobile Telephone Services;

(v) Wireless Local Loop (WLL) (Fixed or Mobile) Telephone Services;

(vi) Very Small Aperture Terminal Services;

(vii) Public Mobile Radio Trunk Services;

(viii) Global Mobile Personal Communication Services;

(ix) Internet or Broadband or Wireless Access Service;

(x) Infrastructure Provider (IP-1);

(xi) Passive Telecom Infrastructure including Telecom Tower Facilities;

(xii) Cable Landing Stations; and

(xiii) Any other related, allied, intermediate or support services in relation to telecommunication activities not indicated above.

Generally the business of a telecom Company can broadly be classified into two subgroups;

A) Services: It's includes various services like

1. Basic Telephone Services;
2. National Long Distance Services;
3. International Long Distance Services;
4. Cellular Mobile Telephone Services;
5. Wireless Local Loop (WLL) (Fixed or Mobile) Telephone Services;
6. Very Small Aperture Terminal Services;
7. Public Mobile Radio Trunk Services;
8. Global Mobile Personal Communication Services;
9. Internet or Broadband or Wireless Access service;

Where material consumption is occurred once in a year from Capital Employed.(for example: Set up of Tower, fixed land line, networking item like router, switch, optical fiber for installation and spread up of services of internet or mobile.)

B) Network Services: It includes

  (i) Infrastructure Provider (IP-1);

  (ii) Passive Telecom Infrastructure including Telecom Tower Facilities;

  (iii) Cable Landing Stations; and

  (iv) Any other related, allied, intermediate or support services in relation to telecommunication activities not indicated above.

In this case material consumption or supplying of material equipment is required as per clients need. E.g. Set up of Data Centre, Cable landing station,network integration (NI), corporate data connectivity (MPLS VPNs and Internet) within and outside India, infrastructure management.

Costing Structure of Telecom Industries is not similar to other Industries. Factors related to **Capital Employed** arise from tangible and intangible assets are allocated to network elements, then each Network wise Capital employed is allocated to product or network services. Since in this sector, we can find a lot of non-moving items which are a part of current assets. Huge amount of working capital gets engaged.

Thus we can find Service wise costing elements, presented in Proforma A of cost statement, where Service wise Costing P& L is to be made. It includes Employee cost; Administrative cost; Sales & Marketing cost; Government charges etc.

In Proforma B, product wise costing profit and loss account is prepared after product wise allocation of different services (accounted for in proforma A) has been made.

So primary Cost Centre includes various revenue generation segments like Telecom units (It's includes sub cost centre Mobile, WLL, CDMA etc); Internet units (like 3G, Wireless, RF, Optical Fiber, VSAT etc.) and others.

There are also other auxiliary Cost Centres like Administration, Billing, Branch Office, Corporate Office, Customer Care, Finance & Accounts, HR, Insurance, IT or EDP, Legal or Regulatory, Maintenance, Marketing and Sales, Planning and Development, Quality Stores or Logistics which allocated to various services and various products on appropriate basis.

(6) Electricity Industries

In our Country Electricity Industries dealing with main following activities;

1. Power generation (through Thermal Plant) like NTPC,
2. Power generation (through Hydro Plant) like NHPC,
3. Power transmission like Power Grid Corporation of India and
4. Power distribution (State owned Company)
5. Now power can be generated by Nuclear also (NPCIL)

Main objective of a Power Company is different from other so activity is also different.

As per Section 209 (1) (d), 600(3) (b) of the Companies Act, 1956 and rule 2 of the Cost Accounting Records (Electricity Industry) Rules, 2011 Activity wise Costing record has to be maintained by all Indian Companies dealing with power.

- Proforma A:Cost of utilities like water collection, water treatment, ash handling plant, effluent treatment, etc
- Proforma B: Cost of procurement of coal, lignite, gas, naphtha, fuel oil, bagasse or any other secondary conventional or non-conventional fuel.
- Proforma C: Cost of generation of Power (Thermal or Hydroelectric or Gas Turbine or Atomic or Wind or Solar, etc.)
- Proforma D: Cost of Transmission or Distribution

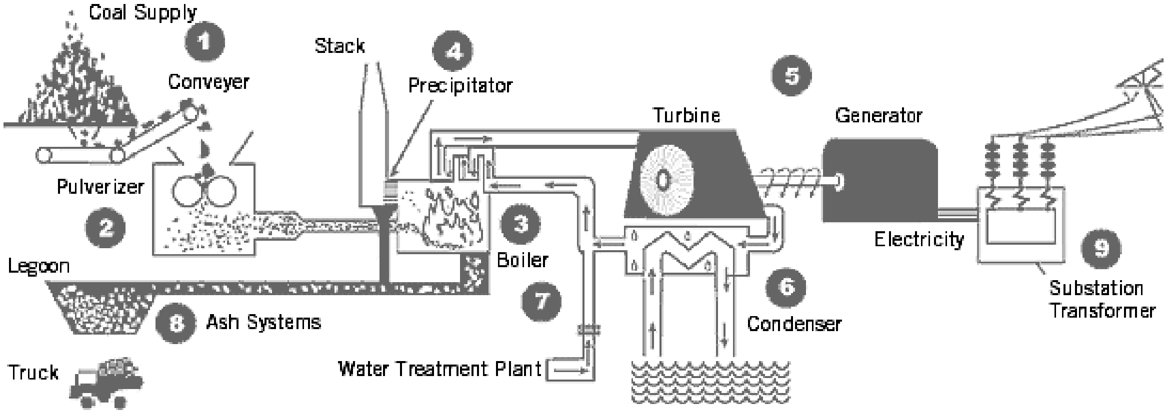
- Proforma E: Cost of supply (consumer servicing and billing, etc.)
- Proforma F: Activity-wise Capital Cost of Plant and Machinery or Equipment relating Electricity Activity and other common services or activities
- Proforma G: Allocation and Apportionment of Total Expenses and Income of the Company
- Proforma G1: Apportionment of Overheads
- Proforma H: Profit Reconciliation

The main Cost Centre is mainly Thermal Unit, Hydro Unit, Turbine/Atomic/Solar unit Transmission unit (Sub Station), Distribution Centre.

Supporting Cost Centre are various utilities like Water collection, Water treatment, Ash handling plant, Effluent treatment, Procurement of coal, lignite, gas, naptha, fuel oil, baggase etc.

Auxiliary Cost Centers are Project, Maintenance, Marketing & Communication and Administration etc.

Since many Companies availed various Government subsidies or any other benefit, allocation of Capital Cost of Plant and Machinery or Equipment has been maintain separately distributed to Generation, Transmission, Servicing /Billing /Marketing and Administration etc.



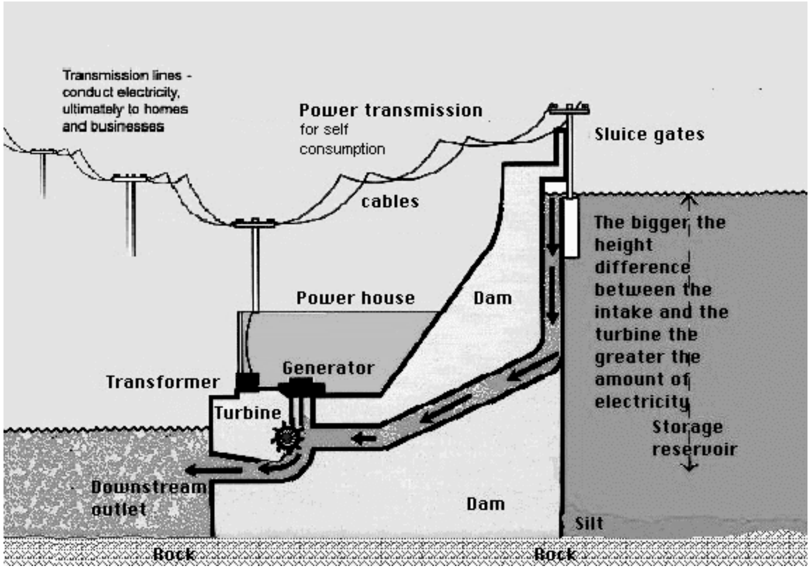


Fig. 19 : Components of a thermal power plant

Study Note - 2

PRODUCTION PLANNING

This Study Note includes

2.1 PRODUCTION PLANNING & CONTROL MEASURES - INTRODUCTION

Production planning and 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 consists of a sequence of operations that transform materials from a given form to a desired form (products). The highest efficiency in production is obtained by manufacturing the required quantity of products, of the required quality, at the required time, by the best and cheapest method. To achieve this objective, production management employs production planning and control function which is a management tool that coordinates all manufacturing activities.

The four factors viz., quantity, quality, time and cost encompasses the production system of which production, planning and control (in short referred to as PPC) is the nerve centre or brain.

Hence, production planning and control may be defined as the planning, direction and coordination of the firm's material and physical facilities towards the attainment of predetermined production objectives in the most economical manner.

Production planning and control is also referred to as operations planning and control because the production planning and control techniques used in production system manufacturing tangible goods can also be employed in operations or service systems providing services.

Production/operation planning and control involves the organisation and control of an overall manufacturing (or service) system to produce a product (or a service).

Scope of Production Planning and Control Functions:

The functions of PPC can be classified under the following:

(i) Materials: Raw materials, spare parts and components which must be available in the correct quantities and specifications at the right time.

(ii) Methods: It involves deciding the best sequence of operations for manufacturing the parts, building up subassemblies and major assemblies which in turn will make up the finished product, within the limitations of existing layout and workflow.

(iii) Machines and Equipments: PPC is concerned with selection of machines and equipments and also with maintenance policy, procedure and schedules, replacement policy and tooling. (Design and manufacture of tools).

(iv) Routing: Routing prescribes the flow of work in the plant and is related to consideration of layout, of temporary storage locations for raw materials, components and semi processed parts, and of material handling systems. Routing is a basic PPC function.

(v) Estimating: The processing times (both set up time and operation time per piece) required for the parts to be manufactured in-house are estimated and the standard time (both machine time and labour time) are established as performance standards.

(vi) Loading and Scheduling: Machines have to be loaded according to their capacity and capability. Machine loading is carried out in conjunction with routing (as indicated in process layouts or operations analysis and routing sheets) to ensure smooth workflow and the prescribed feeds. Speeds of machines are adhered to as well as the estimated time (standard time which is the allowed time to do a job).

Scheduling: Determines the utilisation of equipment and manpower and hence the efficiency of the plant. Scheduling determines the starting time and completion time for each and every operation for each and every part to be manufactured and sub-unit to be assembled so that the finish product is ready to be shipped to the customer as per the predetermined delivery schedules.

(vii) Dispatching: This is concerned with the execution of planning functions. Production orders and instructions are released according to the schedule, sequences indicated in route sheets, and machine loading schedules are adhered to and authorisation is given for release of materials and tools to the operators to carryout the work.

(viii) Expediting or Progressing: This means follow-up or keeping track of the progress made in completing the production as per schedules. This follows dispatching function logically.

(ix) Inspection: This function relates to checking the quality of production and of evaluating the efficiency of the processes, methods and workers so that improvements can be made to achieve the desired level of quality.

(x) Evaluating or Controlling: The objective of evaluation or controlling is to improve performance. Methods and facilities are evaluated to improve their performance. To sum up, we can state that PPC is a management tool, employed for the direction of the manufacturing operations and their co-ordination with other activities of the firm.

In short, production planning and control function is concerned with decision-making regarding.

(a) What to produce	Product planning and development including product design.
(b) How to produce	Process planning, material planning, tool planning etc.
(c) Where to produce	Facilities planning, capacity planning and subcontracting planning.
(d) When to produce	Production scheduling and machine loading
(e) Who will produce	Man power planning
(f) How much to produce	Planning for quantity, Economic batch size etc.

Principles of Production Planning and Control (PPC)

i. Type of production determines the kind of production planning and control system needed.

ii. Number of parts involved in the product affects expenses of operating PPC department.

iii. Complexity of PPC function varies with the number of assemblies involved.

iv. Time is a common denominator for all scheduling activities.

v. Size of the plant has relatively little to do with the type of the PPC system needed.

vi. PPC permits 'management by exception'.

vii. Cost control should be a by-product of PPC function.

viii. "The highest efficiency in production is obtained by manufacturing the required quantity of a product, of the required quality, at the required time by the best and cheapest method" — PPC is a tool to coordinate all manufacturing activities in a production/ operating system.

Objectives of Production Planning and Control

The 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.

The advantage of production planning is that efficiency and economy are maximised. The 4 Ms - resources of **men, machinery, materials** and **money** are analysed to select the most appropriate materials, methods, and facilities for accomplishing the work. This is followed by functions such as routing, estimating and scheduling.

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.

Production Control

(A) Importance of Control Function

The function of production control is to:

(i) Provide for the production of parts, assemblies and products of required quality and quantity at the required time.

(ii) Co-ordinate, monitor and feedback to manufacturing management, the results of the production activities, analyzing and interpreting their significance and taking corrective action if necessary.

(iii) Provide for optimum utilisation of all resources.

(iv) Achieve the broad objectives of low cost production and reliable customer service.

(B) Benefits of Production Control

1. Improvement in profits through -

   (a) Maintenance of a balanced inventory of materials, parts, work-in-process and finished goods.

   (b) Balanced and stabilized production.

   (c) Maximum utilization of equipment, tooling, labour (manpower) and storage space.

   (d) Minimum investment in inventory.

   (e) Reduction in indirect costs.

   (f) Reduction in set up costs.

(g) Reduction in scrap and rework costs.

(h) Reduction in inventory costs.

2. Competitive advantage-

(a) Reliable delivery to customers.

(b) Shortened delivery schedules to customers.

(c) Lower production costs and greater pricing flexibility.

(d) Orderly planning and marketing of new or improved products.

(C) Elements of Production Control

i. Control of Planning: Assure receipt of latest forecast data from sales and production planning, bill of material data from product engineering and routing information from process engineering.

ii. Control of Materials: Control of inventory and providing for issue of materials to the shop and movement of materials within the shop.

iii. Control of Tooling: Check on the availability of tooling and provide for issue of tools to shop floors from tool cribs.

iv. Control of Manufacturing Capacity: Determine the availability of equipment and labour capacities and issue realistic production schedules and provide a means of recording completed production.

v. Control of Activities: Release order and information at assigned times.

vi. Control of Quantity: Follow up of progress of production in order to ensure that the required quantities are processed at each production step and to ensure that corrective action is initiated where work fails to pass each stage of inspection.

vii. Control of Material Handling: Release orders for movement of work to ensure availability of material as required at each stage of the operation.

viii. Control of Due Dates: Check on the relation of actual and planned schedules and determine the cause of delays or stoppages that interfere with weekly schedules of work assigned to each machine or work centre.

ix. Control of Information: Distribute timely information and reports showing deviations from plan so that corrective action can be taken and provide data on production performance measurement for future planning.

The following are the objectives of production planning and control:

i. To deliver quality goods in required quantities to the customer in the required delivery schedule to achieve maximum customer satisfaction and minimum possible cost.

ii. To ensure maximum utilization of all resources.

iii. To ensure production of quality products.

iv. To minimise the product through-put time or production/manufacturing cycle time.

v. To maintain optimum inventory levels.

vi. To maintain flexibility in manufacturing operations.

vii. To co-ordinate, between labour and machines and various supporting departments.

viii. To plan for plant capacities for future requirements.

ix. To remove bottle-necks at all stages of production and to solve problems related to production.

x. To ensure effective cost reduction and cost control.

xi. To prepare production schedules and ensure that promised delivery dates are met.

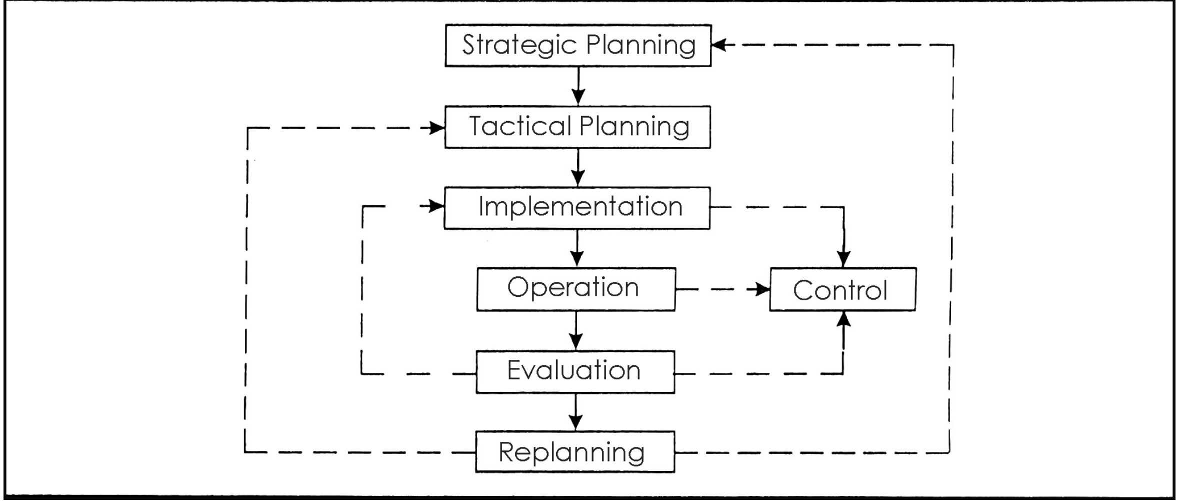
xii. To produce effective results for least total cost.

xiii. To establish routes and schedules for work that will ensure optimum utilization of materials, labour and equipments and machines and to provide the means for ensuring the operation of the plant in accordance with these plans.

xiv. The ultimate objective is to contribute to profit of the enterprise.

Role of Production planning and Control in Operations Management

Exhibit 2.1.1 : The Production/Operations Management Cycle



Operations are at the centre of the diagram in **Exhibit 2.1.1** because they are the dynamic 'doing' elements of the production process. As the Exhibit shows, planning and control never cease in the production area. There are a variety of productions/operations management responsibilities such as:

(i) Product design.

(ii) Job design and process design.

(iii) Equipment selection and replacement.

(iv) Labour skills and training programs.

(v) Input material selection including raw materials and sub-contracting.

(vi) Plant location and layout.

(vii) Scheduling steps of the plan.

(viii) Implementing and controlling the schedule.

(ix) Operating the production system. The above are concerned with the design of the production process.

In addition, the control systems to be considered are:

(i) Inventory control policies.

(ii) Quality control policies.

(iii) Production schedule control policies.

(iv) Productivity and cost control policies.

(v) Constructing control systems.

(vi) Implementing and operating control systems.

(vii) Modifying policies and designs.

Phases in Production Planning and Control Function

1. **Planning Phase:** (a) Pre-planning ; (b) Active planning

   (a) Pre-planning activity involves product planning and development, demand forecasting, resources planning, facilities planning, plant planning, plant location and plant layout.

   (b) Active planning involves planning for quantity, determination of product - mix, routing, scheduling, material planning, process planning, capacity planning and tool planning.

2. **Action Phase:** Execution or implementation phase includes dispatching and progressing function.

3. **Control Phase:** Includes status reporting, material control, tool control, inventory control, quality control, labour output control and cost control.

Exhibit 2.1.2. Production Planning & Control

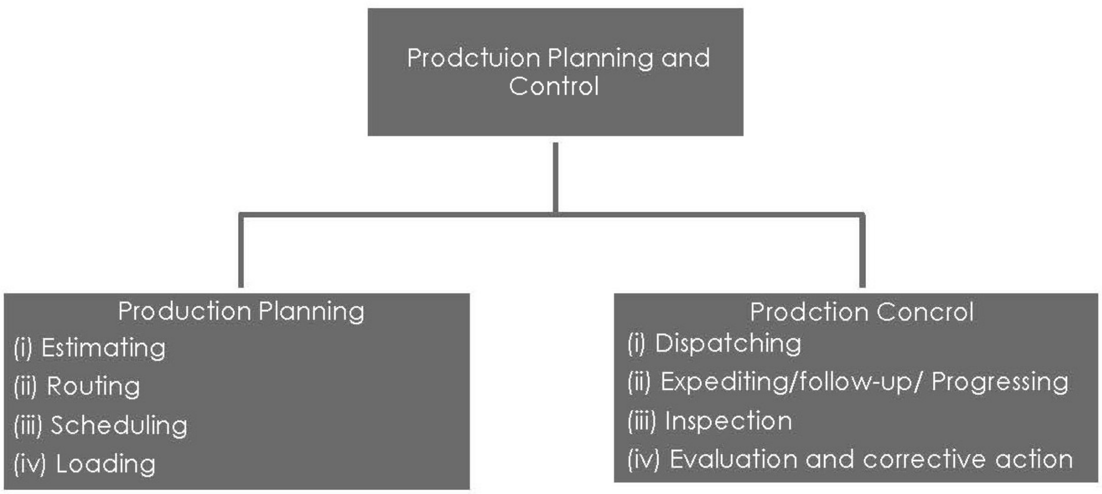


Table 2.1.1 Levels of Planning in a Production Planning System

Planning Horizon	Inputs	Plans/Schedule	Outputs
1. Long-range (Strategic Planning)	(a) Long-range demand forecast (b) Availability of funds and business analysis (c) Capacity data and analysis	Long-range capacity plan	(a) Production facility plans (plant location, layout, size, capacities etc.) (b) Major subcontract plans. (c) Major machinery and process plan.

2. Intermediate range (Tactical Planning)	Intermediate range demand forecast	Aggregate capacity plan	(a) Employment plan. (b) Machinery and utility plan. (c) Subcontract and material supply contracts. (d) Facility modification plans. (e) Aggregate inventory plans.
3. Short-range (Operational Planning)	(a) Short-range demand forecasts (b) On-hand customer order (c) Other orders (Intra-company) (d) Availability of material from suppliers	(a) Master production schedules (MPS) (b) Capacity requirement planning (CRP) (c) Material requirement planning (MRP)	(a) Short-range production schedules for end products. (b) Short-range schedule for parts, components, sub-assemblies and final assemblies. (c) Short-range plan for purchasing materials. (d) Short-range shop floor plans.

Production Planning Functions

The main functions of production planning are:

1. **Estimating**

   Involves deciding the quantity of products to be produced and cost involved in it on the basis of sales forecast.

   Estimating manpower, machine capacity and materials required (Bill of material is the basis) to meet the planned production targets are the key activities before budgeting for resources (e.g., production budget is the basis for materials budget, capital equipment budget and manpower budget).

2. **Routing**

   This is the process of determining the sequence of operations to be performed in the production process. Routing determines what work must be done, where and how?

   Routing information is provided by product or process engineering function and it is useful to prepare machine loading charts and schedules.

   Route Sheet: A route sheet is a document providing information and instructions for converting the raw materials into finished parts or products. It defines each step of the production operation and lays down the precise path or route through which the product will flow during the conversion process.

3. **Scheduling**

   Involves fixing priorities for each job and determining the starting time and finishing time for each operation, the starting dates and finishing dates for each part, sub assembly and final assembly. Scheduling lays down a time table for production indicating the total time required for the manufacture of a product and also the time required for carrying out the operation for each part on each machine or equipment.

4. **Loading**

   Facility loading means loading of facility or work centre and deciding which jobs to be assigned to which work centre or machine. Loading is the process of converting operation schedules into practice. Machine loading is the process of assigning specific jobs to machines, men or work centres based on relative priorities and capacity utilization.

A machine loading chart (Gantt chart) is prepared showing the planned utilisation of men and machines by allocating the jobs to machines or workers as per priority sequencing established at the time of scheduling.

Loading ensures maximum possible utilisation of productive facilities and avoids bottlenecks in production. It is important to avoid either over loading or under loading the facilities, work centres or machines to ensure maximum utilization of resources.

Production Control Functions

The control functions are:

1. Dispatching

Dispatching may be defined as setting production activities in motion through the release of orders (work order, shop order) and instructions in accordance with the previously planned time schedules and routings.

2. Expediting/Followup/Progressing

Expediting or progressing ensures that the work is carried out as per plan and delivery schedules are met.

Progressing includes activities such as status reporting, attending to bottlenecks or holdups in production and removing the same, controlling variations or deviations from planned performance levels, following up and monitoring progress of work through all stages of production, co-ordinating with purchase, stores, tool room and maintenance departments and modifying the production plans and replan if necessary.

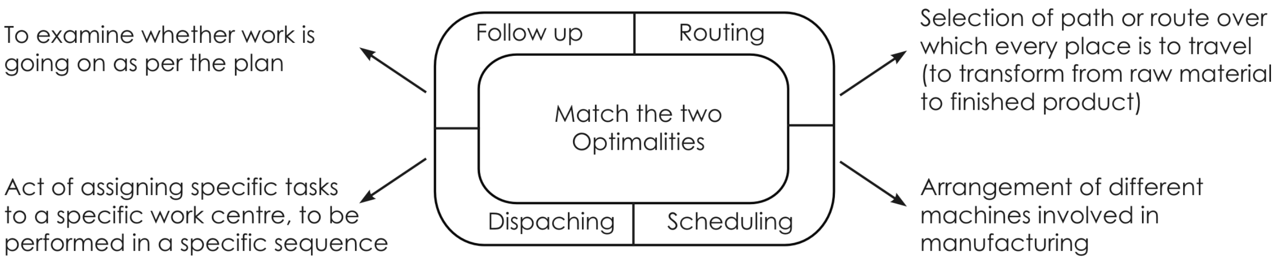


Fig. 2.1.1: Techniques of Production Control

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 ingredients that are proportionally related and handled one batch at a time.

Production Planning and Control in Different Production Systems

1. PPC in Job Production

Job production involves manufacture of products to meet specific customer requirements of special orders. The quantity involved is usually small. Examples of job production are manufacture of large turbo generators, boilers, steam engines, processing equipments, material handling equipments, ship building etc.

Under job production we may have three types according to the regularity of manufacture namely,

(a) A small number of products produced only once.

(b) A small number of products produced intermittently when the need arises.

(c) A small number of products produced periodically at known interval of time.

2. PPC in Batch Production

Batch production is the manufacture of a number of identical articles either to meet a specific order or to satisfy continuous demand. The decisions regarding tooling and jigs and fixtures are dependent on the quantities involved in the production batch.

In batch production too there can be three types namely:

(a) A batch produced only once.

(b) A batch produced repeatedly at irregular intervals, when the need arises.

(c) A batch produced periodically at known intervals, to satisfy continuous demand.

Here again planning and control become more simplified as quantities increase and as manufacture becomes more regular. Two problems that may arise in batch production are due to size of the batch and due to scheduling of production.

The solution to these problems depends on whether the production is governed by:

(a) External customer orders only.

(b) Whether the plant is producing for internal consumption i.e., a subassembly used in the final product.

3. P.P.C. in Continuous Production

Continuous production is normally associated with large quantities of production and with a high rate of demand. Continuous production is justified when the rate of production can be sustained by the market.

Two types of continuous production can be:

(a) Mass production (b) Flow production

In mass production, a large number of identical articles is produced, but inspite of advanced mechanization and tooling, the equipment need not be specially designed for the component to be manufactured.

In flow production, the plant and equipment and layout have been primarily designed to manufacture a particular product. A decision to switch over to a different kind of product needs basic changes in the equipments and the layout, especially when special purpose machines and complex material handling systems are used.

4. Production Planning and Control in Process Industry

PPC in process industry is relatively simple. Routing is automatic and uniform. Standard processes and specialised equipments are used. As the products are standardised and goods are produced to stock and sell, scheduling is easy. Departmental schedules are derived from master production schedules. Dispatching involves issue of repetitive orders to ensure a steady flow of materials throughout the plant. The main task of PPC in process industry is to maintain a continuous and uniform flow of work at the predetermined rate in order to utilise the plant and equipments fully and to complete the production in time.

Requirements of Effective Production Planning and Control System

1. Sound organizational structure with mechanism for proper delegation of authority and fixation of responsibility at all levels.
2. Information feedback system should provide reliable and up-to-date information to all persons carrying out PPC functions.
3. Standardisation of materials, tools, equipments, labour, quality, workmanship etc.
4. Trained personnel for using the special tools, equipments and manufacturing processes.
5. Flexibility to accommodate changes and bottle-necks such as shortage of materials, power failures, machine break downs and absenteeism of employees.
6. Appropriate management policies regarding production and inventory levels, product -mix and inventory turnover.
7. Accurate assessment of manufacturing lead times and procurement lead times.
8. Plant capacity should be adequate to meet the demand. The plant should be flexible in order to respond to the introduction of new products, changes in product-mix and production rate.

Limitations of PPC

(a) Production planning and control function is based on certain assumptions or forecasts of customers' demand, plant capacity, availability of materials, power etc. If these assumptions go wrong, PPC becomes ineffective.

(b) Employees may resist changes is production levels set as per production plans if such plans are rigid.

(c) The production planning process is time consuming when it is necessary to carry out routing and scheduling functions for large and complex products consisting of a large no. of parts going into the product.

(d) Production planning and control function becomes extremely difficult when the environmental factors change very rapidly such as technology, customers' taste regarding fashion or style of products needed, Government policy and controls stoppages of power supply by electricity boards due to power cuts, break in supply chain due to natural calamities such as floods, earthquakes, war etc.

PROBLEMS AND SOLUTIONS

Illustration 1:

Machines K and L, both capable of manufacturing an industrial product, compare as follows:

	Machine K	Machine L
Investment	₹60,000	₹1,00,000
Interest on borrowed capital	15%	15%
Operating cost (wages, power, etc.) per hour	₹12	₹10
Production per hour	6 pieces	10 pieces

The factory whose overhead costs are ₹1,20,000 works effectively for 4,000 hours in 2 shifts during the year.

(i) Justify with appropriate calculations which of the two machines you would choose for regular production.

(ii) If only 4000 pieces are to be produced in a year, which machine would give the lower cost per piece.

(iii) For how many pieces of production per year would the cost of production be same on either machine? (For above comparisons, the cost of material may be excluded as being the same on both machines.)

Solution:

	Machine K	Machine L
Annual interest charges (Fixed Cost)	(₹60,000 × 15) / 100 = ₹9,000	(₹1,00,000 × 15) / 100 = ₹15,000
Annual operating charges	4,000 × 12 = ₹48,000	4,000 × 10 = ₹40,000
Total annual charges	₹57,000	₹55,000
Annual output	4,000 × 6 = 24,000	4,000 × 10 = 40,000
Cost per unit	57,000 / 24,000 = ₹2.375	55,000 / 40,000 = ₹1.375

(i) Thus machine L should be chosen for regular production.

(ii) If only 4,000 pieces are to be produced in a year

Interest cost	₹9,000	₹15,000
Operating cost	(4,000 / 6) × 12 = ₹8,000	(4,000 / 10) × 10 = ₹4,000
Total cost	= ₹17,000	= ₹19,000
Cost per unit	(17,000 / 4,000) = ₹4.25	(19,000 / 4,000) = ₹4.75

Thus, machine K gives the lower cost per piece.

(iii)

Interest charge	= ₹9,000	= ₹15,000
Operating cost per piece	= 12 / 6 = ₹2	= 10/10 = ₹1

Let the production be = X units,

Then, 2X + 9,000 = X + 15,000 or, 2X - X = 15,000 - 9,000 or, X = 6,000 pieces.

For 6,000 pieces of production per year the cost of production will be the same (₹ 21,000) on either machine.

Illustration 2:

A department of a company has to process a large number of components/month. The process equipment time required is 36 minutes/component, whereas the requirement of an imported process chemical is 1.2 litres/component. The manual skilled manpower required is 12 minutes/component for polishing and cleaning. The following additional data is available:

	Availability/month	Efficiency of utilisation
Equipment hour	500	85%
Imported chemicals - Litres	1000	95%
Skilled manpower - hours	250	65%

(i) What is the maximum possible production under the current conditions?

(ii) If skilled man-power availability is increased by overtime by 20%, what will be the impact on production increase?

Solution:

(a) Actual Equipment Hrs. used = 500 × 85/100 = 425 Hrs.

Possible output = 425 × (60/36) = 708 Components

(b) Imported chemicals = 1,000 × 95/100 = 950 litres, actually used;

Possible output = 950/1.2 = 792 Components

(c) Skilled manpower Hrs. used = 250 × 65/100 = 162.5 Hrs.

Possible output =162.5 × (60/12) = 813 Components

The bottle-neck capacity = 708 Components.

(i) Maximum possible production under the given conditions = 708 Components.

(ii) There will be no impact on production increase if skilled manpower is increased by overtime by 20% as the bottle-neck in output is equipment hours.

Illustration 3:

A manufacturing enterprise has introduced a bonus system of wage payment on a slab-rate based on cost of production towards labour and overheads.

The slab-rate being

Between 1% - 10%	Saving in production cost	5% of saving
Between 11%-20%	Saving in production cost	15%
Between 21%-40%	Saving in production cost	30%
Between 41%-70%	Saving in production cost	40%
Above 70%	Saving in production cost	50%

The rate per hour for three workers A, B, C are ₹5, ₹5.50 and ₹5.25 respectively. The overhead recovery rate is 500% of production wages and the material cost is ₹40 per unit. The standard cost of production per unit is determined at ₹160 per unit.

If the time taken by A, B, C to finish 10 units is 26 hours, 30 hours and 16 hours respectively, what is the amount of bonus earned by the individual workers and actual cost of production per unit?

Solution:

Particulars	A	B	C
Unit produced	10	10	10
Wage rate/hr.	5.00	5.50	5.25
Time taken	26 hours	30 hours	16 hours
Wage payable	130.00	165.00	84.00
Overhead recovery	650.00	825.00	420.00
Materials	400.00	400.00	400.00
Total cost of production	1,180.00	1,390.00	904.00
Standard cost of production	1,600.00	1,600.00	1,600.00
Saving in cost of production	420.00	210.00	696.00
% of savings	26.25%	13.13%	43.50%
Bonus slab	30%	15%	40%
Bonus Amount	126.00	31.50	278.40
Actual cost of production	1,306.00	1,421.50	1,182.40
Cost/unit (₹)	130.60	142.15	118.24

Illustration 4:

Calculate the break-even point for the following:

Production Manager of a unit wants to know from what quantity he can use automatic machine against semi-automatic machine.

Data	Automatic	Semi-automatic
Time for the job	2 mts	5 mts
Set up time	2 hrs	1.5 hrs
Cost per hour	₹20	₹12

Solution:

Let x be the break-even quantity between automatic and semi-automatic machines. This means, for volume of output x, the total cost of manufacture is the same on both automatic and semi-automatic machines.

For quantity = x units

Total manufacturing cost on automatic machines = ₹ (2.0 + 2x/60)×20

Total manufacturing cost on semi-automatic machines = $\left(1.5 + \frac{5x}{60} \times 12\right)$

If 'x' is the break-even quantity, then

$$\left(2.0 + \frac{2x}{60}\right) \times 20 = (1.5 + 5x/60)\times 12$$

$$40 + \frac{2x}{60} \times 20 = 18 + \frac{5x}{60} \times 12$$

$$40 + \frac{2x}{3} = 18 + x$$

$$\frac{x}{3} = 22$$

x = 66 units

Hence for quantity upto 65, a semi-automatic machine will be cheaper. For quantity 66, both semi-automatic and automatic machines are equally costly. For quantity more than 66, automatic machine becomes cheaper than semi-automatic machine.

Illustration 5:

Machines A and B are both capable of manufacturing a product. They compare as follows:

Particulars	Machine A	Machine B
Investment	₹50,000	₹80,000
Interest on capital invested	15% per annum	15% per annum
Hourly charges (wages + power)	₹10	₹8
No. of pieces produced per hour	5	8
Annual operating hours	2,000	2,000

(i) Which machine will have the lower cost per unit of output, if run for the whole year?

(ii) If only 4,000 pieces are to be produced in a year, which machine would have the lower cost per piece?

(iii) Will your answer to (i) above query if you are informed that 12.5% of the output of machine B-gets rejected at the inspection stage. If so, what would be the new solution?

Solution:

(i)

Data	Machine A	Machine B
Annual interest charges	₹50,000 × $\frac{15}{100}$ = ₹7,500	₹80,000 × (15/100) = ₹12,000
Annual operating charges	₹10 × 2,000 = ₹20,000	₹ 8 × 2,000= ₹16,000
Total annual charges	7,500 + 20,000 = ₹27,500	12,000 + 16,000= ₹28,000
Annual production (units) for 2,000 hours	5 × 2,000 =10,000 nos.	8 × 2000=16,000 nos.
Cost per unit	$\frac{27,500}{10,000}$ = ₹2.75	$\frac{28,000}{16,000}$ ₹1.75

Machine 'B' gives the lower cost per unit if run for the whole year (for 2,000 hours).

(ii)

Data	Machine A	Machine B
Operating hours required for producing 4,000 nos	4,000/5 = 800 hrs	4,000/8 = 500 hrs
Operating charges	₹ 10 × 800 = ₹8,000	₹8 × 500 = ₹4,000
Interest charges	₹7,500	₹12,000
Total annual charges	8,000 + 7,500 = ₹15,500	4,000 + 12,000 = ₹16,000
Cost per unit	$\frac{15,500}{4,000}$ = ₹3.875	$\frac{16,000}{4,000}$ = ₹4

Machine 'A' gives lower cost per unit.

(iii) If 12.5% of output of Machine B is rejected, net annual production

From Machine B = $16,000 \times \frac{100 - 12.5}{100} = \frac{16,000 \times 87.5}{100}$ =14,000 nos.

Cost per unit = $\frac{28,000}{14,000}$ = ₹2

Even though, unit cost of production on Machine B increases from ₹1.75 to 2.0, still machine B continues to be cheaper, if used for 2,000 hours in the year.

Illustration 6:

Methods P and Q are both capable of manufacturing a product. They compare as follows:

Data			Method P	Method Q
Fixture	-	cost	₹24,000	₹16,000
	-	life	6 months	4 months
Tooling	-	cost	₹2,560	₹4,800
	-	life	300 pieces	500 pieces
Processing time per piece			6 mts.	4 mts.

The annual requirement is 1,500 nos. Operating cost per hour of the process is ₹128 for both processes. Material cost is same in each case.

Which method would you choose for production during a period of one year?

Solution:

Data	Method P	Method Q
Cost of manufacture per year:		
Fixture cost	₹ 24,000 × 2 = ₹ 48,000	₹ 16,000 × 3 = ₹ 48,000
(2 nos of fixtures are required per year in method P and 3 nos required in method Q)		
Tooling cost	$2,560 \times \frac{1,500}{300} = 2,560 \times 5$ = ₹12,800	$4,800 \times \frac{1500}{500} = 4800 \times 3 =$ ₹14,400
Operating hours to produce 1,500 nos.	1,500 × 6/60 =150 hrs	1,500 × 4/60 =100 hrs
Operating cost per year	₹128 × 150 = ₹19,200	₹128 × 100 = ₹12,800
Total manufacturing cost per year	₹48,000 + ₹12,800 + ₹19,200 = ₹80,000	₹48,000 + ₹14,400 + ₹12,800 = ₹75,200

Since method Q is cheaper than method P, method 'Q' is the choice for production during the whole one year period.

Illustration 7:

Two alternative set-ups, A and B are available for the manufacture of a component on a particular machine, where the operating cost per hour is ₹20.

Particulars	Set-up A	Set-up B
Components/set-up	4,000 pieces	3,000 pieces
Set-up cost	₹ 300	₹ 1500
Production rate/hour	10 pieces	15 pieces

Which of these set-ups should be used for long range and economic production?

Solution:

Considering one set-up

Particulars	Set-up A	Set-up B
Set-up cost per year	₹300	₹1,500
Operating hours	$\frac{4,000}{10}$ = 400 hours	$\frac{3,000}{15}$ = 200 hours
Operating cost	₹8,000	₹4,000
Total manufacturing cost	300 + 8,000 = ₹8,300	1,500 + 4,000 = ₹5,500
Manufacturing cost/piece	$\frac{8,300}{4,000}$ = ₹2.057	$\frac{5,500}{3,000}$ = ₹1.833

Assuming that the machine is used for production for one year having 2,000 hours of working.

For annual production,

Particulars	Setup A	Setup B
No. of set-ups	$\frac{2,000}{400}$ =5	$\frac{2,000}{200}$ =10
Set-up cost per year	5 × 300 = ₹1,500	10 × 1,500 = ₹15,000
Operating cost	2,000 × ₹20 = ₹40,000	2,000 × ₹20 = ₹40,000
No. of units produced/year	2,000 × 10 = 20,000 nos.	2,000 × 15 = 30,000 nos.
Total annual manufacturing cost	₹1,500 + 40,000 = ₹41,500	₹15,000 + 40,000 = ₹55,000
Manufacturing cost/unit	$\frac{41,500}{20,000}$ = ₹2.075	$\frac{55,500}{30,000}$ = ₹1.85

Since the manufacturing cost for set B is less, use setup B for long range and economic production.

2.2 ECONOMICS AND OPTIMIZATION

Optimization – the backbone of Economics

Optimizing behavior is one of the basic postulates of traditional Micro economics, according to which an "economic actor" is necessarily an economic man, that is, a person who always takes rational decisions with respect to economic matters. The rationality is defined in terms of optimizing behavior. For example, a household would always try to maximize utility; a producer would maximize output at minimum cost; a firm would aim to maximize profits or market share; and so on.

The job of such an economic man has been facilitated by economic theory with manifold assumptions, which, as discussed earlier, bestow him with an omnipotent character. The assumption of perfect knowledge, for example, makes him omniscient, possessing all information that is required for decision making. He knows the values of marginal revenue and marginal cost and is meticulous enough to calculate his profit-maximizing output. He is also capable of producing such an output and the resources required to produce the requisite level of output are at his command. Post-production problem such as warehousing space and inventory costs too do not trouble him.

Moreover, the economic man is able to sell all his profit-maximizing output. This is possible only if the omnipotent seller has well-developed distribution channels for the smooth transfer of output from producer to consumers; his consumers also possess perfect knowledge of the market and Say's Law of market is fully operative. In short, economic theory believes in "unbounded maximizing behaviour, and the whole theoretical infrastructure is geared to achieve the objectives based on the same. It is, therefore, natural that economic literature is exceptionally rich in optimization models.

Constraint Optimization – A

There have been some deviations from such a practice, where economists have suggested the achievement of an objective subject to a constraint such as the following:

1. **Baumol's model** of "sales maximization subject to a profit constraint" and its opposite "maximization of short-run profits subject to a minimum sales or market share constraint" is summarized as below:

   Total Revenue (R) = f_1 (X, a)

   Where X = output

   a = advertisement.

   Total Production Cost (C)= f_2 (X)

   Π = minimum acceptable profit

   A(a) = total cost of the advertising function

   A firm aims at the maximization of

   $$R = f_1 (X, a)$$

   Subject to the minimum profit constraint

   $$\Pi = R - C - A \geq \Pi$$

   Its variant with Yarrow's constraints suggests sales maximization subject to a maximum market valuation due to wealth maximizing shareholders.

2. **Williamson's model** suggests the maximization of managerial utility subject to a minimum profit after tax. This is summarized below.

   $$\text{Max } U = U (S, M, I)$$

Subject to

$$\Pi R > \Pi \min + T$$

Where S = excess expenditure on staff

M = management slack

I = discretionary investment expenditure

and, $S = \Pi \max - \Pi A$

= Maximum profit – Actual profit

$M = \Pi A - \Pi R$

= Actual profit – Reported profit

$I = \Pi R - \Pi \min - T$

= Reported profit – Minimum profit acceptable to shareholders – Total taxes.

3. **Marris's growth model** suggests a balanced growth rate between the rate of growth demand (g_b) and rate of growth of capital (g_c). Managers would like to maximize their utility (U_m) which is dependent on the growth of demand (g_b), whereas shareholders' utility (U_o) will depend on the growth of capital (g_c). The overall growth of the firm can be maximized subject to these two being balanced.

$$g_{max} = g_b = g_c$$

subject to a security constraint = a

Marris's model can be summarized as follows:

Demand growth $g_b = f_1 (m, d)$

m = average profit margin

d = rate of diversification

Profit $\Pi = f_4(m,d)$

Capital growth $g_c = a\,[f_4 (m, d)]$

$a < a^*$ (a saturation level of security constraint)

$g_b = g_c$

$f_1 (m, d) = a\,[f_4 (m, d)]$

However, these modifications do not change the nature of the analysis. They may be called non-profit maximizing models but the maximizing behavior still remains an implied assumption.

Price Mechanism and Optimal Resource Allocation

It is generally believed that the price mechanism always leads to the optimal allocation of resources. Since the market is characterized by perfect competition (which means perfect knowledge and perfect mobility), price signals would move fast enough to take corrective decisions and actions on the part of consumers and producers. Therefore, there will always be a tendency towards equilibrium. It would be better to make a distinction between a free market economy and a capitalist economy. A free market economy is always characterized by perfect competition whereas capitalism, a real life case, embraces all forms of competition-perfect and imperfect. The free market economy, characterized by perfect competition, is supposed to lead to the optimal allocation of resources.

Another important assumption relates to the industrial structure and behaviour, according to which it is the number of firms that determines the nature of the market such as monopoly, oligopoly, and so on. No efforts were made to explain what determined such a market. The interaction between structure and behaviour was studied but it was only one-sided, it studied only the impact of structure on behaviour, not vice versa. However, recent advances in analysis explicitly recognize that the "market structure is, in fact, not determined by unidentifiable and indescribable forces but is the product of workings of the free market, the technological circumstances of the industry in question and the economic forces that impinge upon it. Indeed there is a feedback relationship between the structure of the industry and its behaviour……".

In the traditional analysis, economics of scale are considered to be the basic barriers to entry. They are also considered to be harmful because they restrict competition. Recent analysis, however, suggests that technological factors, particularly huge amounts required to set up such industries, act as barriers to entry. According to this approach, if the amounts required for fixed investments (sunk costs) were freely transferable to other uses or were disposable, the entrants would be hitting the industry at a time when profits are high, wipe out profits, and run away. In Baumol's barrier and the main type of entry cost that really does impede the workings of the market mechanism and serves as a haven for monopolistic or oligopolistic behaviour using tools such as predation, pre-emption and strategic counter measures".

The nature of the industry also plays an important role in determining the impact of numbers and size on the degree of competition. The technology that is used will determine whether small or big firms will be more efficient in an industry.

Economic Problems and Optimization Techniques

The process of finding, the best or optimal strategies is called optimization and includes the problems related to both maximization and minimization. Mathematical techniques employed in finding optimal strategies are called optimization techniques. The first condition for such techniques to be useful is that economic relationships or functions are expressed in algebraic form which, in turn, demands that objectives are well defined and transformed into targets. These objectives have to be optimized under two conditions: (a) without any constraints and (b) with constraints. They can be divided further.

1. **Unconstrained optimization** into (i) functions with the (independent) variable and (ii) multi-variate functions.
2. **Constrained optimization** into (i) equality constrained optimization, (ii) inequality constrained optimization, (iii) static optimization (Kuhn-Tucker conditions), and (iv) dynamic optimization (Hamiltonian conditions)

Equality constrained problems can, again, be of two kinds. In Economics, the popular examples are: (a) the maximization of the utility subject to a budget constraint and (b) the minimization of the cost subject to a production (technology) constraint or maximization of output subject to a resource (cost) constraint. Here, the problems expressed are usually with one constraint and the technique used is the Lagrangian multiplier. More than one multiplier has to be incorporated for multiple constraints. If the constraints are expressed in the form of inequalities, the most popular technique used is linear programming. The lagrangian technique is also used by seeking complementary slackness relationships. These models and techniques can be summarized as in **Table 2.2.1.**

Role and Limitations of Techniques in Economic Analysis

The optimization techniques mentioned in **Table 2.2.1**, are, in fact, products of gradual development over a period of time. They have filled in one or the other gap by proposing a technique which helps to solve problems of optimization with relaxation of one or more of their assumptions; and, thus, carry economic analysis a bit closer to real life. Linear programming, for example, removed one of the fundamental assumptions of neo-classical economics, that is, unbounded maximization and brought it closer to real life situations where economic actors have to optimize under given constraints.

Table 2.2.1 Optimization Techniques

Economic model	Example	Optimization technique
1. Unconstrained Optimization (a) A single variable without constraint (b) a multi-variate function without constraints	Max R or sales = f (P) Minimize C = f(x) Max π (R – C) = f(x) Max π = f (price and adv)	Differential calculus First derivative should be equal to zero. Partial derivative with respect to one variable assuming other as constant.
2. Constrained optimization (a) With Equality constraint (b) With Inequality constraints	(a) Max utility subject to a budget constraint. Minimize cost subject to a production function. (b) Max profit subject to energy, budget capacity, or time constraints	(a) Lagrangian multipliers (b) Linear programming and its extensions.
3. Optimization with multiple goals	Max more than one objective in order of sequence	(i) Multi-criteria decision making (ii) Goal programming (as one of the techniques)
4. Dynamic optimization	Max net profit stream; Max utility stream; Max social welfare in the presence of pollution from production	(i) Optimal control theory in the case of continuous time optimization problems. (ii) Dynamic programming in the case of discrete-time optimization problems.

But Linear programming itself suffered from several limitations:

1. It assumes all functions to be linear which implies perfect competition. Take, for example, the maximization of profit, sales, or revenue. When an objective function is expressed in a linear form, if is assumed that all the output can be sold at a given (constant) price. This is possible only when a firm faces "Horizontal Straight Line" demand curve, a feature of perfect competition.
2. It deals with a single objective and given constraints.
3. It is confined to non-negative values only.
4. It accepts rational values, which sometimes an awkward situation. For example, it may be difficult to acquire half a machine or truck or warehouse.
5. It is a "deterministic" technique, which means that the values of all the variables and all the coefficients must be known with certainty.
6. There are several practical limitations particularly related to: (a) difficulties in calculation and (b) the exorbitant cost of gathering data.
7. It also suffers from several other limitations common to operations research techniques as a group.

PROBLEMS OF OPTIMIZATION IN ECONOMICS

Illustration 1:

A firm's total cost function is $C = \frac{1}{3}q^3 - 7q^2 + 111q + 50$ and the demand function is $q = 100 - p$ [C = total cost, q = level of output and p = price]. Determine the profit maximising level of output and the amount of maximum profit.

Solution:

Suppose total revenue of the firm is R and total profit is π. Now, from the demand function we get,

$q = 100 - p$, or, $p = 100 - q$

$R = pq = (100 - q)q = 100q - q^2$

$\therefore \pi = R - C = 100q - q^2 - (1/3q^3 - 7q^2 + 111q + 50)$

or $\pi = -1/3q^3 + 6q^2 - 11q - 50$.

The first order condition to maximise π requires $\frac{d\pi}{dq} = 0$

$\therefore -q^2 + 12q - 11 = 0$

or, $q^2 - 12q + 11 = 0$

or, $(q - 1)(q - 11) = 0$

$\therefore q = 1$ or $q = 11$.

Thus the first order condition is fulfilled for two values of q. The second order condition to maximise π it requires that

$\frac{d^2\pi}{dq^2} < 0$.

Now,

$\frac{d^2\pi}{dq^2} = -2q + 12$.

When $q = 1$, $\frac{d^2\pi}{dq^2} = -2q + 12 = -2 + 12 = 10 > 0$.

When $q = 11$, $\frac{d^2\pi}{dq^2} = -2q + 12 = -22 + 12 = -10 < 0$.

So, when $q = 11$, $\frac{d\pi}{dq} = 0$ and $\frac{d^2\pi}{dq^2} < 0$ i.e., both the first order and the second order conditions are fulfilled. Hence, profit will be maximum when q = 11. Now, putting q = 11 in the profit function we get the value of maximum profit.

Maximum profit $= -1/3(11)^3 + 6(11)^2 - 11(11) - 50$

$= 111.33$

Alternative solution: Profit will be maximum when (i) MR = MC and (ii) slope of MC > slope of MR.

Now, our demand function is $q = 100 - p$

$\therefore p = 100 - q$.

So, $R = p.q = 100q - q^2$

$\therefore MR = \frac{dR}{dq} = 100 - 2q$.

Again, $C = \frac{1}{3}q^3 - 7q^2 + 111q + 50$

$\therefore$ MC = $\frac{dC}{dq}$ = q^2 -14q + 111

Putting MR = MC, we get, $q^2 - 14q + 111 = 100 - 2q$

$\therefore$ $q^2 - 12q + 11 = 0$, or, (q - 1) (q - 11) = 0

$\therefore$ q = 1 or q = 11.

We have to see where the second order condition is fulfilled.

Slope of MR = $\frac{d(MR)}{dq}$ = -2.

Again, slope of MC = $\frac{d(MC)}{dq}$ = 2q - 14

When q = 1, slope of MC = 2 - 14 = - 12 < slope of MR.

When q = 11, slope of MC = 2 x 11-14= 8 > slope of MR.

Thus the second order condition is fulfilled if q = 11.

So profit is maximum when the level of output is 11.

Now, putting q = 11 in the total revenue function,

$R = 100q - q^2 = 100 \times 11 - 11^2 = 1100 - 121 = 979$

Similarly, C = $\frac{1}{3}q^3 - 7q^2 + 111q + 50$

$= 1/3(11)^3 - 7(11)^2 - 111(11) + 50 = 867.67$ (Approx.)

$\therefore$ Maximum profit = 979 - 867.67 = 111.33 (Approx.)

Illustration 2:

A radio marmfacturer makes x sets of radio per week and total cost is $\left(\frac{x^2}{25} + 3x + 100\right)$. The equation of the demand function is x = 75 - 3p (p = price). Show that if he wants to maximise profit, he will produce about 30 sets of radio per week. What price per set will he charge ?

Solution :

[We can follow either of the two methods shown above. Here we follow the alternative method]

Suppose total costs C and total revenue is R. So, C = $\left(\frac{x2}{25} + 3x + 100\right)$ and R = px

$= \left(\frac{75 - x}{3}\right).x = 25x - \frac{x^2}{3}$

Now, MC = $\frac{dC}{dx} = \frac{2x}{25} + 3$ and $MR = \frac{dR}{dx} = 25 - \frac{2x}{3}$

The first order condition to maximise profit is MR = MC or, $25 - \frac{2x}{3} = \frac{2x}{25} + 3$

or, $\frac{2}{25}x + \frac{2}{3}x = 25 - 3$

56 r>n

or, $\frac{56}{75}x = 22$

$\therefore$ x = $\frac{22 \times 75}{56}$ = 29.5 or 30 (approx.)

The second order condition to maximise profit requires, slope of MC > slope of MR.

Now, slope of MC = $\frac{d(MC)}{dx} = \frac{2}{25}$

and slope of MR = $\frac{d(MR)}{dx} = -\frac{2}{3}$. As $\frac{2}{25} > -\frac{2}{3}$, the second order condition is also fulfilled.

So, to maximise profit, the firm will produce 30 radio sets per week.

Price (p)= $\frac{75 - x}{3} = \frac{75 - 30}{3} = 15$

So, price per set = ₹ 15.

Illustration 3:

The demand function of a firm is q = 200 – 10 p and the average cost function is AC = 10 + $\frac{q}{25}$.

If the firm's objective is to maximise profit, what will be its, profit maximising output?

Solution :

Here the equation of the demand curve is

$q = 200 - 10\,p$

or, $10\,p = 200 - q$

or, $p = \frac{200 - q}{10} = 20 - \frac{1}{10}q$

So, total revenue (R) = pq = $20q - \frac{1}{10}q^2$

$\therefore$ Marginal revenue (MR) = $\frac{dR}{dq} = 20 - \frac{1}{5}q$

Again, AC = $10 + \frac{q}{25}$

$\therefore$ Total cost (C) = AC x q = $10q + \frac{q^2}{25}$

$\therefore$ Marginal cost $\left(\frac{dC}{dq}\right) = 10 + \frac{2}{25}q$

Now, the first order condition for profit maximisation requires, MR = MC.

$\therefore 20 - \frac{1}{5}q = 10 + \frac{2}{25}q$

or, $\frac{1}{5}q + \frac{2}{25}q = 20 - 10$

or, $\frac{7}{25}q = 10 \therefore q = \frac{10 \times 25}{7} = \frac{250}{7}$

The second order condition requires that slope of MC > slope of MR.

Now, slope of MR = $\frac{d\,(MR)}{dq}$ = -1/5 < 0 and slope of MC = $\frac{d\,(MC)}{dq} = \frac{2}{25}$ > 0. So the second order condition is fulfilled.

Hence, to get maximum profit, the firm will produce $\frac{250}{7}$ units of output.

Illustration 4:

Unit price of a commodity produced by a company is ₹2. The cost function of the company is C = $1000 + \frac{1}{2}\left(\frac{q}{50}\right)^2$ where q is the level of output. How many units of the commodity will the company produce in order to maximise profit?

Solution:

Here p = 2. $\therefore$ Total revenue (R) = pq = 2q

Now, total profit (π) = R - C

$$\text{or, } (\pi) = 2q - 1000 - \frac{1}{2}\left(\frac{q}{50}\right)^2 = 2q - 1000 - \frac{q^2}{5000}$$

The first order condition to maximise π requires $\frac{d\pi}{dq} = 0$

$$\text{or, } 2 - \frac{q}{2500} = 0 \text{ or, } q = 5{,}000.$$

The second order condition requires that $\frac{d^2\pi}{dq^2} < 0$.

Now, $\frac{d^2\pi}{dq^2} = -\frac{1}{2500} < 0$.

$\therefore$ The second order condition is fulfilled.

So, to maximise profit the firm will produce 5,000 units of the commodity.

Illustration 5:

The total cost function of a firm is $C = \frac{1}{3}x^3 - 5x^2 + 28x + 10$ (x = level of output) and the demand function is p = 2530 — 5x (p = price). A tax of ₹ 2 per unit is imposed. The firm adds this tax to total cost. How many units of output should be produced by the firm in order to maximise profit ?

Solution:

Here total revenue (R)= px = (2530 - 5x)x = $2530x - 5x^2$ and total cost (C) = $1/3x^3 - 5x^2 + 28x + 10 + 2x$

$\therefore$ Profit (π) - R - C = $2530x - 5x^2 - 1/3x^3 + 5x^2 - 30x - 10$

or, $\pi = -1/3x^3 + 2500x - 10$.

The first order condition to maximise π requires $\frac{d\pi}{dx} = 0$

or, $-x^2 + 2500 = 0$ or, $x^2 = 2500$,

$\therefore$ $x = \pm 50$.

The second order condition requires that $\frac{d^2\pi}{dx^2} < 0$. Here $\frac{d^2\pi}{dx^2} = -2x$. So $\frac{d^2\pi}{dx^2} < 0$ if x = 50

So, to maximise profit the firm will produce 50 units of output.

Alternatively, as $x \geqslant 0, x = 50$

Illustration 6:

The demand curve faced by a firm is p = 20 - 4x and the cost function is C = 4x (where p = price, x = output, and C = total cost).

(i) Determine the optimum level of output, price and maximum profit if the objective of the firm is to maximise profit.

(ii) What will be the new price if a unit tax of ₹ 0.50 is imposed?

(iii) Determine the rate of unit tax so that tax revenue is maximum.

Solution :

(i) Suppose R = total revenue and π = total profit.

Then $R = px = (20 - 4x)x = 20x - 4x^2$

$\therefore \pi = R - C = 20x - 4x^2 - 4x = 16x - 4x^2$

To maximise π, the first order condition requires, $\frac{d\pi}{dx} = 0$.

So, $\frac{d\pi}{dx} = 16 - 8x = 0$

or, $8x = 16$,

or, $x = \frac{16}{8} = 2$.

The second order condition requires that $\frac{d^2\pi}{dx^2} < 0$. Here,

$\frac{d^2\pi}{dx^2} = -8 < 0$. So the second order condition is fulfilled.

So, x = 2. Then p = 20 -4 x 2 = 20 – 8 =12

The amount of maximum profit $\pi = 16(2) - 4(2)^2 = 32 - 16 = 16$.

(ii) When tax per unit is ₹ 0.50, net profit (N) = $20x - 4x^2 - 4x - 0.5x$

or, $N = 15.5x - 4x^2$

To maximise N, the first order condition requires $\frac{dN}{dx} = 0$

or, $15.5 - 8x = 0$

or, $8x = 15.5$

$\therefore x = \frac{15.5}{8} = 1.9375$

Here $\frac{d^2N}{dx^2} = -8 < 0$. So the second order condition is fulfilled. $\therefore x = 1.9375$.

When x = 1.9375, p = 20 - 4(1.9375) = 20 - 7.75 = 12.25.

(iii) Let the tax per unit be t.

Then, net profit $N = 20x - 4x^2 - 4x - tx = 16x - 4x^2 - tx$

To maximise N, $\frac{dN}{dx} = 0$ and $\frac{d^2N}{dx^2} < 0$

Now, $\frac{dN}{dx} = 16 - 8x - t = 0$

or, $8x = 16 - t$

$\therefore x = \frac{16-t}{8} = 2 - \frac{t}{8}$

$\frac{d^2N}{dx^2} = -8 < 0$ i.e., the second order condition is fulfilled.

$\therefore x = 2 - \frac{t}{8}$. Now, total revenue $T = tx = t(2 - \frac{t}{8}) = 2t - \frac{t^2}{8}$

To maximise T, the first order condition requires

$\frac{dT}{dt} = 0$ and $\frac{d^2T}{dt^2} < 0$

Now, $\frac{dT}{dt} = 2 - \frac{2t}{8} = 0$

or, $\frac{t}{4} = 2$

$\therefore t = 8$

Again $\frac{d^2T}{dt^2} = -\frac{2}{8} < 0$. So the second order condition is fulfilled. Hence tax revenue will be maximum if t = 8.

Illustration 7:

The cost function of a monopolist is $C = ax^2 + bx + c$ and the demand function is $p = \alpha - \beta x$. A unit tax t is imposed on sale. The monopolist seller adds this tax to production cost

(i) Determine the price and output of the monopolist before and after the imposition of the unit tax.

(ii) Show that total tax revenue will be maximum if $t = \frac{1}{2}(\alpha - b)$

Solution:

(i) Profit of the monopolist before the imposition of tax,

$\pi = px - C = (\alpha - \beta x)x - ax^2 - bx - c$

or, $\pi = \alpha x - \beta x^2 - ax^2 - bx - c$.

To maximise π, the first order condition requires, $\frac{d\pi}{dx} = 0$

or, $\alpha - 2\beta x - 2ax - b = 0$

or, $2(\beta + a)x = \alpha - b$. $\therefore x = \frac{\alpha - b}{2(\beta + a)}$

This is the level of output before the imposition of tax. Price before tax is

$$P = \alpha - \beta x = \alpha - \frac{\beta(\alpha - b)}{2(\beta + a)}$$

$$\frac{2\alpha\beta + 2\alpha a - \alpha\beta - b\beta}{2(\beta + a)} = \frac{\alpha\beta + 2\alpha a + b\beta}{2(\beta + a)}$$

When a unit tax t is imposed, total cost is $C = ax^2 + bx + c + tx$

Suppose profit after tax is N.

Then $N = \alpha x - \beta x^2 - ax^2 - bx - c - tx$

Now, to maximise N, the first order condition is $\frac{dN}{dx} = 0$,

i.e., $\alpha - 2\beta x - 2ax - b - t = 0$

or, $2(\beta + a)x = \alpha - b - t$

$\therefore x = \frac{\alpha - b - t}{2(\beta - \alpha)}$

This is the amount of sale after the imposition of tax. Price after the' imposition of tax is

$$P = \alpha - \frac{\beta(\alpha - b - t)}{2(\beta + a)}$$

$$= \frac{2\alpha\beta + 2\alpha a - \alpha\beta + b\beta + t\beta}{2(\beta + a)}$$

$$= \frac{\alpha\beta + 2\alpha a + b\beta + t\beta}{2(\beta + a)}$$

(ii) Suppose the tax revenue is T.

$$\therefore T = tx = \frac{t(\alpha - b - t)}{2(\beta + a)} = \frac{\alpha t - bt - t^2}{2(\beta + a)}$$

The amount of tax revenue (T) depends on the rate of tax (t).

The tax revenue will be maximum when $\frac{dT}{dt} = 0$.

i.e.,

$$\frac{\alpha - b - 2t}{2(\beta + a)} = 0$$

$\therefore \alpha - b - 2t = 0.$

or, $2t = \alpha - b$

$\therefore t = \frac{1}{2}(\alpha - b)$

Here $\frac{d^2T}{dt} = -\frac{2}{2(\beta + a)} < 0$. So the second order condition is also fulfilled. Hence, tax revenue will be maximum when $t = \frac{1}{2}(\alpha - b)$ (Proved).

Illustration 8:

A radio manufacturer makes x sets of radio per week. His cost function is $C = x^2 + 78x + 2500$. He is a monopolist seller and his demand function is $x = \frac{600 - p}{8}$. How many radio sets should he produce in order to maximise profit? What will be the price?

Solution :

The demand function is, $x = \frac{600 - p}{8}$

$\therefore$ p = 600 - 8x. So, total revenue $R = px = 600x - 8x^2$

Now, total profit $(\pi) = R - C = 600x - 8x^2 - x^2 - 78x - 2500$. $\therefore \pi = 522x - 9x^2 - 2500$.

To maximise , the first order condition is $\frac{d\pi}{dx} = 0$

or, $522 - 18x = 0$ or, $18x = 522$ $\therefore x = \frac{522}{18} = 29$.

The second order condition requires $\frac{d^2\pi}{dx^2} < 0$. Here, $\frac{d^2\pi}{dx^2} = -18 < 0$.

Thus the second order condition is also fulfilled. So profit is maximum when the level of output x = 29 units. Then price p = 600 – 8x = 600 - 8 x 29 = 600 - 232 = 368. So, price per unit is ₹368.

Illustration 9:

The equation of the demand function of a commodity is x = 1/3(25-2p). If the average cost of the commodity is ₹40 then in terms of p (i) express total revenue (ii) express total cost (iii) express total profit, (iv) Determine the price at which profit is maximum.

Solution :

(i) Suppose total revenue = R

$\therefore$ $R = px = p1/3(25 - 2p) = \dfrac{25p - 2p^2}{3}$

(ii) Suppose total cost = C

$\therefore C = 40x = \dfrac{40}{3}(25 - 2p) = \dfrac{1000 - 80p}{3}$

(iii) Suppose total profit = π.

Now, $\pi = R - C = \dfrac{25p - 2p^2}{3} - \dfrac{1000 - 80p}{3}$.

$= \dfrac{1}{3}(25p - 2p^2 - 1000 + 80p)$

$\therefore \pi = \dfrac{1}{3}(105p - 2p^2 - 1000)$

(iv) To maximise π the first order condition is, $\dfrac{d\pi}{dp} = 0$ i.e., 1/3(105 - 4p) = 0 or, 105 - 4p = 0,

or, 4p = 105

$p = \dfrac{105}{4} = 26.25$. The second order condition requires that $\dfrac{d^2\pi}{dp^2} < 0$.

Here $\dfrac{d^2\pi}{dp^2} = -\dfrac{4}{3} < 0$.

So, to maximise profit, price should be ₹ 26.25.

Illustration 10:

The demand function of a commodity is, p=500-0.2x and the cost function is, C=25x +10,000 (p= price, x =output, C= total cost). For what value of x, is profit maximum? What will then be the price?

Solution :

Here p =500 - 0.2x $\quad\therefore R = px = 500x – 0.2x^2$

$\therefore MR = \dfrac{dR}{dx} = 500 - 0.4x$. $MC = \dfrac{dC}{dx} = 25$.

The first order condition for profit maximisation requires,

MR = MC

$\therefore 500 - 0.4x = 25$

$\therefore 0.4x = 500 - 25 = 475$

$\therefore x = 475 \times \dfrac{10}{4} = 1187.50$

The second order condition requires that slope of MC > slope of MR. Here, slope of MC = 0 and slope of MR = - 0.4. So the second order condition is fulfilled. Hence x = 1187.5.

Then p = 500 - 0.2 x 1187.50 = 500 - 237.50 = 262.50.

So, price will be ₹262.50.

Illustration 11:

If demand curve of a commodity is p = 20 - q and the equation of the total cost curve is C = q^2 + 8q + 2, answer the following questions:

(i) For what output will profit be maximum? What will be the price, profit and sales then?

(ii) For what value of q, will sales (in terms of money) be maximum? What will be the price, profit and sales then?

(iii) If profit does not fall below ₹8, What will be the level of output in order to maximise sales. What will be the price, profit and sales then?

Solution :

(i) Suppose total sales revenue or total revenue = R and total profit = π

$\therefore\ \pi = R - C = pq - C.$

or, $\pi = (20 - q)q - q^2 - 8q - 2$

$= 20q - q^2 - q^2 - 8q - 2 = -2q^2 + 12q - 2$

The first order condition to maximise π requires

$\frac{d\pi}{dq} = 0$

or, $-4q+12 = 0 \therefore q=3$

The second order condition is $\frac{d^2\pi}{dq^2} < 0$.

Here, $\frac{d^2\pi}{dq^2} = -4 < 0$. So, q = 3.

When q = 3, p = 20 - q = 20 - 3 = 17.

R = pq = 3 x 17 = 51

$\pi = -2q^2 + 12q - 2 = -2(3)^2 + 12(3) - 2 = 16.$

(ii) Total sales revenue (R) = pq = (20 - q)q = $20q - q^2$.

To maximise R, the first order condition requires, $\frac{dR}{dq} = 0$,

or, 20 – 2q = 0

$\therefore$ q = 10. The second order condition requires, $\frac{d^2R}{dq^2} < 0$.

Here, $\frac{d^2R}{dq^2} = -2 < 0.\ \therefore q=10$

When q = 10, p = 20 - q = 20 - 10 = 10

R = pq = 10 X 10 = 100

$\pi = -2q^2 + 12q - 2 = -2(10)^2 + 12(10) - 2 = -82$

(iii) The firm's profit should be ₹ 8. Total revenue is to be maximised subject to this profit. Let us see when the firm can get a profit of ₹ 8.

When $\pi = 8$, or, $-2q^2 + 12q - 2 = 8$

or, $2q^2 - 12q + 10 = 0$ or, $q^2 - 6q + 5 = 0$

or, $(q - 1)(q - 5) = 0 \therefore q = 1$ or, $q = 5$

When $q = 1$, $p = 20 - 1 = 19$ and $R = pq = 1 \times 19 = 19$.

When $q = 5$, $p = 20 - 5 = 15$ and $R = pq = 15 \times 5 = 75$.

So, when $q = 5$, sales revenue (R) is maximum.

Then $p = 15$ and $\pi = 8$.

Illustration 12:

The equation of the demand curve of a firm is $p = 12 - 0.4q$ and the equation of the total cost curve is $C = 0.6q^2 + 4q + 5$

(i) Determine price, output, total revenue and profit if the objective of the firm is to maximise profit.

(ii) Determine price, output, profit and total revenue if the objective of the firm is to maximise revenue.

(ii) Determine output, price and total revenue if the objective of the firm is to maximise revenue subject to a minimum profit of ₹10.

Solution:

(i) Suppose total revenue = R and total profit = π

So, $\pi = R - C = pq - C$

or, $\pi = (12 - 0.4q)q - (0.6q^2 + 4q + 5)$

$= 12q - 0.4q^2 - 0.6q^2 - 4q - 5$

$= - q^2 + 8q - 5$.

The first order condition to maximise π requires, $\frac{d\pi}{dq} = 0$ or, $- 2q + 8 = 0$ or, $2q = 8$ or, $q = 4$

$\frac{d^2\pi}{dq^2} = - 2 < 0$. So the second order condition is also fulfilled.

Now, when $q = 4$,

$p = 12 - 0.4(4) = 12 - 1.6 = 10.40$

$R = pq = 10.4(4) = 41.6$ and $\pi = -(4)^2 + 8(4) - 5$

$= - 16 + 32 - 5 = 11$

(ii) $R = 12q - 0.4q^2$

To maximise R, the first order condition is $\frac{dR}{dq} = 0$

or, $12 - 0.8q = 0$, or, $0.8q = 12 \therefore q = 12 \times \frac{10}{8} = 15$

$\frac{d^2R}{dq^2} = - 0.8 < 0$. So the second order condition is also fulfilled.

When $q = 15$, $p = 12 - 0.4(15) = 6$

$\therefore R = pq = 6 \times 15 = 90$.

$\pi = -(15)^2 + 8(15) - 5 = -225 + 120 - 5 = 120-230 = -110$

(iii) When revenue is maximum, the firm is not getting the minimum profit. Let us see when the firm can get the minimum profit of ₹10. Putting π = 10,

we have, $- q^2 + 8q - 5 = 10$

i.e., $q^2 – 8q + 15 = 0$ or, $(q - 3) (q - 5) = 0$

$\therefore$ q = 3 or, q = 5

When q = 3, p = 12 - 0.4(3) = 12 - 1.2 = 10.8

and R = pq= 10.8 x 3 = 32.4.

When q = 5, p = 12 - 0.4(5) = 12 - 2 = 10

and R = pq = 10 x 5 = 50

$\therefore$ When q = 5, total revenue is maximum. Then p = 10,

R = 50 and π = 10

Illustration 13:

The equation of the demand curve of the firm is $p = 16-q + \frac{24}{q}$ and the equation of the total cost curve is C = 43 + 4q

(i) Determine output, price and profit if the objective of the firm is to maximise revenue.

(ii) Determine output, price and total revenue if the objective of the firm is to maximise revenue subject to a minimum profit of ₹16.

Solution:

(i) Total revenue $R = pq = (16-q + \frac{24}{q})q = 16q - q^2 + 24$.

The first order condition to maximise R requires $\frac{dR}{dq} = 0$ i.e.,16 - 2q = 0 or, 2q = 16

or, q = 8. Here $\frac{d^2R}{dq^2} = - 2 < 0$. So the second order condition is fulfilled. Hence, total revenue is maximum when q = 8. Then $p = 16 - 8 + \frac{24}{8} = 11$.

Maximum revenue =pq= 11x8 = 88

When q = 8, total cost C = 43 + 4q = 43 + 4(8) = 75

$\therefore$ π = R - C = 88 - 75 = 13.

(ii) The firm wants a minimum profit of ₹16. Let us see when the firm can get it.

$\pi = R - C = 16q – q^2 + 24 - 43 – 4q$.

$= - q^2 + 12q - 19$

Putting it = 16, we get, $- q^2 + 12q - 19 = 16$

or, $q^2 – 12q + 35 = 0$

or, (q - 5) (q - 7) - 0

$\therefore$ q = 5 or q = 7.

When q = 5, $R = 16q – q^2 + 24 = 16(5) - (5)^2 + 24 = 79$

When q = 7, $R = 16(7) - (7)^2 + 24 = 87$

So, R is maximum when q = 7.

Then, $P = 16 - 7 + \frac{24}{8} = 9 + \frac{24}{7} = \frac{87}{7}$,

Alternatively,

$P = \frac{R}{q} = \frac{87}{7}$ and $\pi = 16$.

Illustration 14:

The demand function of a monopolist is $p = \frac{3}{q}$ and the cost function is $C = 2q + 3q^2$. Will the monopolist produce the commodity if his objective is to maximise profit ?

Solution:

$\pi = R - C = pq - C = \frac{3}{q}.q - C$ Where , $\pi =$ Total Profit, R = Reunue & C = Cast

$\therefore\ \pi = 3 - 2q + 3q^3$

To maximise π, the first order condition is $\frac{d\pi}{dq} = 0$

or, $-2 - 6q = 0$, or, $6q = -2$ or, $q = -\frac{1}{3} < 0$.

But the level of output cannot be negative. So, the monopolist will not produce the commodity.

Illustration 15:

Demand function is $p = 12 - 4q$ and the cost function is $C = 8q - q^2$. Determine profit-maximising price and output and also the maximum profit.

Solution:

$\pi = R - C = pq - C = (12 - 4q)q - (8q - q^2)$

$\therefore\ \pi = 12q - 4q^2 - 8q + q^2 = -3q^2 + 4q$

To maximize π, the first order condition requires $\frac{d\pi}{dq} = 0$ or, $-6q + 4 = 0$ or, $6q = 4$.

$\therefore q = \frac{4}{6} = \frac{2}{3}$

The second order condition is $\frac{d^2\pi}{dq^2} < 0$

Here $\frac{d^2\pi}{dq^2} = -6 < 0$. So, π is maximum at $q = \frac{2}{3}$

Then $P = 12 - 4q = 12 - 4 \times \frac{2}{3} = \frac{28}{3}$

$\pi = -3q^2 + 4q = -3(\frac{2}{3})^2 + 4 \times \frac{2}{3}$

$= -\frac{4}{3} + \frac{8}{3} + = \frac{4}{3}$

2.3 STUDIES AT WORK PLACE

Work Study - Nature

Work study is concerned primarily with human manual work. Specifically, it deals with the efficient design and execution of manual work, and with the establishment of standards of performance. Work study is practised extensively in manufacturing, services, transport and supply industries. Some of the major developments in the subject took place in the service sector, e.g. in hospitals, and in transport. It has been a controversial subject. The principles were laid down many years ago; they still exist and are applied, but not without criticism. The work study practitioner, in whatever industry, will now be concerned with applying these principles in a sensitive and adaptable way, in particular taking into account work conditions, the characteristics of workers, and behavioural and organizational factors. Their application is relevant in most industrial and business sectors.

In planning the layout of facilities and methods and procedures for the handling of materials, etc., it will often be necessary to conduct some form of work study investigation. Wherever it is necessary to obtain estimates for the duration of activities for the purposes of scheduling, capacity management, work/worker allocation, incentive payments, etc., some form of work measurement will be needed. The study of work methods will be necessary for the development of training plans, for the design of workplaces, for the design of equipment, and in satisfying health and safety requirements at the workplace.

The structure and purposes of work study

The British Standards Institution defines work study as 'a generic term for those techniques, particularly method study and work measurement, which are used in the examination of human work in all its contexts, and which lead systematically to the investigation of all the factors which affect the efficiency and economy of the situations being reviewed, in order to effect improvements'.

The aims of work study are, by analysis of work methods and the materials and equipment used, to:

(a) establish the most economical way of doing the work;

(b) standardize this method, and the materials and equipment involved;

(c) establish the time required by a qualified and adequately trained worker to do the job while working at a defined level of performance;

(d) install this work method as standard practice.

Work study, then, is a comparatively low-cost way of either designing work for high productivity or improving productivity in existing work by improving current work methods and reducing ineffective or wasted time. In each case the design or improvements are sought within the context of existing resources and equipment; consequently work study is an immediate tool and is not dependent on the redesign of goods or services, research and development of operating processes, or extensive rearrangement of facilities.

We must apply the technique in circumstances from which we expect maximum returns The economic results of the study, whether they are increases in throughput, reduction in waste, improved safety, reduction in training time, or better use of equipment or labour should outweigh the cost of the investigation. To ensure this we should consider:

(a) the anticipated life of the job;

(b) whether manual work is an important part of the job, e.g. (1) the wage rate for the job, (2) the ratio of machine time to manual time in the work cycle;

(c) utilization of equipment, machines, tools, etc., the cost of such equipment, and whether the utilization is dependent on the work method;

(d) the importance of the job to the company.

We should distinguish between work study of existing jobs and that of proposed or anticipated jobs. Whenever new products or services are to be provided or new equipment used, jobs must be designed. Consequently the question is to what extent work study should be used and how much effort is justified by the importance of the job. Some investigation may be necessary on existing jobs, not necessarily because they were inadequately designed in the first place, but perhaps because there has been a slight change in the product or service, new equipment is being used, or wage rates or incentives are to be altered. Examinations of existing work methods could also result from low machine utilization, excessive labour overtime or idle time, complaints from the workers, inadequate quality, high scrap or wastage rate, etc.

Figure 2.3.1 shows the structure of work study. Two aspects exist: first, method study, concerned with establishing optimum work methods; and second, work measurement, concerned with establishing time standards for those methods.

Method study is normally conducted before work measurement. Apart from the possible-need to compare the times for old work methods with the times for new methods, work measurement conducted before method study is poor practice.

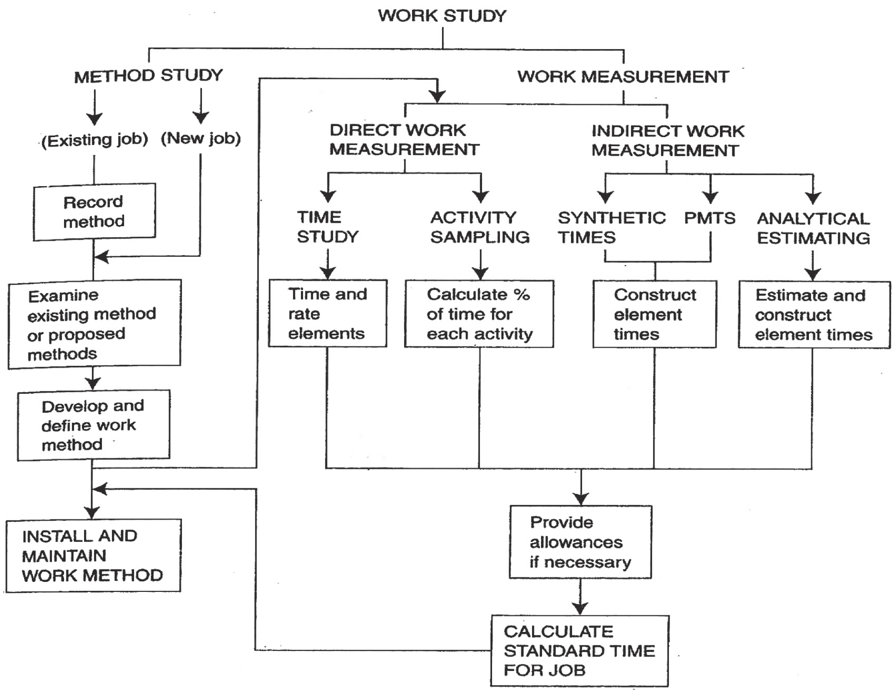


Fig. 2.3.1: The structure of work study

Table 2.3.1: Definitions of Terms often Used

Term	Definition
Work Design or Work System Design	Systematic investigation of contemplated and present work systems in order to formulate, through the ideal system concept, the easiest and most effective systems and methods for achieving the necessary functions/ goals/purposes.
Work Study	The generic term used for those techniques, particularly method study and work measurement, which are used in the examination of human work in all its contexts and which lead systematically to the investigation of the facts which affect efficiency and economy of the situation being reviewed, in order to effect improvement.

Term	Definition
Methods Engineering	That body of knowledge concerned with the analysis of the methods and the equipment used in performing a job, the design of an optimum method and the standardization of the proposed methods. Also frequently referred to as "Work Study".
Industrial Engineering	Concerned with the design, improvement and installation of integrated systems of men, materials and equipments to improve productivity.
Method Study or Methods Analysis or Operations Analysis	The systematic recording and critical examination of existing and proposed ways of doing work as a means of developing and applying easier and more effective methods and reducing costs.
Motion Study or Motion Analysis	Detailed study of the manual and/or body motions used in a work-task or at one work area often involving comparative analysis of right hand and left hand motions. (Part of method study)
Work Measurement	The application of techniques designed to establish the time for a qualified worker to carry out a specified job at a defined level of performance.
Work Simplification	Involves improvements in work methods or work flow initiated and developed by workers or supervisors on the job as a result of methods training and/or economic incentives. It is an organised use of common sense to find and apply better ways of doing any work at lesser cost.
Time Study	A technique of work-measurement used for determining as accurately as possible from a limited number of observations, the time necessary to carry out a given activity at a denned standard of performance. A stop watch is used for the purpose of recording the actual time taken by the worker under observation to perform various elements of the work or task.

Benefits of Work Study

1. Increased productivity and operational efficiency.
2. Reduced manufacturing costs.
3. Improved work place layout.
4. Better manpower planning and capacity planning.
5. Fair wages to employees.
6. Better working conditions to employees.
7. Improved work flow.
8. Reduced material handling costs.
9. Provides a standard of performance to measure labour efficiency.
10. Better industrial relations and employee morale.
11. Basis for sound incentive scheme.
12. Provides better job satisfaction to employees.

The purpose of work study is to determine the best or most effective method of accomplishing a necessary operation or function. The criteria for the best method could be an increase in job satisfaction and individual morale, reduction in physiological fatigue, decrease in number of accidents and personal injuries, minimization of material usage, tool breakage or usage of consumable supplies and increase in productivity by reduction of performance time. Every operation/activity in an organization contains to a certain degree, mechanical, physiological, psychological and sociological factors. The purpose of work measurement is to quantify these factors.

Relationship of Time and Motion Study to Work Study

Both time study and motion study which resulted from the integration of concepts and practices developed by F.W. Taylor and by Frank B. and Lilian M. Gilbreth, are concerned with the systematic analysis and improvement of manually controlled work situations. However, time study is a quantitative analysis leading to the establishment of a time standard whereas motion study is a qualitative analysis of a work station leading to the design or improvement of an operation/activity. **Exhibit 2.3.1** illustrates the relationship between motion and time studies as a part of the total work study procedure.

Work study as a discipline is concerned with -

(a) Better ways of performing jobs/tasks, and

(b) Exercising control over the output in respect of those jobs/tasks by setting standards for performance (i.e., for output/work) with respect to time.

The former technique is known as method study (also known as method analysis or operation analysis) and the latter technique is known as work measurement (or time study).

Exhibit 2.3.1: Relationship of Motion and Time Study to Work Design

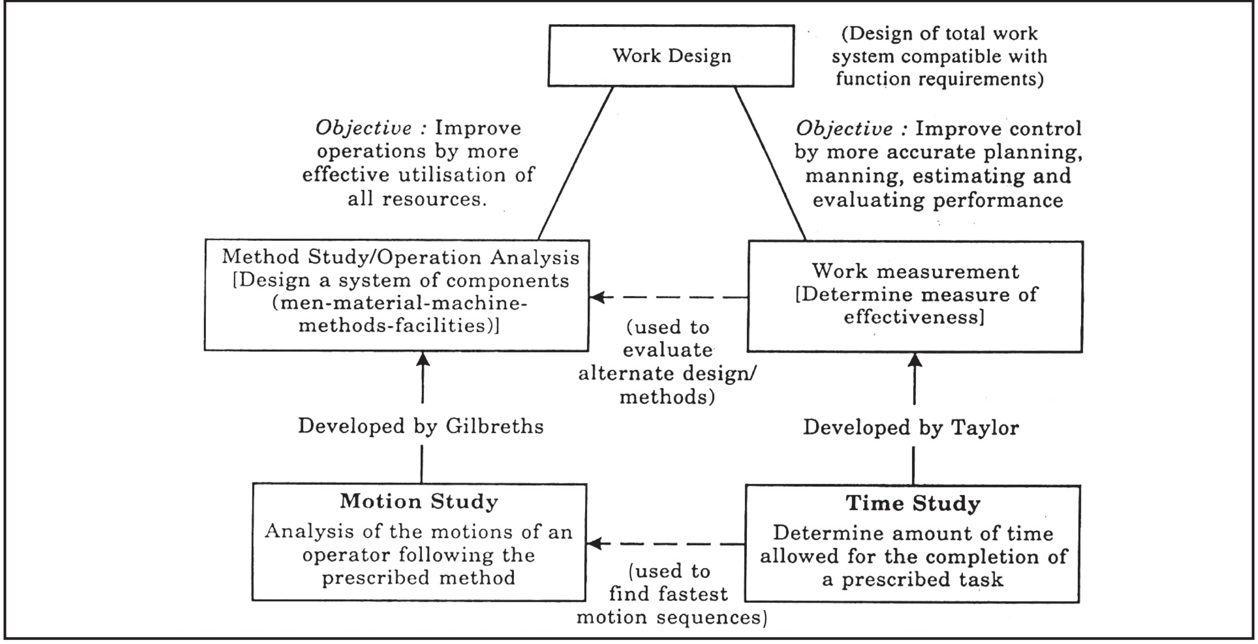
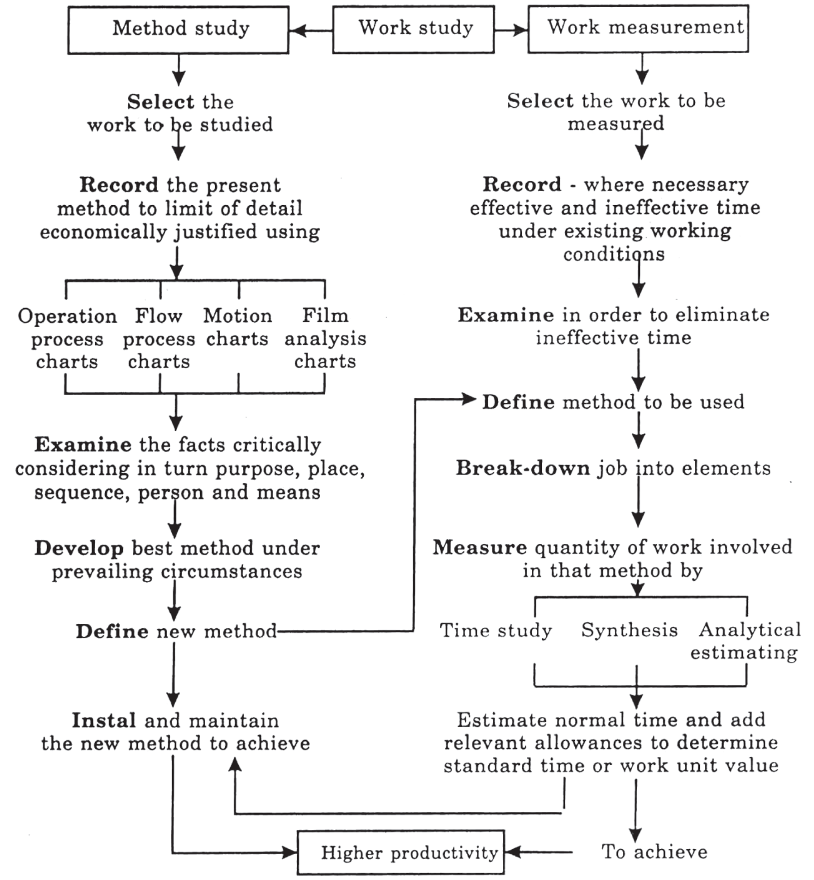


Exhibit 2.3.2 illustrates the steps involved in work study comprising the techniques of method study and work measurement.

Method study and work measurement are closely linked. Method study is concerned with reduction of work content while work measurement is concerned with the investigation and reduction of the ineffective time and the subsequent establishment of time standards for the task or job or operation on the basis of the work content established by method study. Usually method study should precede work measurement. However, when time-standards for output are being set, it is often necessary to use an appropriate work-measurement technique such as activity sampling (also known as work sampling) in order to determine the ineffective time or idle time. This will facilitate corrective action to be taken by management before going for method study. On the other hand, time study may be used to compare the effectiveness of alternative work methods or operations.

Exhibit 2.3.2 : Relationship of Motion and Time Study to Work Design



Basic Work Study Procedure

There are eight basic steps involved in a work study procedure. Some of them are common to both method study and work measurement. These steps are:

1. Select the job or the process or the operation to be studied.
2. Record all relevant facts about the job or process or operation using suitable charting techniques such as operation process chart, flow process chart, flow diagram, SIMO chart (simultaneous motion chart) and man-machine chart.
3. Examine critically all the recorded facts, questioning the purpose, place, sequence, person and the means of doing the job/process/operation.
4. Develop the new method for the job/process/operation.
5. Measure the work content and establish the standard time using an appropriate work measurement technique, viz; time study using stop watch, synthesis method, analytical estimating method, pre-determined motion time system and work sampling.
6. Define the new method for the job/process/operation.
7. Install the new method as standard practice.
8. Maintain the new method for the job/process/operation.

Method Study or Methods Analysis

Work methods analysis or method study is a scientific technique of observing, recording and critically examining the present method of performing a task or job or operation with the aim of improving the present method and developing a new and cheaper method. It is also known as methods improvement or work improvement. It encompasses the study of work processes, working conditions and equipments and tools used to carry out the job.

Method study may be understood as the systematic recording and critical examination of existing and proposed ways of doing work, as a means of developing and applying easier and more effective method and reducing costs.

Objectives of Method Study

1. To study the existing proposed method of doing any job, operation or activity.
2. To develop an improved method to improve productivity and to reduce operating costs.
3. To reduce excessive material handling or movement and thereby reduce fatigue to workmen.
4. To improve utilization of resources.
5. To eliminate wasteful and inefficient motions.
6. To standardise work methods or processes, working conditions, machinery, equipments and tools.

Advantages of Method Study

1. Work simplification
2. Improved working method (cheaper method)
3. Better product quality
4. Improved workplace layout
5. Improved equipment design
6. Better working conditions/environment
7. Better material handling and lesser material handling cost
8. Improved work flow
9. Less fatigue to operator
10. Optimum utilization of all resources
11. Higher safety to workmen
12. Shorter production cycle time
13. Higher job satisfaction for workmen
14. Reduced material consumption and wastages
15. Reduced manufacturing cost and higher productivity

Factors Facilitating Method Study

1. High operating cost
2. High wastage and scrap
3. Excessive movement of materials and workmen
4. Excessive production bottlenecks
5. Excessive rejections and rework

6. Complaints about quality
7. Complaints about poor working condition
8. Increasing number of accidents
9. Excessive use of overtime

Method Study Procedure

The various steps involved in method study are:

1. Select the work or job to be studied and define the objectives to be achieved by method study. The job selected to have maximum economic advantage, shall offer vast scope for work improvement through reduction of excessive material handling and fatigue to workmen, offer scope for improving the working conditions and improving the utilization of resources.
2. Record all the relevant facts or informations pertaining to the existing method using the recording techniques such as -
   (a) Process charts
      i. Outline process chart
      ii. Operation process chart
      iii. Flow process chart-material type, man type and machine type/equipment type.
      iv. Man-machine chart
      v. Two handed process chart
      vi. Diagrams such as
      vii. Multiple activity chart
      viii. Simultaneous motion chart (SIMO chart)
      ix. Motion chart
   (b) Diagram such as
      i. Flow diagram
      ii. String diagram
      iii. Cycle graph
      iv. Chronocycligraph
3. Examine the recorded facts critically challenging everything being clone and seeking alternatives, questioning the purpose (What is achieved?), the means (How is it achieved?), sequence (When it is achieved?), place (Where it is achieved?), and the person (Who achieves it?).

Box 2.3.1: The Questioning Attitudes of Methods Study

1. What is done? What is the purpose of the operation? Why should it be done? What would happen if it were not done? Is every part of the operation necessary?
2. Who does the work ? Why does this person do it? Who could do it better? Can changes be made to permit a person with less skill and training to do the work?
3. Where is the work done? Why is, it done there? Could it be done somewhere else more economically?
4. When is the work done? Why should it be done then? Would it be better to do it at some.
5. How is the work done? Why is it done this way?

4. Develop the improved method by generating several alternatives and selecting the best method. The factors to be considered while evaluating alternatives and selecting the best method are:
   (a) Cost of implementation
   (b) Expected savings in time and cost
   (c) Feasibility
   (d) Producibility
   (e) Acceptance to design, production planning and control, quality control, production and sales departments
   (f) Reaction of employees to the new method
   (g) Short term or long term implication of the alternative.

   Establish the new method by providing suitable equipment design, mechanical aids, jigs and fixtures, tools, working conditions, material handling equipments, workplace layout and work planning and control techniques.
5. Install the improved (new) method in three phases — planning, arranging and implementing phases. In the first two phases, the programme of installation and a schedule (i.e., time table) are planned and necessary requirements such as resources, equipments, tools, operating instructions to workers, are provided. The implementation phase involves the introduction of the developed method as standard practice to achieve the desired results.
6. Maintain the new method by ensuring that the installed method is functioning well. This is done by periodic checks and verifications at regular intervals. Proper control procedures are used to ensure that the new method is practised to achieve the benefits of methods study and also to achieve higher productivity.

Recording Techniques Used in Method Study

Some of the useful recording techniques used in method study are process charts, flow process charts, multiple activity charts, man-machine charts, flow diagram and string diagram.

To facilitate the charting process, some symbols are used such as those illustrated in **Exhibit 2.3.3**.

Process Charts used in Method Study

1. **Outline process chart:** An outline process chart records an overall picture of the process and records only the main events sequence wise. It considers only the main operations and inspections.

Exhibit 2.3.3 : Symbols used in Process Charting

Standard Symbol	Name of Activity	Definition of Activity
○	Operation	Modification of an object at one work place. Object may be changed in any of its physical or chemical characteristics, assembled or disassembled or arranged for another operation, transportation, inspection or storage.
⇨	Transportation or movement	Change in location of an object from one place to another.
□	Inspection	Examination of an object to check on quality or quantity characteristics.
D	Delay/Temporary storage	Retention of an object in a location awaiting next activity.
▽	Storage	Retention of an object in location in storage which is protected against unauthorized removal.
□⇨	Combined	A combined activity occurs when two activity activities occur simultaneously. Various combinations of simultaneous occurrence of two activities could be possible.

2. **Operation process chart:** The basic process chart, called an operation process chart, is understood as a graphic representation of the points at which the materials are introduced into the process and of the sequence of inspections and all operations except those involved in materials handling. It includes information considered desirable for analysis such as time required to carry out the operation and the location.

3. **Flow process charts** are graphic representations of the sequence of all operations, transportation, inspections, delays and storages occurring during a process or a procedure and include information considered desirable for analysis such as time required and distance moved.

   The flow process chart could be of three types, viz., (i) Flow process chart material or product type. (ii) Flow process chart-man type. (iii) Flow process chart machine type or equipment type.

   Material or product type flow process chart records what happens to the material or product i.e., the changes the material or product undergoes in location or condition (includes operation and transportation). Man type process chart records the activities of a worker or operator i.e., what a worker or operator does, whereas equipment or machine type flow process chart records the manner in which an equipment or machine is used.

4. **Two handed process chart:** in this chart the activities of a worker's or operator's both hands or limbs are recorded chronographically.

5. **Multiple activity chart:** In this chart the activities of more than one subject (worker, machine or equipment) are recorded on a common time scale to show their interrelationship.

6. **The man machine chart or worker-machine chart:** This is a variation of multiple activity chart and illustrates the operation and delays of the operator and the machine which he operates. An example of man machine chart may be one worker running two machines simultaneously.

7. **Flow diagram:** The flow diagram is a drawing or diagram drawn to a scale to show the relative position of a machine or equipment, jigs and fixtures, gangways or aisles and shows the path followed by materials or machines.

8. **String diagram:** It is a scale plan or model on which a string or a thread is used to trace and measure the path of workers, materials or equipments during a specified sequence of events.

9. **SIMO chart:** The simultaneous motion cycle chart (SIMO) is a type of two handed process chart in which the micromotions (therbligs) of both hands are recorded.

Motion Study

Motion study is the science of eliminating wastefulness resulting from using unnecessary; ill-directed and inefficient motion. The aim of motion study is to find and perpetuate the scheme of least waste methods of labour.

Micro-motion study provides a valuable technique for making minute analysis of those operations that are short in cycle, contain rapid movements and involve high production over a long period of time. For example, sewing of garments and assembling small parts. Micromotion study may be used for the following purposes in addition to its primary use for job-analysis work:

(i) To study the inter-relationship among the members of a work group.

(ii) To study the relationship between an operator and the machine which he operates.

(iii) To obtain the time for an operation

(iv) To establish a permanent record of the method of doing a job.

The usual procedure of performing micro-motion study is to take motion picture of the operations, analyse the film and to prepare a SIMO chart from the results of the film analysis. In analysing the film, very small time values (commonly 1/2000 minute) may be obtained by reading a clock (micro-chronometer) that appears in each of the motion pictures.

The film is analyzed by breaking the job cycle into micro-motions or therbligs which indicate the basic body motions of the worker.

Therbligs indicate the basic motions consisting of three parts, viz;

(i) When the motion begins.

(ii) The nature of the motion.

(iii) When the motion ends.

The examples of therbligs are

1. Search (Sr): That part of the cycle during which the eyes or the hands are hunting or groping for the object. Search begins when the eyes or hands begin to hunt for the object and ends when the objects have been found.

2. Select (St): The choice of one object from among several. Select refers to the hunting and locating of one object from among several.

   Example: Locating a particular pencil in a box containing pencils, pens and miscellaneous articles.

3. Grasp (G): Taking hold of an object, closing the fingers around it, preparatory to picking it up, holding it or manipulating it.

   Example: Closing the fingers around a pen on the desk.

4. Transport empty (TE): Moving the empty hand in reaching for an object.

   — Design of Work Systems

5. Transport loaded (TL): Moving an object from one place to another.

6. Hold (H): Retention of an object after it has been grasped, no movement of the object taking place.

7. Release load (RL): Letting go of the object. Release load begins when the object starts to leave the hand, and ends when the object has been completely separated from the hand or finger.

8. Position (P): Turning or locating an object in such a way that it will be properly oriented to fit into the location for which it is intended.

   Example: Lining up a door key preparatory to inserting it in the key hole.

9. Pre-position (PP): Locating an object in a predetermined place or locating it in the correct position for some subsequent motion.

10. Inspect (I): Examining an object to determine whether or not it complies with standard size, shape, colour or other qualities previously determined.

11. Assemble (A): Placing one object into or on another object with which it becomes an integral part.

12. Disassemble (DA): Separating one object from another object of which it is an integral part.

13. Use (U): Manipulating a tool, device or piece of apparatus for the purpose for which it was intended.

14. Unavoidable delay (UD): A delay beyond the control of the operator.

15. Avoidable delay (AD): Any delay of the operator for which he is responsible and over which he has control.

16. Plan (Pn): A mental reaction which precedes the physical movement, i.e., deciding how to proceed with job.

17. Rest for overcoming fatigue (R): A fatigue or delay factor or allowance provided to permit the worker to recover from fatigue incurred by his work.

18. Find (F): Mental reaction at the end of search.

Motion Economy and Work Efficiency

Most workers do not enjoy making unnecessary or wasted motions, particularly if they result in unnecessary fatigue. In addition to providing some social and psychological rewards, a job should be reasonably efficient. Motion study helps to reduce fatigue and waste motions.

Principles of Motion Economy

The rules of motion economy and efficiency which referred to hand motions of operators were developed by Gilbreths. The principles of motion economy are divided into three groups, viz.,

(a) Effective use of the operator

(b) Arrangement of the workplace

(c) Tools and equipment

Table 2.3.1: lists twenty two principles of motion economy as developed by Barnes.

Through the application of the principles of motion economy, it is possible to greatly increase the output of manual labour with a minimum of fatigue.

Table 2.3.1: Principles of Motion Economy

(a) Rules concerning use of human body 1. The two hands should begin as well as complete their motions at the same time. 2. The two hands should not be idle at the same time except during rest periods. 3. Motions of the arms should be made in opposite and symmetrical directions, and should be made simultaneously. 4. Hand and body motions should be confined to the lowest classification with which it is possible to perform the work satisfactorily. The ascending order of motion classification is (a) Fingers only, (b) Fingers and wrists, (c) Fingers, wrists and lower arms, (d) Fingers, wrists, lower and upper arms, (e) Hands, arms and body. 5. Momentum should be employed to assist the worker wherever possible, and it should be reduced to a minimum if it must be overcome by muscular effort. 6. Smooth, continuous curved motions of the hands are preferable to straight line motions involving sudden and sharp changes in direction. 7. Ballistic movements are faster, easier and more accurate than restricted or controlled movements. 8. Work should be arranged to permit easy and natural rhythm wherever possible. 9. Eye fixation should be as free and as close together as possible. **(b) Rules concerning arrangement of the work place** 10. There should be a definite and fixed place for all tools and materials. 11. Tools, materials and controls should be located close to the point of use.	12. Gravity feed bins and containers should be used to deliver material close to the point of use. 13. Drop deliveries should be used wherever possible. 14. Materials and tools should be located to permit the best sequence of motions. 15. Provisions should be made for adequate conditions for seeing. 'Good illumination' is the first requirement for satisfactory visual perception. 16. The height of the work place and the chair should preferably be arranged so that alternate shifting and standing at work are easily possible. 17. A chair of the type and height to permit good posture should be provided for every worker. **(c) Rules concerning the design of tools and equipment** 18. The hands should be relieved of all work that can be done more advantageously by a jig, a fixture or a foot-operated device. 19. Two or more tools should be combined wherever possible. 20. Tools and materials should be pre-positioned whenever possible. 21. Where each finger performs some specific movement such as in type writing, the load should be distributed in accordance with the inherent: capacities of the fingers 22. Levers, cross bars, and hand wheels which should be located in such positions that the operator can manipulate them with the least change in body : position and with the greatest mechanical, advantage

Definition of Work Measurement

Work measurement is defined as the application of techniques designed to establish the work content of a specified task by determining the time required for carrying out the task at a defined standard of performance by a qualified worker.

Qualified Worker

"A qualified worker is one who is accepted as having the necessary physical attributes, possessing the required intelligence and education and having acquired the necessary skill and knowledge to carry out the work in hand to satisfactory standards of safety, quantity and quality" - definition by International Labour organization (ILO) In short, work measurement may be defined as the techniques applied to determine the amount of time necessary for a qualified worker to perform a particular task. The amount of time that a job is expected to take is expressed as "time standard", "work standard", "labour standard" or "production standard" or "standard time". The "standard time" is the amount of time a qualified worker, working at a normal rate of speed, will require to perform the specified task. It may be expressed as minutes per unit of output or units of output per hour (i.e., standard output).

Work measurement is concerned with measuring the work content of any activity under study with a view to assess the human effectiveness or to compare one method with another or to develop labour standards that will be used for planning and controlling operations and there by achieving high labour productivity.

Objectives of work measurement can be to achieve

1. Improved planning and control of activities or operations;
2. More efficient manning of the plant;
3. Reliable indices for labour performance;
4. Reliable basis for labour cost control;
5. Basis for sound incentive schemes.

Benefits of Work Measurement

Work measurement helps

1. To develop a basis for comparing alternate methods developed in method study by establishing the work content in each method of doing the job.
2. To prepare realistic work schedules by accurate assessment of human work.
3. To set standards of performances for labour utilization by establishing the labour standards for an element of work, operation or product under ordinary working condition.
4. To compare actual time taken by the worker with the allowed time (standard time) for proper control of labour.
5. To assist in labour cost estimation.
6. To provide information related to estimation of tenders, fixation of selling price and assessment of delivery schedule.

Techniques of Work Measurement

The main techniques used to measure work are:

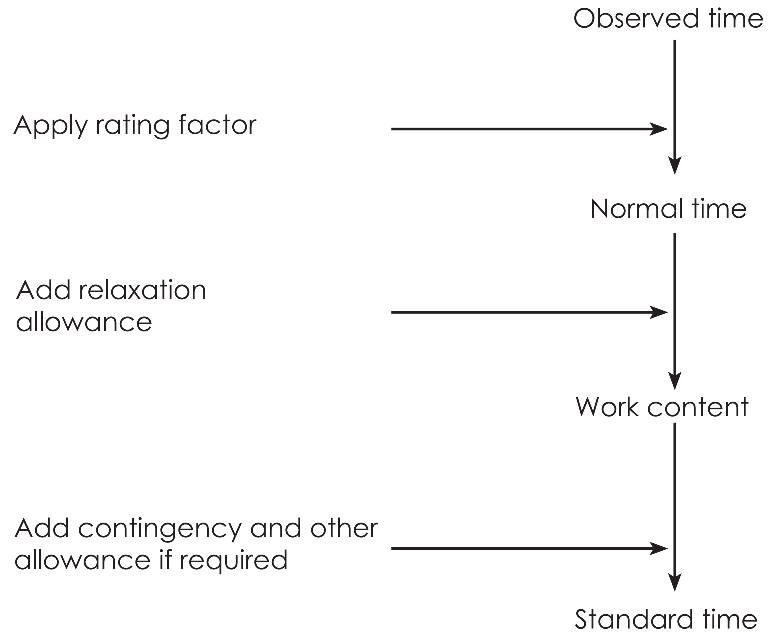
1. Direct Time Study.
2. Synthesis Method.
3. Analytical Estimating.
4. Pre determined Motion Time System (PMTS).
5. Work Sampling or Activity Sampling or Ratio Delay Method.

Steps in Work Measurement

The various steps are:

1. Break the job into elements
2. Record the observed time for each element by means of either time study, synthesis or analytical estimating.
3. Establish elemental time values by extending observed time into normal time for each element by applying a rating factor.

4. Assess relaxation allowance for personal needs and physical and mental fatigue involved in carrying out each element.
5. Add the relaxation allowance time to the normal time for each element to arrive at the work content.
6. Determine the frequency of occurrences of each element in the job, multiply the work content of each element by its frequency (i.e., number of time the element occurs in the job) and add up the times to arrive at the work content for the job.
7. Add contingency allowance if any to arrive at the standard time to do the job. The above procedure may be explained as follows:



The important work measurement techniques are explained below:

1. TIME STUDY

Time study is concerned with the determination of the amount of time required to perform a unit of work. It consists of the process of observing and recording the time required to perform each element of an operation so as to determine the reasonable time in which the work should be completed. Time study is defined as below "Time study is a work measurement technique for recording the times and rates of working for the elements of a specified job carried out under specified conditions and for analysing the data so as to obtain the time necessary for carrying out the job at a defined level of performance".

Objective of time study: The main objective is "to determine by direct observation, the quantity of human work in a specified task and hence to establish the standard time, within which an average worker working at a normal pace should complete the task using a specified method".

The other objectives are:

(a) To furnish a basis of comparison for determining operating effectiveness.

(b) To set labour standard for satisfactory performance.

(c) To compare alternative methods in method study in order to select the best method.

(d) To determine standard costs.

(e) To determine equipment and labour requirements.

(f) To determine basic times/normal times.

(g) To determine the number of machines an operator can handle.

(h) To balance the work of operators in production or assembly lines.

(i) To provide a basis for setting piece rate or incentive wages.

(j) To set the completion schedules for individual operations or jobs.

(k) To determine the cycle time for completion of a job.

Time study by stop watch: The steps involved are

1. Select the Job to be Studied

The reason for selecting a job for time study are

(a) New job taken for production.

(b) Change in manufacturing method.

(c) Design change.

(d) Change in raw material or components used for a job.

(e) Complaint about inadequacy of allowed time.

(f) For bottle neck operations.

(g) When labour cost is high.

(h) To establish standard time as a basis for incentive scheme.

(i) When new tools, jigs and fixtures are used.

2. Select the Worker to be Studied

The ideal worker would be the 'qualified worker 1, who is defined earlier in this chapter. Since the ideal worker or qualified worker may not be available in the organization, the best available worker is chosen and his rating is determined as compared with the qualified worker.

3. Conducting Stop Watch Time Study

In this step, the various activities involved are

(a) Obtain and record all information available about the job, operator and working conditions

(b) Record the method of doing the job and break down the job into elements.

An **element** is a distinct part of a specified job selected for convenience of observation, measurement and analysis.

The various type of elements involved in a job are:

(i) Repetitive element: which occurs in every work cycle of the job. E.g., picking up a component from the container before assembly operation.

(ii) Occasional element: which occurs at intervals e.g., setting a tool on a machine.

(iii) Constant element: for which the basic or normal time remains constant, whenever it is performed: e.g., measuring a dimension

(iv) Variable element: for which the basic or normal time varies

(v) Manual element: which is performed manually

(vi) Machine element: which is performed automatically by a machine

(vii) Governing element: which occupies a longer time than any other element in a job,

(viii) Foreign element: which is found to be an unnecessary element of a job e.g., unexpected breakage of a tool.

(c) Examine the various elements to ensure that the most effective motions are used in the elements of job performed.

(d) Measure the actual time taken by the operator to perform each element of the job, using a stop watch.

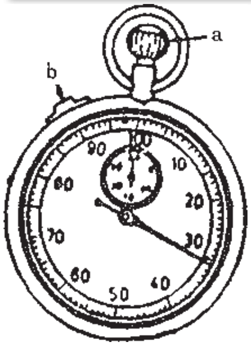
A stop watch may be of the following types

(i) Non fly back (ii) Fly back (iii) Split hand

(i) The **non-fly back** stopwatch is preferred for recording continuous timing. Pressing of the winding knob first starts the watch and long hand begins to move. If winding knob is pressed second time, the long hand stops and with the third pressing, the hands return to zero position. **Exhibits 2.3.4** shows the stop watch.

Stop watch is used to measure the decimal-minute stop watch has a long hand making one revolution per minute (100 divisions) and the small handle makes one revolution in 30 minutes.

Exhibit 2.3.4 : The Centiminute shows the Stop Watch



a-winding knob
b-slide

(ii) In **fly back** stop watch, the watch is started and stopped with the help of the slide (item b in **Exhibit 2.3.4**). Pressing the winding knob brings the hands back to zero, but they do not stop but start immediately moving forward again. The slide is used to stop the hands at any point.

(iii) **Split hand** type of stop watch gives higher accuracy in reading when two elements are to be timed successively. As one element is completed, pressing the winding knob makes one hand to stop while the other hand keeps moving. After the time taken for the first element is recorded on the time study observation sheet, a second pressing of the knob restarts the stopped hand and the two hands move together. (The first hand catches up with the other moving hand immediately after pressing the knob).

(e) Assess the effective speed of working of the operator with respect to the time study observer's concept of the speed of working of the qualified worker who is assumed to have a standard rating.

Rating factor or levelling factor is determined by comparing the actual pace or speed of working (of the worker studied) with the standard pace or speed of working (of the qualified worker)

Rating Scale: The commonly used rating scales are:

Split-hand type of stop watch gives higher accuracy in reading when two elements are to be timed successively.

(i) 60 - 80 Scale

(ii) 100 - 133 Scale

(iii) 75 - 100 Scale

These three rating scales are compared as below:

Rating assigned in the scale			**Level of performance**	**Corresponds to walking speed**
60 - 80	75 - 100	100 - 133 $\frac{1}{3}$		
0	0	0	No activity	Nil
40	50	67	Very slow, clumsy, no interest to do the job	2 mph
60	75	100	Normal, steady, unhurried performance	3 mph
80	100	133 $\frac{1}{3}$	Businessmen like, brisk, performance of a qualified worker	4 mph
100	125	167	Very fast, incentive motivated	5 mph

$$\text{Rating Factor} = \frac{\text{(Rating of the observed worker)}}{\text{(Rating of the qualified worker)}}$$

(f) Determination of normal or basic time: Once a particular rating scale is chosen and the rating of the worker under observation is assessed as compared to the standard rating of qualified worker (for e.g., In a 75 -100 scale, the qualified worker's rating is 100),

$$\text{Normal or Basic time} = \text{Observed time} \times \text{Rating factor}$$

$$= \text{Observed time} \times \frac{\text{(Observed rating)}}{\text{(Standard rating)}}$$

The observed time for each element is calculated as follow: A number of reading are taken for each element depending on the degree of accuracy desired and the length of the work cycle. The average observed time for each element is calculated by dividing the total of the element times by the number of cycles for which the element times are recorded.

(g) Determine the relevant allowances: Once the basic time per cycle required by the qualified worker to perform each element at standard rate of working is determined, the next step is to determine the time allowance to be given to the operator for relaxation, fatigue, contingency etc. Usually these allowances are taken as a percentage of basic or normal time. The various type of allowances are:

(i) Relaxation allowance (RA): This is also known as personal, fatigue on delay allowance (PFD allowance), This allowance is given to the work to overcome the fatigue due to physical exertion, posture, concentration, working condition and personal needs such as going to toilet, drinking water, attending phone calls etc., it usually varies from 10% to 20% of normal or basic time.

(ii) Contingency allowance (CA): This allowance is given for infrequent or non-repetitive activities such as obtaining special materials from stores, sharpening of tools, getting a special tool from the tool stores, and consultation with the supervisor. It is usually about 5% of normal or basic time.

(iii) Process allowance: Allowance given to the worker to compensate himself for enforced idleness due to the nature of a process or operation; for e.g., working on automatic machine, electroplating etc., during which the worker is forced to be idle during a part of the work cycle.

(iv) Special allowances:

(a) Interference allowance given to a worker when he/she is looking after 2 or 3 machines. One machine may idle when the worker works on another machine for a short period and allowance has to be given to the worker for this loss of production.

Design of Work Systems

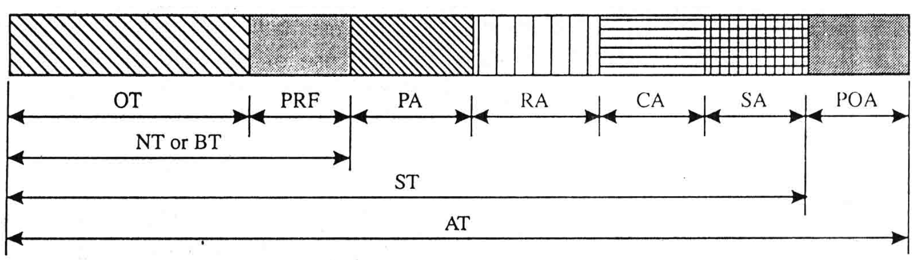
(b) Periodic activity allowance - for activities carried out periodically during a work cycle e.g., setting up a tool on the machine.

(c) Determine the standard time by adding the relevant allowance to the normal or basic time.

Standard time = Normal time + all relevant allowances

Exhibit 2.3.5 Shows the conversion of observed time to standard time.

Exhibit 2.3.5 : Computation of Standard Time



OT = Observed time	PRF = Performance Rating Factor
NT = Normal Time	BT = Basic Time
PA = Process Allowance	POA = Policy Allowance
RA = Relaxation Allowance	CA = Contingency Allowance
SA = Special Allowance	ST = Standard Time
AT = Allowed Time	

2. Synthesis Method

Synthesis is a technique of work measurement for building up the time required to do a job at a defined level of performance by synthesising or totalling elemental time values obtained from previous time studies on other jobs containing similar job elements or from standard data or synthetic data or built-up time standards.

Standard data: Standard data is a catalogue of 'normal' or 'basic' time values for different elements of jobs. This catalogue is prepared by compiling the timings of a number of standard elements. Since many similar elements or motions are involved in many jobs (for e.g., drilling holes), if time study is to be conducted for a new job, it is wasteful to retime those elements of the new job which are in common with the previously timed jobs. In such cases, it is always economical to use the previously timed and complied data known as standard data. Once the standard data catalogue is built up, one requires to list the job elements of an operation, refer to the standard data catalogue and obtain the elemental time values from the standard data catalogue and add them up (i.e., synthesise). The total time thus obtained gives an estimate of normal time for a job which can then be converted into standard time by adding relevant allowances.

Advantage of Synthesis Method

1. Reliable as the built-up time values of the 'standard data' catalogue are based on data derived from a large number of time studies.
2. Economical as less time is required when compared to 'stop watch' time study.
3. Used for estimating labour times for preparing cost estimates for new jobs for which the selling price has to be quoted to customers.

Applications of Synthesis Method

(a) To estimate standard time for new jobs.

(b) To estimate production time for determining the prices of products to be sold.

(c) Used as a basis for designing incentive schemes.

3. Analytical Estimating

This technique of work measurement is used to determine the lime values for jobs having long and non-repetitive operations. The time values are determined by using synthetic data or on the basis of the past experience of the work study engineer, when no synthetic or standard data is available. It is essential that the estimator must have adequate experience of estimating, motion study, time study and the use of standard data (or synthesised time standards).

Procedure of Analytical Estimating

The various steps involved are:

(a) Find out the job details such as job dimension, standard procedure to do the job, and the job conditions, such as poor illumination, high temperature, hazardous environments, availability of jigs, fixture or tools etc.,

(b) Break the job into its elements.

(c) Select time values from the standard data catalogue for as many elements as possible.

(i.e., use synthetic data wherever available),

(d) Estimate the time values for the remaining elements (for which synthetic data is not available) from past knowledge and experience.

(e) Add the time values obtained by steps (c) and (d) to get the total 'Basic' or 'Normal' time (for 100% rating).

(f) Add the appropriate blanket relaxation allowance (say 10% to 20% of total normal or basic time) Note that in analytical estimating the relaxation allowance is not added to time values of individual elements. The blanket relaxation allowances depends on the type of the job and the job conditions.

(g) Add any other allowances if applicable to arrive at the standard time for the given job.

Advantages of Analytical Estimating Technique

(a) Offers the same advantages enjoyed by synthesis method.

(b) Helps in planning and scheduling the production.

(c) Provides a basis for fixing the labour rate for non-repetitive jobs,

(d) Steps to improve labour control.

Disadvantages

Since analytical estimating technique relies upon the judgement of the estimator, the time values obtained may not be as accurate and reliable as that estimated by stop-watch time study.

Applications of Analytical Estimating Technique

(i) For non-repetitive jobs, jobs having long cycle times and jobs having elements of variable nature. For such jobs stop watch time study proves to be uneconomical.

(ii) For repair and maintenance work, job production, one time large projects, offer routines, tool room jobs and engineering construction works.

4. Predetermined Motion Time System (PMTS)

Predetermined motion time system is defined as a work measurement technique by which normal or basic times are established for basic human motions and these time values are used to build up the time for a job at a defined level of performance.

PMTS is an improvement over motion study because besides affording detailed analysis of the motion, it makes it possible to set a measure of the time that a series of motion ought to take.

Predetermined time standards are standard data for wide variety of basic body motions which are common in many industrial operations. For example, some of the basic or elementary human body motions are - 'move', 'reach', 'position' etc. Predetermined time standards contain table of standard time values for such basic motions.

Advantages of PMTs

1. Affords fine analysis and improvement of work methods.
2. Since the time for each basic motion is predetermined, the computation of standard time for a job or an operation is faster and more economical than time study using stop watch.
3. Offers a precise means of recording time, avoiding subjective judgement or bias of the rater.
4. Involves no interference in the normal work routine and hence faces little resistance from workers.
5. More effective and economical tool for work measurement for repetitive jobs of short duration.

Disadvantages

1. Such standards are not available for each and every human activity.
2. Limited to only uninhibited work in its application i.e., for the work which does not involve motions restricted by the process.
3. Has limited application in non-repetitive and office activities.
4. Fairly long period of intensive training under expert guidance is necessary to use this technique.

   Despite their limitations, PMTs represents the most accurate time estimates as it is based on careful analysis of the motion required to perform a job.

5. Work Sampling or Activity Sampling or Ratio-Delay Method

Work sampling is a work measurement technique that randomly samples the work of one or more employees at periodic intervals to determine the proportion of total operations that is accounted for in one particular activity.

These studies are frequently used to estimate the percentage of time spent by the employees in unavoidable delays (commonly called ratio-delay studies), repairing finished products from an operation, and supplying material to an operation.

Uses of Work Sampling Technique

1. To estimate the percentage of a protracted time period consumed by various activity states of a resource such as equipment, machines or operators.
2. To determine the allowances for inclusion in standard times.
3. To indicate the nature of the distribution of work activities within a gang operation.
4. To estimate the percentage of utilization of groups of similar machines or equipment.
5. To indicate how materials handling equipments are being used.
6. To provide a basis for indirect labour time standards.
7. To determine the productive and nonproductive utilization of clerical operations.
8. To determine the standard time for a repetitive operation as an attention to stop watch method.

Work Sampling Procedure

In work sampling study, the works study engineer takes a great number of observations of a worker or machine random times throughout the working shift or day. He records precisely what the worker or the machine is doing (i.e., working or idle) at the time of observation. No stop-watch is used. The objective is to find the frequency of occurrence of every work element.

The technique is based upon the laws of probability. It is based on the statistical premise that the occurrences in an adequate random sample observations of an activity will follow the same distribution pattern that might be found in a lengthy, continuous study of the same activity.

Algebraically put,

$$P = \frac{x}{N} = \frac{\text{(Number of observation of the activity)}}{\text{(Total number of observations)}}$$

Thus, the work sampling method, as stated above consists of taking a number of intermittent, randomly spaced instantaneous observations of the activity being studied and from this determining the percent of time devoted to each aspect of the operation.

In order to set a standard by the work sampling procedure, it is necessary to level or rate the performance of the worker being studied (as with stop watch time study) and to count the actual number of units produced during the period under study.

Finally it may be stated that the accuracy of the approach depends on the number of observations made. Higher the number of observations, greater is the occurrence.

Steps in Work Sampling

The work sampling study consists of essentially the following steps:

1. Determine the objective of the study, including definitions of the states of activity to be observed.
2. Plan the sampling procedure including:
   (a) An estimate of the percentage of time being devoted to each phase of the activity.

(b) The setting of accuracy limits.

(c) An estimation of the number of observations required.

(d) The selection of the length of the study period and the programming of the number of readings over this period.

(e) The establishment of the mechanics of making the observations, the route to follow and the recording of data.

3. Collect the data as planned.

4. Process the data and present the results.

Principles Involved In Work Sampling

Work sampling is based on statistical theory of random sampling and probability of normal distribution and confidence level associated with standard deviation. This is best illustrated by the following example.

Let x = number of observation of the activity in a pilot study

n = Total number of observations of the activity in the pilot study. Then proportion Y

of activity p = $\frac{X}{N}$

The proportion of 'no activity' = 1 - p = q (say)

The total of the two state which are mutually exclusive is 1, i.e.,, p + q = 1.

Where p = probability of an occurrence (e.g., working)

q = probability of no occurrence (e.g., not working or idling)

If this expression may be extended to include several observations (N) and then becomes,

$$(p + q)^N = 1$$

If this expression is expanded by the binomial theorem, the first term of the expression will have a probability that x = 0, the second term x = 1 and so forth. The distribution of these probabilities will follow the binomial distribution and will have mean value equal to Np and a standard deviation equal to $\sqrt{Npq}$ *As N become larger,* the binomial distribution approaches the normal distribution as a satisfactory approximation.

In order to use the normal distribution approximation, we need to divide both mean and the standard deviation by $\frac{Np}{N}$, thus we have the mean equal to $\frac{Np}{N}$ and the standard deviation $\sigma_p = \frac{\sqrt{Npq}}{N} =$ where q = 1-p

thus, $\sigma_p = \frac{\sqrt{Npq}}{N} = \frac{\sqrt{pq}}{N} = \frac{\sqrt{p(1-p)}}{N}$

On the basis of sampling theory , we cannot expect the 'p' determined by an estimate to be the true value of p. However on the basis of normal distribution, we can expect the true p to be within $2\sigma_p$ approximately 95% of the time and within $\pm\ 3\sigma_p$ approximately 99% of the time. In view of this relationship, if we wished to evaluate p so that the sampling error is reduced to the point where we may say the chances are 95 out of 100, that 'p' is correct to within ± 5% of the true value of p, then,

$$2\sigma_p = 0.05 = 2 = \sqrt{\frac{p(1-p)}{N}}$$

$$\therefore \sqrt{\frac{p(1-p)}{N}} = \left(\frac{0.05}{2}\right)$$

or, $\frac{p(1-p)}{N} = \left(\frac{0.05}{2}\right)^2 = \frac{(0.05)^2}{4}$

$$N = \frac{4p\,(1-p)}{(0.05)}$$

In general, if E is the absolute error (%), then $N = \frac{4p\,(1-p)}{(E)^2}$

Where N is the number of observation needed for work sampling study to get a result with in the error of ± E% and a confidence level of 95% for which the standard deviation under normal distribution curve is $+2\sigma_{p.}$

Similarly if, a confidence level of 99% is needed with an absolute error of E (%) then

$$3\sigma_p = E = 3\sqrt{\frac{p\,(1-p)}{N}}$$

or, $E^2 = \frac{9p\,(1-p)}{N}$

or, $N = \frac{9p\,(1-p)}{E^2}$

If we assume that C is a constant corresponding to confidence level, then values of C will be 1 for 68.3% confidence level, C=2 for 95.45% (or 95%) confidence level and C=3 for 99% confidence level. Then the number of observation needed for the work sampling study to get the result within an absolute error of ± E (%) is N = $N = \frac{C^2p\,(1-p)}{E^2}$

If is the relative error or accuracy desired as a decimal fraction of true proportion p, then, absolute error E = s × p

And $N = \frac{C^2p\,(1-p)}{(sp)^2}$

Or, $\frac{C^2p\,(1-p)}{E^2}$

Or, $\frac{C^2pq}{E^2}$

p = percentage or true proportion of activity or idling which is being observed based on pilot study

s = relative error of the true proportion 'p'

c = contact having values of 1, 2 and 3. corresponding to the confidence level of 68.3%, 95% and 99% respectively.

Advantages of Work Sampling over Conventional Work Measurement Methods

1. Economical to use and usually costs considerably less than a continuous time study.
2. Can be used to measure many activities that are impractical to measure by time study.
3. Not necessary to use a trained work measurement analyst to make the observations.
4. Work sampling measurements may be made with a preassignecl degree of reliability.
5. Measures the utilization of people and equipment directly.
6. Eliminates the necessity of using stop watch for measurements.
7. Provides observation over a sufficiently long period of time to decrease the chance of day to day variation affecting the results.

Limitations of Work Sampling

1. It is of little value in helping to improve work methods and doesn't offer some of the opportunity for methods analysis that accompanies time study methods.
2. Statistical work sampling may not be understood by workers.
3. If random sampling is not done, the results may be biased.

Illustration 1:

The work - study engineer carries out the work sampling study. The following observations were made for a machine shop.

Total number of observations	7,000
No. Working activities	1,200
Ratio between manual to machine elements	2:1
Average rating factor	120%
Total number of jobs produced during study	800 units
Rest and personal allowances	17%

Compute the standard time for the job.

Solution:

(i) Overall time per unit $(T_o) = \dfrac{\text{Duration of study}}{\text{Number of jobs produced during study}} = \dfrac{120 \times 60}{800} = 9$ min.

(ii) Effective time per piece $[T_e x] = T_o \times \dfrac{\text{Production Observation}}{\text{Total observation}} = 9 \times \dfrac{5{,}810}{7{,}000} = 7.47\text{mm}$

The effective time is to be segregated into manual time and machine element time.

Machine controlled time per piece (Tm) = 7.47 × 1/3 = 2.49 min

Hand controlled time per piece (Th) = 7.47 × 2/3 = 4.98 min

Normal time per piece = Tm + Th × performance rating = 2.49 + 4.98 × 1.2 = 8.46 min. Standard time per piece = 8.46 (1 + 0.17) = 9.9 minutes.

Illustration 2:

The time study of a machinery operation recorded cycle times of 8.0, 7.0, 8.0 and 9.0 minutes. The analyst rated the observed worker as 90%. The firm uses a 0.15 allowance fraction. Compute the standard time.

Solution:

Average cycle time = $\dfrac{8.0+7.0+8.0+9.0}{4}$ = 8.0 minutes

Normal time = 8.0 × 0.9 = 7.2 minutes.

Standard Time = $\dfrac{7.2}{(1-0.15)}$ = 8.47 minutes

The standard time for this machinery operation would be set at 8.47 minutes, which is greater than the average cycle time observed. The average cycle time was adjusted for the rating factor (90%) and the allowance fraction (0.15).

Illustration 3:

An analyst wants to obtain a cycle time estimate that is within ± 5% of the true value. A preliminary run of 20 cycles took 40 minutes to complete and had a calculated standard deviation of 0.3 minutes. What is the coefficient of variation to be used for computing the sample size for the forthcoming time study?

Solution:

Standard deviation of sample(s) = 0.3 min/cycle.

$$\text{Mean of sample} = \bar{x} = \frac{40 \text{ min}}{20 \text{ cycle}} = 2 \text{ min/cycle}$$

$$\text{Co-effficient of variation } (v) = \frac{S}{\bar{x}} = \frac{0.3}{2} = 0.15$$

Illustration 4:

A job has been time standard for 20 observations. The mean actual time was 5.83 minutes and the standard deviation of the time is estimated to be 2.04 minutes. How many total observations should be taken for 95% confidence that the mean actual time has been determined within 10%?

Solution:

$$n = \left[\frac{Zs}{A\bar{X}}\right]^2 = \left|\frac{(1+0.95)]\ (2.04)}{[\ 0.10\ (5.83)]}\right|^2 \left|\frac{[1.96(2.04)]}{[0.10(5.83)]}\right|^2 = 47$$

Therefore, a total of 47 observations should be made. Since 20 observations have already been made, only 27 more are necessary.

Illustration 5:

For a certain element of work, the basic time is established to be 20 seconds. If for three observations, a time study observer records ratings of 100, 125 and 80 respectively, on a "100-normal scale", what are the observed timings?

Solution:

[(observed time) × (observed rating) = (Basic or Normal time) × (standard rating)]

$$\text{Observed time} = \frac{(\text{Basic or Normal time}) \times (\text{Standard rating})}{\text{Observed rating}}$$

Data: Basic or Normal time = 20 seconds

given   Standard rating = 100

For observation No. 1, Observed rating = 100

$$\therefore \text{ Observed time} = \frac{20 \times 100}{100} = 20 \text{ seconds}$$

$$\text{For observation No. 2, Observed time} = \frac{20 \times 100}{125} = 16 \text{ seconds}$$

$$\text{For observation No. 2, Observed time} = \frac{20 \times 100}{80} = 25 \text{ seconds}$$

Illustration 6:

An 8 hours work measurement study in a plant reveals the following: Units produced = 320 nos. Idle time = 15%. Performance rating = 120%. Allowances =12% of normal time. Determine the standard time per unit produced.

Solution:

Observed time for 320 units = Working time - Idle time

= 8 - 8 x 0.15

= 8 -1.2

= 6.8 hours - 6.8 × 60 = 408 minutes.

Observed time per unit = $\frac{408}{320}$ = 1.275 minutes

Normal time per unit = $\frac{\text{Observed time/unit} \times \text{Observed rating}}{\text{Standard rating}}$

= Observed time/unit x Performance rating= $\frac{1.275 \times 120}{100}$ = 1.53 minutes

Standard time/unit = Normal time/unit + Allowances

= 1.53 minutes + 12% of 1.53 minutes

$= 1.53 + \frac{12}{100} \times 1.53$

= (1.53 + 0.184) minutes = 1.714 minutes

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 = $33\frac{1}{3}\%$ of normal time.

Solution:

Normal time per unit = Observed time/unit × Rating factor

$= 5 \times \frac{120}{100}$ = 6 minutes

Allowances = $33\frac{1}{3}\%$ of normal time

$= \frac{33.33 \times 6}{100}$ = 2 minutes

Standard time/unit = Normal time/unit + Allowances

= 6 + 2 = 8 minutes/unit

$\left.\begin{array}{l}\text{Standard production}\\ \text{in shift of 8 hours}\end{array}\right\} = \frac{8 \times 60}{8} = 60 \text{ unit}$

Illustration 8:

A work study practitioner who conducted a work sampling study assesses the activity level of a worker to be 70%. During the space of 8 hours working, this worker turns out 320 components. If the company policy is to inflate the normal time arrived at by work sampling study by 20%, what should be the allowed time per unit?

Solution:

Activity level as per work sampling study = 70%

Actual working time per shift of 8 hours = $8 \times \frac{70}{100}$ = 5.6 hours

Normal time taken per unit = $\frac{5.6 \times 60}{320}$ = 1.05 minutes

Allowed time = $1.05 \times \frac{120}{100}$ =1.26 minutes

= 1.26 minutes

Illustration 9:

Calculate the standard time per article produced from the following data obtained by a work sampling study.

Total no. of observations = 2,500   No. of working observations = 2,100

No. of units produced in 100 hours duration = 6,000 numbers

Proportion of manual labour = 2/3

Proportion of machine time = 1/3

Observed rating factor = 115%

Total allowances = 12% of normal time

Solution:

Actual working time in the duration of 100 hours = $100 \times \frac{2,100}{2,500}$ = 84 hours

Time taken per article = $\frac{84 \times 60}{6,000}$ = 0.84 minutes

Observed manual labour time per article = $0.84 \times \frac{2}{3}$ = 0.56 minute

Observed machine time per article = $0.84 \times \frac{1}{3}$ = 0.28 minute

Normal labour time per unit = Observed time/unit × Rating factor

= 0.56 × 1.15 = 0.644 minute

Standard labour time per unit = $0.644 + \frac{12}{100} \times 0.644$ = 0.721 minute

Standard time per unit of article produced = 0.721 + 0.28 =1.0 minute

Illustration 10:

Pilot study showed percentage of occurrence of an activity as 50%. Determine the number of observation required for a work sampling study for 95% confidence level and a relative error of ± 2%.

Solution:

Number of observations required for work sampling study $N = \frac{C^2 - p}{(s.p)^2}$ $N = \frac{C^2 p.q}{(s.p\ )^2}$

Where C is the constant based on confidence level selected.

C = 2 for 95% confidence level

p = Percentage of occurrence of an activity based on a pilot study (p = 50% or 0.5)

s = relative error, (s = 2% or 0.02)

$$\therefore \quad N = \frac{4 \times 0.5\,(1 - 0.5)}{(0.02 \times 0.5)^2}$$

$$= 10{,}000 \text{ nos.}$$

Illustration 11:

Compute the production cost per piece from the following data,

(i) Direct material per piece - ₹ 2

(ii) Wage rate ₹ 2,000 per month consisting of 25 working days and 8 hours per day.

(iii) Overheads expressed as a percentage of direct labour cost - 200%.

(iv) The time for manufacture of 4 pieces of the item was observed during time study. The manufacture of the item consists of 4 elements a, b, c and d. The data collected during the time study are as under. Time observed (in minutes) during the various cycles are as below:

Element	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Element rating on B.S. Scale (0-1 00)
a	1.2	1.3	1.3	1.4	85
b	0.7	0.6	0.65	0.75	120
c	1.4	1.3	1.3	1.2	90
d	0.5	0.5	0.6	0.4	70

The personal, fatigue and delay allowance may be taken as 25%.

Solution:

Step No. 1: Calculate of the standard time for the job based on the data given.

Element	Average observed time (O.T) (minutes)	Normal time (minutes) $= \left(\frac{\text{O.T} \times \text{Observed rating}}{\text{Standard rating}}\right)$
a	$\frac{1.2 + 1.3 + 1.3 + 1.4}{4} = 1.3$	$\frac{1.3 \times 85}{100} = 1.105$
b	$\frac{0.7 + 0.6 + 0.65 + 0.75}{4} = 0.675$	$\frac{0.675 \times 120}{100} = 0.81$
c	$\frac{1.4 + 1.3 + 1.3 + 1.2}{4} = 1.3$	$\frac{1.3 \times 9.0}{100} = 1.17$
d	$\frac{0.5 + 0.5 + 0.6 + 0.4}{4} = 0.5$	$\frac{0.5 \times 70}{100} = 0.35$
Normal time for the job = 3.435 minutes		

Standard time for the job = Normal time + Allowances

$= 3.435 + \frac{25}{100} \times 3.435$

= 3.435 + 0.858 = 4.29 = 4.3 minutes

As this time is the time taken for producing 4 pieces.

Standard time per piece = $\frac{4.3}{4}$ =1.075 minutes

Step No. 2: Calculation of costs

Direct labour cost of the job = Standard time/job in hour x Labour rate/hour

Labour rate per hour = $\frac{2,000}{25 \times 8}$ = ₹ 10

Direct labour cost for the job = $\frac{1.075}{60}$ = ₹ 0.18

Direct material cost per piece = ₹ 2

Overhead cost 200% of labour cost= $\frac{200}{100} \times 0.18 =$ ₹ 0.36

Total production cost per piece = 0.18 + 2.0 + 0.36 = ₹ 2.54

Illustration 12:

A work sampling study is to be made of a typist pool. It is felt that typists are idle 30 percent of the item. How many observations should be made in order to have 95.5% confidence that accuracy is within ±4%.

Solution:

Number of observations required for $N = \frac{C^2pq}{E^2}$

work sampling study

Where C = constant depending on confidence level

p = percentage of being idle ; q = percentage of being activity ; E = error

C = 2 for 95.5% confidence level ; p = 0.3 ; q = 1 - p .= 0.7 ; E = ±4%

$\therefore N = \frac{4 \times 0.3 \times 0.7}{(0.04)^2} = \frac{0.84}{0.0016} = 525$

Illustration 13:

In a work sampling study, a mechanic was found to idle for 20% of the time. Find out the number of observation needed to conform to the above figures with a confidence level of 95% and a relative error level by ± 5%.

Solution:

Number of observation required, $N = \frac{C^2pq}{E^2}$

E = absolute error = s × p where s is the relative error

p = percentage of idling ; q = percentage of activity = 1 - p

C = constant depending on confidence level

C = 2 for 95% confidence level.

$$N = \frac{4 \times 0.2 \times 0.8}{(0.05 \times 0.2)^2} = \frac{4 \times 0.16}{(0.010)^2} = \frac{0.64}{0.0001} = 6,400$$

Illustration 14:

Premabai undertakes knitting of sweaters for various shops. She has several helping hands who, besides knitting also carry out cleaning, disentangling woollen thread, measuring and cutting, sewing and customer contact activities. Hema, an enthusiastic industrial engineer, did an activities sampling (work sampling) study and came up with the following data:

Activity	No. of Observations
Knitting	120
Cleaning	40
Disentangling	75
Measuring and Cutting	20
Sewing	20
Speaking to Customers	25
Total No. of Observations	300

Hema rated the help she had observed at 95 for the disentangling activity and 100 for the knitting activity. If at the end of the four-day (36 work hours) study, Hema found that the helping hand had disentangled 2.3 kg of woollen thread and knitted a two meter-length equivalent, what are the standard times for these activities? Take total allowances at 25 per cent.

If Premabai gives the work of disentangling woollen thread to a helper for four hours, how much wool should be disentangled?

Solution:

Assuming that the total number of observations are adequate, the ratios are:

Disentangling: $\left(\frac{75}{300}\right) = 0.25$

which means, (0.25 × 36h) = nine working-hours have been spent on disentangling with an output of 2.3 kg at a pace of 95 per cent rating.

Therefore,

$$\text{Normal time} = \frac{9h \times 0.95}{2.3kg} = 3.72 \text{ h per kg}$$

$$\text{Standard time} = \frac{\text{Normal Time}}{(1 - \text{allowance})} = \frac{(3.72)}{(1 - 0.25)}$$

$$= 4.96 \text{ hours per kg}$$

In four hours, the output should be, as per the standard:

$$\frac{4}{4.96} \text{ kg} = 0.806 \text{ kg}$$

The ‘ratio’ for knitting being 0.40 and rating being a 100:

Normal time = $\frac{(36 \times 0.40)\,h}{2m}$ = 7.2 h per m

Standard time for knitting = $\frac{7.2}{(1 - 0.25)}$ = 9.6 h per m

Illustration 15:

Sonar Gold Fields miners at 10th level have an accepted production standard of two trolley-loads an hour in an eight-hour working day. In addition to the mining of the gold-bearing soil, the miners have to do a few routine jobs such as cleaning, sharpening and maintaining the tools, for which they are paid a wage of ₹9 per hour upto a maximum of two hours per day. The base wage rate of the miners engaged in production/mining job is ₹6.60 per hour.

If Subrato, a miner, produced 18 trolley-loads in addition to performing his routine tasks, what wages should he get at the end of the day?

Solution:

Subrato worked for 18 ÷ 2 = 9 standard hours on the 'incentive job'.

This is equivalent to a productivity rate of:

9 std. hrs 6 hrs. worked = 150%

The 'incentive wages' earned by Subrato are:

$\frac{150}{100}$ × (₹6.60) × (6 hours) = ₹59.40

The 'non-incentive' wages earned by Subrato are:

(₹9.00) × (2 hours) = ₹18.00

The total wages to be paid to him are

₹59.40 + ₹18.00 = ₹77.40

2.4 FORECASTING

Introduction

Planning is fundamental to management. Forecasting, which involves a study of the present and past date with a view to estimate the future activities, forms the basis of planning. The better the management is able to forecast the future, the better will it be prepared to face to future. Forecasting is important to production and operations management in a number of decisions; to make an annual plan of production/ operations, to make a weekly or daily schedule of production or service operations, to procure or manufacture the raw materials or components and to plan the manpower, requirement amongst various other things.

Everyone needs information to base his plans. A sales executive makes frequent visits to various destinations to meet his customers. He depends upon various data and information collected / observed by him in the past to manage his time and plan his travel. An organized sales executive would have all the information about his activities of the past analyzed and might even note down the information systematically for future reference.

To keep up the appointments, with his customers the sales executive has to plan much ahead of the visits so that he can manage to visit all of them even if they are at different locations far from each other. He forecasts his plans, manages them well and controls the various activities to make sure that he achieves what he has scheduled.

Similar situations are encountered in various other activities as well. Whether it is related to industrial production, imparting university education, executing a health program or providing transport services or other services to the public, past data is required, based on which plans are prepared. Various questions are required to be answered in the case of an industrial unit producing goods, such as:

- What to produce?
- How to produce?
- When to produce?
- Which technology to use?
- Which machines are more suitable to produce?
- What materials are required to make the product(s)?
- What is the quantity and quality of various materials required to produce the product(s)?
- Whether all the materials would be available when needed?
- Where are the materials to be obtained from?
- What type of manpower is required?
- How much manpower is required?
- What packaging materials are to be used?
- Which transportation mode is to be used for dispatching the finished goods?

The answers to these questions are derived promptly and correctly from the past data and information.

- **Principles of Forecasting**

Many types of forecasting models that differ in complexity and amount of data & way they generate forecasts:

(i) Forecasts are rarely perfect

(ii) Forecasts are more accurate for grouped data than for individual items

(iii) Forecast are more accurate for shorter than longer time periods

Steps in the Forecasting Process

There are six basic steps in the forecasting process:

(i) Determine the purpose of the forecast. How will it be used and when will it be needed? This step will provide an indication of the level of detail required in the forecast, the amount of resources (personnel, computer time, dollars) that can be justified, and the level of accuracy necessary.

(ii) Establish a time horizon. The forecast must indicate a time interval, keeping in mind that accuracy decreases as the time horizon increases.

(iii) Obtain, clean, and analyze appropriate data. Obtaining the data can involve significant effort. Once obtained, the data may need to be "cleaned" to get rid of outliers and obviously incorrect data before analysis.

(iv) Select a forecasting technique.

(v) Make the forecast.

(vi) Monitor the forecast. A forecast has to be monitored to determine whether it is performing in a satisfactory manner. If it is not, reexamine the method, assumptions, and validity of data, and so on; modify as needed; and prepare a revised forecast.

Note too that additional action may be necessary. For example, if demand was much less than the forecast, an action such as a price reduction or a promotion may be needed. Conversely, if demand was much more than predicted, increased output may be advantageous. That may involve working overtime, outsourcing, or taking other measures.

Advantages of Forecasting

Advantages of forecasting are stated as under:

- Past data provides guidance for future and is a tool to train. Forecasts based on past data helps in correct planning.
- Forecasting of customer's demand help in strategy planning, capacity planning, location planning and layout planning.
- Past data provides trends, which are used to forecast the future trends and helps to decide on products or services pursued or to be stopped or abandoned.
- Forecast of manufacturing is essential to ensure the availability of materials for sub-assemblies and final assemblies.
- Forecasting helps in optimizing various costs as it lays down benchmarks to control the project. Actual demand and actual output are monitored, compared with previous plans and give feedback for the demand forecasting sub-system.
- Forecasting by specifying future demands reduce the costs of readjustment of operations in response to the unexpected deviation.
- Accurate estimation of future demands of goods and services through forecasting increases the operating efficiency.
- Forecasting is an important component of strategic and operational planning.
- Utilization of the plant is improved with correct forecasts.

Forecast Error

Normally there is a gap between forecasted demand and actual demand. If the forecasted demand is less than the actual demand, the company would find difficulty in meeting the customer's demands and in some cases might even lose some of its customers, as they could go to other suppliers when their requirements are not met in time. On the contrary, if the forecasted demand is greater than the actual demand, there would be excessive stock of finished goods. Forecast error is the numeric difference between the forecasted and actual demand. It is desirable that the difference between forecasted and actual demand is low as possible. There are two measures of error as stated below.

- Mean Absolute Deviation (MAD)
- Bias

Mean Absolute Deviation (MAD): MAD is the ratio of sum of absolute deviations for all periods to the total number of periods studied. It is represented as below:

$$\text{MAD}=\frac{\text{Sum of absolute values of deviations for all periods}}{\text{Total number of periods studied}}$$

$$=\frac{\sum_{i=1}^{n}\left|\text{Forecasted demand} - \text{Actual demand}\right| i}{n}$$

Where n is the number of periods studied.

Actual demand is compared with forecasted demand for each period (i) When the forecast is accurate, actual demand equals to the forecasted demand and there is no error. The extent of error is worked out and recorded period by period and then summed up. Average (mean) size of the forecasting error is then determined by dividing the sum of all absolute deviations by the number of periods studied. Mean Absolute Deviation (MAD) is an average of the number of deviations recorded without considering the sign. MAD, therefore, expresses the extent of error.

Bias: Bias is worked out by using algebraic difference between forecasted and actual demands for all the periods. The algebraic differences are summed up and divided by the total number of periods studied. Bias is represented as:

$$\text{Bias} = \frac{\text{Sum of algebraic errors for all the periods}}{\text{Total number of periods studied}}$$

$$=\frac{\sum_{i=1}^{n}(\text{Forecasteddemand} - \text{Acutaldemand})\, i}{n}$$

Bias indicates the directional tendency of the forecast errors.

Forecast error functions in a similar manner as inputs to quality improvement. The process of measuring forecast accuracy resembles the process control problems. The ideal forecast should have zero MAD and zero Bias. Usually tread off is attempted between MAD and Bias i.e., one must be kept low at the cost of the other. In general, focus should be on MAD. Lowering MAD to or near zero will automatically hold Bias low.

The essentials for effective forecasts are:

- It should be accurate enough to help the decision making process.
- It should provide timely indications of major shifts in process performance.
- It should be simple to use.
- It should be easily understandable.

Illustration 1:

The demand for sewing machine was estimated as 1000 per month for 5 months. Later on the actual demand was found as 900, 1050, 1000,1100 and 950, respectively. Workout MAD and Bias. Analyze whether the forecast made was accurate.

Solution:

$$\text{MAD}=\frac{|1000-900|+|1000-1050|+|1000-1000|+|1000-1100|+|1000-950|}{5}$$

$$=\frac{100+50+0+100+50}{5}$$

= 60 units of sewing machines.

$$\text{Bias} = \frac{(1000-900)+(1000-1050)+(1000-1000)+(1000-1100)+(1000-950)}{5}$$

$$= \frac{100 - 50 + 0 - 100 + 50}{5}$$

= 0 units of sewing machines.

In this case, MAD is 60 units whereas Bias has no deviation. Since MAD measures the overall accuracy of the forecasting method, it is found that the forecast is not based on accurate model and the error is 6% (60/1000 x 100).

Tracking Signals (TS)

The difference in forecasted demand and the actual demand has always been of concern to the management. The difference should be as low as possible. Tracking Signals are often used to monitor the forecasts especially when the overall forecast is suspect. If the TS is around zero, the forecasting model is performing well. A forecast is considered out of control, if the value of Tracking Signal exceeds plus or minus 4. Tracking Signal (TS) is calculated to indicate the deviations in cases where cumulative actual are either above or below the forecast by a substantial amount. The TS indicates the direction of the forecasting error, if TS is positive – increase the forecasts, but if it is negative – decrease the forecasts. It is the ratio of the cumulative algebraic sum of the deviations between the forecasts and the actual values to the mean absolute deviation. Mathematically, Tracking Signal is presented as below:

$$\text{Tracking Singals (TS)} = \frac{\text{Algebraic sum of deviations}}{\text{Mean Absolute Deviations (MAD)}}$$

$$= \sum_{i-l}^{n} \frac{(\text{Actual demand}_i - \text{Forecast demand}_i)}{\text{MAD}}$$

Illustration 2:

Calculate the value of Tracking Signal for the demand overcast of sewing machine based on the actual demand data given in Illustration 1. State if the forecast for the demand of the sewing machines is under control.

Solution:

Algebraic sum of deviations in Illustration 1

= (1000-900)+(1000-1050)+(1000-1000)+(1000-1100)+(1000-950)
= 100 – 50 + 0 – 100 + 50
= 0

Mean Absolute Deviation (MAD) = 60 (As calculated in Illustration 1)

Tracking Signal (TS)

= Algebraic sum of deviations/Mean Absolute Deviations (MAD)
= 0/60 = 0 (Zero)

Since the value of Tracking Signal is zero and falls within 4, the forecast made for the demand for sewing machines is in control.

Forecasting Approaches

Broadly forecasting approaches are divided into three categories. Different models are used under each category (Fig. 2.4.1). The main classification is as follows:

- **Qualitative Approaches:** Frequently used for longer range strategic planning and facilities decision.
- **Quantitative Approaches:** Frequently used for short-term operational planning such as production and inventory control. This approach uses more of an analytical method like time series analysis model.

- **Casual Technique Approach:** These approaches are helpful in intermediate term aggregate planning for various planning situations.

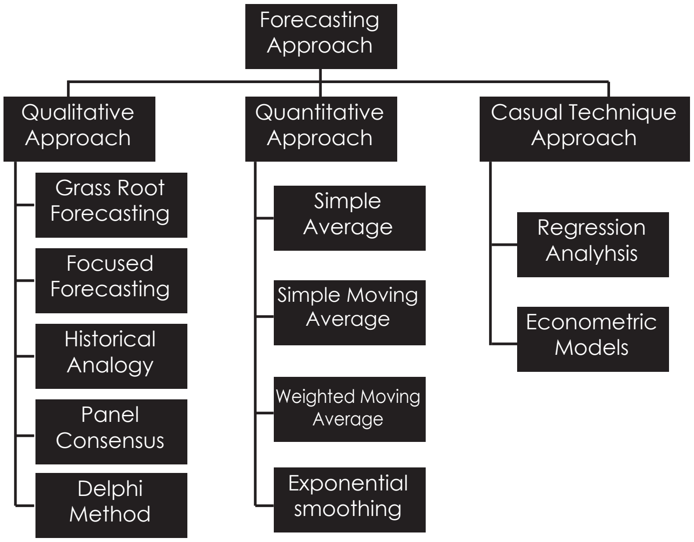


Fig. 2.4.1 : Various forecasting approaches

Qualitative Approaches

Qualitative approaches include five forecasting techniques:

- Grass-root Forecasting
- Focused Forecasting
- Historical Analogy
- Panel Consensus
- Delphi Method

Grass-root Forecasting: People at the grass-root level in the organization, who are in direct contact with the phenomenon under study, are asked to give inputs in forecasting.

Focused Forecasting: This method integrates common sense, grass-root inputs and computer simulation processes to assess the forecasts.

Historical Analogy: Information of past events is used to give insights into prediction on related future developments. It is assumed that the future events would follow similar pattern as the of the past events.

Panel Consensus: A group of knowledgeable persons are invited for an open discussion on a topic selected for forecasting. It is believed that a single person might not be able to consider all the aspects on the topic.

Delphi Method: A number of experts associated with the subject is asked to give their response to pre-selected questions, which would help in forecasting. The experts could be persons from within the organization or from outside the organization.

As the experts come from diverse backgrounds, they look at the issue independently from their own perspectives. On getting the feedback, they are able to appreciate the views of the experts from other expertise fields also. This gives them better understanding of the issue. The result of Delphi is arrived by pooling up the knowledge of various experts and brings very good results.

Merits of Delphi

Delphi is preferred for the following reasons:

- It involves knowledgeable persons on the subject.
- Members in Delphi exercise come from different backgrounds and therefore the method is able to consider and pool up various aspects of the issue.
- Since the members do not meet each other, their views are not influenced by the views of others.
- No conflict of personality is seen in the process.
- No dominance by any influential expert on the other experts.
- It gives quick results as compared to quantitative techniques and helps in timely decisions.

Demerits of Delphi

The approach also has disadvantages as at times the experts take too much time in giving responses. It also becomes a disadvantage when serious treatment is not given to the questionnaire, while giving their responses.

Quantitative Forecasting

Quantitative forecasting techniques use the past numerical data for forecasting the future events. The quantitative techniques use time series, which includes the following:

- Simple Average.
- Simple Moving Average
- Weighted Moving Average
- Exponential Smoothing

Simple Average : The simple average is calculated as under:

$$\text{Simple Average} = \frac{\text{Sum of demands for all past periods}}{\text{Number of demand periods}}$$

$$= \frac{D_1 + D_2 + D_3 \ldots.. + D_N}{n}$$

Where D_1 = Demand of period No. 1, i.e., the most recent period

D_2 = Demand of period No. 2, i.e. the period just prior to the recent period

D_3 = Demand of period No. 3, i.e. the period prior to period No. 2

D_n = Demand of period No. n

In the simple average method, demand is equally weighted in all the periods. The objective of the method is to determine the pattern or central tendency of the demand. The high demands that occurred in several periods are likely to be offset by the low demands in the other periods. Averaging helps in reducing the changes of influence from random fluctuation occurring in any single period. This method has a demerit that though the demand from many periods that happened earlier do not reflect the recent trends, they are given as much weightage as the most recent demands, and hence it might not be true for future events. Over a period, there could be changes in the method of work or even some technological improvements could be incorporated in the system, which might not have their due weight on the results.

Illustration 3:

The demand for 100 Watt bulbs in the months of January, February, March and April was 500, 600, 800 and 700. Forecast the monthly demand for the bulbs.

Solution:

$$\text{Simple Average (SA)} = \frac{D_1 + D_2 + D_3 + D_4}{n}$$

$$= \frac{500 + 600 + 800 + 700}{4}$$

$$= \frac{2600}{4}$$

$$= 650$$

The average demand for 100 Watt bulbs is 650 per month.

Simple Moving Average :

In this method, the number of past periods is selected. The average of the selected number of periods is calculated instead of average of all the periods taken together. In this case, the average is changing as we move forward and reflects the demand of the recent period more closely. As the one period elapses, the demand for the oldest period is not counted and the demand for the most recent period is added for the next calculation.

$$\text{Moving Average(MA)} = \frac{\text{Sum of demands for last n periods}}{\text{Number of periods selected in the moving average}}$$

$$MA = \frac{\sum_{t=1}^{n} D_t}{n} = \frac{1}{n}\ (D_1 + D_2 + ... + D_n)$$

Where t = 1, the earliest period in the n-period average

t = n, the most recent time period

if we have a demand data of 8 months and have selected a 5 months period to work out the simple moving average, then:

$$MA_1 = \frac{D_1 + D_2 + D_3 + D_4 + D_5}{5}$$

$$MA_2 = \frac{D_2 + D_3 + D_4 + D_5 + D_6}{5}$$

$$MA_3 = \frac{D_3 + D_4 + D_5 + D_6 + D_7}{5}$$

$$MA_4 = \frac{D_4 + D_5 + D_6 + D_7 + D_8}{5}$$

Based on the eight months data, these averages are plotted on the graph to provide the trend for the demand.

Illustration 4:

The demand for 100 Watt bulbs in the past 8 months is given as below:

Month	Demand
January	500
February	600
March	800
April	700
May	700
June	800
July	600
August	500

Calculate the moving average for a period of 5 months.

Solution:

$$MA_1 = \frac{500+600+800+700+700}{5} = 660$$

$$MA_2 = \frac{600+800+700+700+800}{5} = 720$$

$$MA_3 = \frac{800+700+700+800+600}{5} = 720$$

$$MA_4 = \frac{700+700+800+600+500}{5} = 660$$

Weighted Moving Average: In case the planner wants to give different weights to different periods, he could use weighted moving average method by incorporating some weight for old demand instead of equal weightage for all past periods under consideration. The model for weighted moving average is stated as below:

Weighted Moving Average (WMA) = Sum of the product of weight factor and demand for the month

$$= \sum_{t-1}^{n} W_t D_t$$

When $0 \le W_t \le 1$

and $\sum_{t-1}^{n} W_t = 1$

Where W_t is the weight for the period t and D_t is the demand for the period t. The sum of all the weights is expressed as $\sum W_t$ and $\sum W_i$ is equal to 1.

This method allows compensation for some trend or for some seasonality by proper selection of coefficients for the demand W_t. The planner could weight his forecast for the recent months more heavily and keep the weight lower for the older month's demand.

Illustration 5:

The demand for three months for 100 Watt bulbs are given below:

Period	January	February	March
Demand	500	600	800

If the weight assigned to the period of January, February and March are 0.25, 0.35 and 0.4 respectively, forecast the demand for the months of April by using Weighted Moving Average Method .

Solution:

D_1=500 Nos. W_1=0.25

D_2=600 Nos. W_2=0.35

D_3=800 Nos. W_3=0.4

Therefore Weighted Moving Average $= W_1 \times D_1 + W_2 \times D_2 + W_3 \times D_3$

$= 0.25 \times 500 + 0.35 \times 600 + 0.4 \times 800$

$= 125+210+320$

$= 655$

The demand for the month of April is 655 Nos. of 100 Watt bulbs.

Exponential Smoothing

This method is more popular. The pattern of weight is exponential in form. In this method, the demand for the most recent period is weighted most heavily and the weights of just preceding periods are lowered exponentially. As we go back in time, the weight is decreased exponentially. This method cannot be used for an item, which has trend or seasonal pattern. This is best suited for independent demand with no trend and seasonality. A new forecast is presented as under:

$$NF = OF + \alpha\,(AD-OF)$$

Where NF = New Forecast

OF = Old Forecast

α = Weight Factor, normally called smoothing coefficient

AD = Actual Demand.

Mathematically the forecast for time t can be presented as under:

$$F_t = \alpha\,(1-\alpha)^0 D_{t-1} + (1-\alpha)^1 D_{t-2} + (1-\alpha)2\, D_{t-3} + \ldots.$$

$$= \alpha\, D_{(t-1)} + (1-\alpha) F_{t-1}$$

Where F_1 = Forecast for the period t

D_{t-1}= Actual Demand in period t-1

Where $0 \le \alpha \le 1.0$, the terms $\alpha\,(1-\alpha)^0$, $\alpha(1-\alpha)^1$, $\alpha\,(1-\alpha)^2$….are successively smaller in value.

A high value of 'α' places heave weight on the most recent demand. If a value is selected low, the weight to the recent demand is also less heave. For new products or products for which the demand is not yet established, smoothing coefficient (α) of higher value is more appropriate, which could range from 0.7 to 0.9. However, in case of products where demand is established and is stable, a low value of 0.1 to 0.3 of smoothing coefficient (α) is preferred to smooth out the effect of any sudden phenomenon,. The middle range 0.4 to 0.6 of smoothing coefficient is more appropriate for the products, which are able to partially stabilize the demand.

As the method uses the most recent forecast and the latest actual demand, there is no need for carrying historical sales data. This forecasting approach is simple and easy to understand as it requires only the selected value for smoothing coefficient (α), last period's demand and the last period's forecast. The main advantage of this approach is that it gives results very quickly and with less effort.

Illustration 6:

A restaurant had a demand of 500 sweet dishes in January and 600 sweet dishes in February. So far the restaurant manager had used average monthly demand to forecast for each month of the next year. Average monthly demand for the sweet dish last year was 250. Using 250 sweet dishes as the January forecast and a smoothing coefficient of 0.8 weight the recent demand and calculate the forecast for the month of March this year.

Solution:

As we know $F_t = \alpha D_{t-1} + (1-\alpha)F_{t-1}$

Smoothing coefficient (α) = 0.8

D_{Jan} = 500 units

F_{Jan} = 250 units

The forecast for the months of February would be

F_{Feb} = 0.8 (500) + (1-0.8) (250)

= 400 + 50

= 450 units

Forecast for March would be

$F_{March} = \alpha D_{Feb} + (1-\alpha)F_{Feb}$

D_{Feb} = 600 units

F_{Feb} = 450 units

F_{March} = 0.8 (600) + (1-0.8) 450

= 480 + 90 = 570 units

Illustration 7:

(a) The actual demand for five periods are 1100,1,000, 1120, 1400, and 1250 and the opening forecast for the period 1 was 1000. Smoothing coefficient is 0.2. Calculate the new forecasts for the five periods.

(b) If the smoothing coefficient is changed to 0.3 before the end of period 3, what would be the new forecast for period 4?

Solution:

(a) When α = 0.2

Period	OF	AD	AD-OF	α (AD-OF)	NF = [OF+ α (AD-OF)]
1	1000	1100	+100	+20	1020
2	1020	1000	-20	-4	1016
3	1016	1120	+104	+20.8	1036.8
4	1036.8	1400	+363.2	+72.64	1109.44
5	1109.44	1250	+140.56	+28.11	1137.55

(b) When α = 0.3

3 1016 1120 +104 +31.2 1047.2

Forecasting methods can be classified into :

(i) Time series methods;

(ii) Casual methods and

(iii) Opinion-based methods.

The time series methods make no attempt to discover the factors affecting the demand (or any other thing) being forecasted, unlike in the casual methods. In the time-series methods, the multiplicity of causative factors are, so to say, all bundled together into one factor – time, and demand is expressed as a series of date (outputs) in time. Opinion-based methods recognize that there is more to forecasting than just the quantitative aspects. Demand in the ultimate analysis is generated by people and therefore a study of their behavior patterns is very important.

Time Series Methods

In terms of time, the past data can vary over time due to :

(i) Random errors,

(ii) Underlying trend,

(iii) Seasonality, and

(iv) Cycles.

An example of the demand variations over time is presented in **Fig. 2.4.2.**

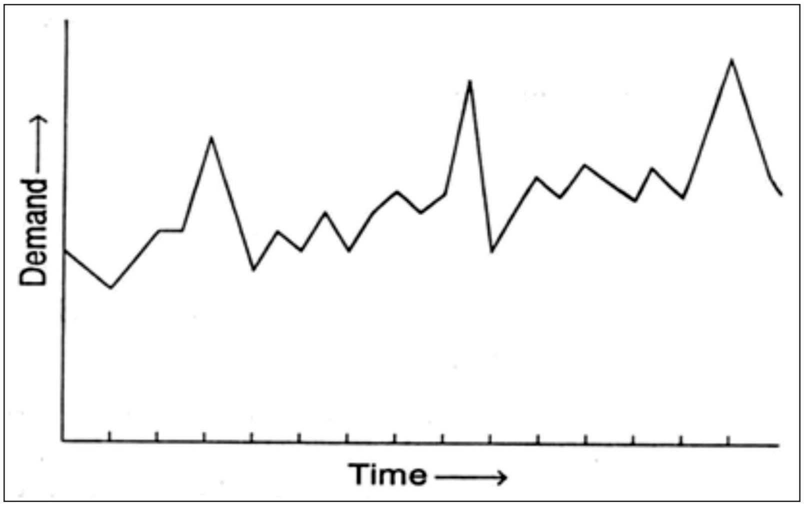


Fig. 2.4.2: Demand variations over time

Seasonality and cycles may appear to be similar as both of them represent periodicity in the time series. However, cycles are generally related to macro-level changes such as national economy or the state of the industry, etc. and seasonality is related to company/ unit level or micro-level factors that repeat quite regularly and frequently.

Smoothing methods try to filter out the random error by appropriately weighting the series of past data. Appropriate trend corrections are made in the smoothened - forecast because just smoothing does not truly represent the history of demand. In cases where seasonality is present, appropriate measures are taken while smoothing the data.

Decomposition methods may also use smoothing in their analysis. However they break down each component of the time series, (viz. seasonality, trend, cycle and random error), separately. Forecasting will necessitate putting together separate components by a process of multiplication or addition.

Thus, while smoothing methods try to locate a single pattern in the demand and trace every period of the demand, the decomposition methods involve sitting back, taking note of each component and assembling them all together. The aim is to determine where the target would be and shoot at that point accordingly.

Let us now study each of these methods in detail.

Smoothing Methods

1. Moving Averages : A simple moving average involves taking a simple arithmetical average of a set of observed values, from the present time period to a certain time period in the past, and then using that average as the forecast for the time period in the immediate future.

As we move into the future, the size of the slice of time still remains the same. Thus, some old data are discarded while new (present) values are added. The message given by the moving averages technique is that while history helps to plan the future, only a small fragment of the past is relevant. Thus, if we have monthly demand data, we may calculate the average of only six months values in the data (including the present value) to get the forecast for the next month; and such a moving average is called a six month moving average. The selection of the number of periods in the moving average depends upon (a) what is being forecasted and (b) the characteristics of the demand.

Simple n-period moving average forecast for the period (t + 1) = $\frac{1}{n}\sum_{k=t-n+1}^{k=t} D_k$

Simple moving average gives equal weights to all the periods. One can have a weighted moving average which gives different weights to different periods in the past.

Weighted n-period moving average forecast for the period (t + 1)

$$= W_t D_t + W_{t-1} D_{t-1} + W_{t-2} D_{t-2} + \dots\dots + W_{t-n+1} D_{t-n+1}$$

$$= \sum_{k=t-n+1}^{k=t} W_k D_k$$

Illustration 8:

The past data about the load on a stamping centre are as follows:

Month	Load, Machine Hours
May 2014	584
June 2014	610
July 2014	655
Aug. 2014	747
Sept. 2014	862
Oct. 2014	913
Nov. 2014	963

(a) If a five month moving average is used to forecast the next month's demand, compute the forecast of the load on the centre in the month of December (2014).

(b) Compute a weighted three month moving average for December 2014, where the weights are 0.5 for the latest month, 0.3 and 0.2 for the other months, respectively.

Solution:

(a) Five month moving average forecast for December 2012

$$= \frac{D_{Nov} + D_{Oct} + D_{Sep} + D_{Aug} + D_{Jul}}{5}$$

$$= \frac{963 + 913 + 862 + 747 + 655}{5}$$

$$= \frac{4140}{5} = 828 \text{ machine hours}$$

(b) A three month weighted moving average forecast for December 2012

$$(W_{Nov}\ D_{Nov}) + (W_{Oct}\ D_{OCt}) + (W_{Sep}\ D_{Sep})$$

= (0.5 X 963) + (0. 3 X 913) + (0.2 X 862)

= 927.8 machine hour

Centred moving averages are used many a time to refine the past data by removing the randomness. The centred data would then be used for some other purpose (including forecasting).

Components of a Time Series

The pattern or behavior of the data in a time series involves several components. The usual assumption is that four separate components—trend, cyclical, seasonal, and irregular— combine to provide specific values for the time series. Let us look more closely at each of these components.

Trend Component

In time series analysis, the measurements may be taken every hour, day, week, month, or year, or at any other regular interval. Although time series data generally exhibit random fluctuations, the time series may still show gradual shifts or movements to relatively higher or lower values over a longer period of time. The gradual shifting of the time series is referred to as the trend in the time series; this shifting or trend is usually the result of long-term factors such as changes in the population, demographic characteristics of the population, technology, and/or consumer preferences.

Cyclical Component

Although a time series may exhibit a trend over long periods of time, all future values of the time series will not fall exactly on the trend line. In fact, time series often show alternating sequences of points below and above the trend line. Any recurring sequence of points above and below the trend line lasting more than one year can be attributed to the cyclical component of the time series;

Seasonal Component

Whereas the trend and cyclical components of a time series are identified by analyzing multi-year movements in historical data, many time series show a regular pattern over one-year periods. For example, a manufacturer of swimming pools expects low sales activity in the fall and winter months, with peak sales in the spring and summer months. Manufacturers of snow removal equipment and heavy clothing, however, expect just the opposite yearly pattern. Not surprisingly, the component of the time series that represents the variability in the data due to seasonal influences is called the seasonal component. Although we generally think of seasonal movement in a time series as occurring within one year, the seasonal component can also be used to represent any regularly repeating pattern that is less than one year in duration. For example, daily traffic volume data show within-the-day “seasonal” behavior, with peak levels occurring during rush hours, moderate flow during the rest of the day and early evening, and light flow from midnight to early morning.

Irregular Component

The irregular component of the time series is the residual, or "catch-all," factor that accounts for the deviations of the actual time series values from those expected given the effects of the trend, cyclical, and seasonal components. The irregular component is caused by the short-term, unanticipated, and nonrecurring factors that affect the time series. Because this component accounts for the random variability in the time series, it is unpredictable. We cannot attempt to predict its impact on the time series.

Smoothing Methods

In this section we discuss three forecasting methods: moving averages, weighted moving averages, and exponential smoothing. The objective of each of these methods is to "smooth out" the random fluctuations caused by the irregular component of the time series, therefore they are referred to as smoothing methods. Smoothing methods are appropriate for a stable time series—that is, one that exhibits no significant trend, cyclical, or seasonal effects—because they adapt well to changes in the level of the time series. However, without modification, they do not work as well when significant trend, cyclical, or seasonal variations are present.

Smoothing methods are easy to use and generally provide a high level of accuracy for short-range forecasts, such as a forecast for the next time period. One of the methods, exponential smoothing, has minimal data requirements and thus is a good method to use when forecasts are required for large numbers of items.

Moving Averages

The moving averages method uses the average of the most recent n data values in the time series as the forecast for the next period. Mathematically, the moving average calculation is made as follows:

$$\text{Moving Average} = \frac{\sum(\text{most recent n date values})}{n} \qquad \textbf{[Equation 2.4.1]}$$

The term moving is used because every time a new observation becomes available for the time series, it replaces the oldest observation in **equation 2.4.1** and a new average is computed. As a result, the average will change, or move, as new observations become available.

To illustrate the moving averages method, consider the 12 weeks of data in **Table 2.4.1**. These data show the number of gallons of gasoline sold by a gasoline distributor in Bennington, Vermont, over the past 12 weeks.

Table 2.4.1: Gasoline sales time series

Week	Sales ('000s of gallons)
1	17
2	21
3	19
4	23
5	18
6	16
7	20
8	18
9	22
10	20
11	15
12	22

To use moving averages to forecast gasoline sales, we must first select the number of data values to be included in the moving average. As an example, let us compute forecasts using a three-week moving average. The moving average calculation for the first three weeks of the gasoline sales time series is

$$\text{Moving average (weeks 1-3)} = \frac{17 + 21 + 19}{3} = 19$$

We then use this moving average as the forecast for week 4. Because the actual value observed in week 4 is 23, the forecast error in week 4 is 23 - 19 = 4. In general, the error associated with any forecast is the difference between the observed value of the time series and the forecast.

The calculation for the second three-week moving average is

$$\text{Moving average (weeks 2-4)} = \frac{21 + 19 + 23}{3} = 21$$

Weighted Moving Averages

In the moving averages method, each observation in the moving average calculation receives the same weight. One variation, known as weighted moving averages, involves selecting a different weight for each data value and then computing a weighted average of the most recent n values as the forecast. In most cases, the most recent observation receives the most weight, and the weight decreases for older data values. For example, we can use the gasoline sales time series to illustrate the computation of a weighted three-week moving average, with the most recent observation receiving a weight three times as great as that given the oldest observation, and the next oldest observation receiving a weight twice as great as the oldest. For week 4 the computation is:

Table 2.4.2: Summary of Three-Week Moving Average Calculations

Week	Time series value	Moving Average Forecast	Forecast Errors	Squared Forecast Error
1	17			
2	21			
3	19			
4	23	19	4	16
5	18	21	-3	9
6	16	20	-4	16
7	20	19	1	1
8	18	18	0	0
9	22	18	4	16
10	20	20	0	0
11	15	20	-5	25
12	22	19	3	9
		Total	**0**	**92**

Forecast for week 4 = 1/6 (17) + 2/6 (21) + 3/6 (19) = 19.33

Note that for the weighted moving average the sum of the weights is equal to 1. Actually the sum of the weights for the simple moving average also equalled 1: Each weight was 1/3. However, recall that the simple or unweighted moving average provided a forecast of 19.

Exponential Smoothing

Exponential smoothing is simple and has few data requirements, which makes it an inexpensive approach for firms that make many forecasts each period.

Exponential smoothing uses a weighted average of past time series values as the forecast; it is a special case of the weighted moving averages method in which we select only one weight—the weight for the most recent observation. The weights for the other data values are computed automatically and become smaller as the observations move farther into the past. The basic exponential smoothing model follows.

Exponential Smoothing Model

$F_{t+1} = \alpha Y_t + (1 - \alpha) F_t$ **[Equation 2.4.2]**

Where, F_{t+1} = Forecast of the time series for period t + 1

Y_t = Actual value of the time series in period t

F_t = Forecast of the time series for period t

α = Smoothing constant ($0 \leq \alpha \leq 1$)

Equation 2.4.2 shows that the forecast for period t + 1 is a weighted average of the actual value in period t and the forecast for period t; note in particular that the weight given to the actual value in period t is α and that the weight given to the forecast in period t is $1-\alpha$. We can demonstrate that the exponential smoothing forecast for any period is also a weighted average of all the previous actual values for the time series with a time series consisting of three periods of data: Y_1, Y_2 and Y_3. To start the calculations, we let F_1 equal the actual value of the time series in period 1 ; that is, $F_1 = Y_1$ Hence, the forecast for period 2 is

$F_2 = \alpha Y_1 + (1 - \alpha) F_1$

$= \alpha Y_1 + (1 - \alpha) Y_1$

$= Y_1$

Thus, the exponential smoothing forecast for period 2 is equal to the actual value of the time series in period 1. The forecast for period 3 is

$F_3 = \alpha Y_2 + (1 - \alpha) F_2 = \alpha Y_2 + (1 - \alpha) Y_1$

Finally, substituting this expression for F_3 in the expression for F_4, we obtain

$F_4 = \alpha Y_3 + (1 - \alpha) F_3$

$= \alpha Y_3 + (1 - \alpha) [\alpha Y_2 + (1 - \alpha) Y_1]$

$= \alpha Y_3 + \alpha (1 - \alpha) Y_2 + (1 - \alpha)^2 Y_1$

Hence, F_4 is a weighted average of the first three time series values. The sum of the coefficients, or weights, for F_t, Y_2 and Y_3 equals one. A similar argument can be made to show that, in general, any forecast F_{t+1} is a weighted average of all the previous time series values.

Despite the fact that exponential smoothing provides a forecast that is a weighted average of all past observations, all past data do not need to be saved to compute the forecast for the next period. In fact, once the smoothing constant α is selected, only two pieces of information are needed to compute the forecast. **Equation 2.4.2** shows that with α given a we can compute the forecast for period t + I simply by knowing the actual and forecast time series values for period t — that is, Y_t and F_t.

To illustrate the exponential smoothing approach to forecasting, consider the gasoline sales time series in **Table 2.4.1**. As indicated, the exponential smoothing forecast for period 2 is equal to the actual value of the time series in period 1. Thus, with Y_1= 17, we will set F_2= 17 to start the exponential smoothing computations. Referring to the time series data in **Table 2.4.1**, we find an actual time series value in period 2 of Y_2 = 21. Thus, period 2 has a forecast error of 21 - 17 = 4.

Continuing with the exponential smoothing computations using a smoothing constant of α=0.2, we obtain the following forecast for period 3.

$F_3 = 0.2Y_2 + 0.8F_2 = 0.2(21) + 0.8(17) = 17.80$

Once the actual time series value in period 3, $Y_3 = 19$, is known, we can generate a forecast for period 4 as follows.

$$F_4 = 0.2Y_3 + 0.8F_3 = 0.2(19) + 0.8(17.80) = 18.04$$

By continuing the exponential smoothing calculations, we can determine the weekly forecast values and the corresponding weekly forecast errors, as shown in Table 2.4.3. Note that we have not shown an exponential smoothing forecast or the forecast error for period 1 because no forecast was made. For week 12, we have $Y_{12} = 22$ and $F_{12} = 18.48$. Can we use this information to generate a forecast for week 13 before the actual value of week 13 becomes known? Using the exponential smoothing model, we have

$$F_{13} = 0.2Y_{12} + 0.8F_{12} = 0.2(22) + 0.8(18.48) = 19.18$$

Thus, the exponential smoothing forecast of the amount sold in week 13 is 19.18, or 19,180 gallons of gasoline. With this forecast, the firm can make plans and decisions accordingly. The accuracy of the forecast will not be known until the end of week 13.

Trend Projection

In this section we show how to forecast a time series that has a long-term linear trend. The type of time series for which the trend projection method is applicable shows a consistent increase or decrease over time; because it is not stable, the smoothing methods described in the preceding section are not applicable.

Consider the time series for bicycle sales of a particular manufacturer over the past 10 years, as shown in **Table 2.4.3** and **Figure 2.4.3.** Note that 21,600 bicycles were sold in year 1, 22,900 were sold in year 2, and so on. In year 10, the most recent year, 31,400 bicycles were sold. Although **Figure 2.4.3** shows some up and down movement over the past 10 years, the time series seems to have an overall increasing or upward trend.

We do not want the trend component of a time series to follow each and every up and down movement. Rather, the trend component should reflect the gradual shifting in this case, growth of the time series values. After we view the time series data in Table 2.4.6 and the graph in **Figure 2.4.3**, we might agree that a linear trend as shown in **Figure 2.4.4** provides a reasonable description of the long-run movement in the series.

We use the bicycle sales data to illustrate the calculations involved in applying regression analysis to identify a linear trend. We will use that same methodology to develop the trend line for the bicycle sales time series. Specifically, we will be using regression analysis to estimate the relationship between time and sales volume.

Table 2.4.3 Bicycle Sales Time Series

Year (t)	Sales ('000s) (Y_t)
1	21.6
2	22.9
3	25.5
4	21.9
5	23.9
6	27.5
7	31.5
8	29.7
9	28.6
10	31.4

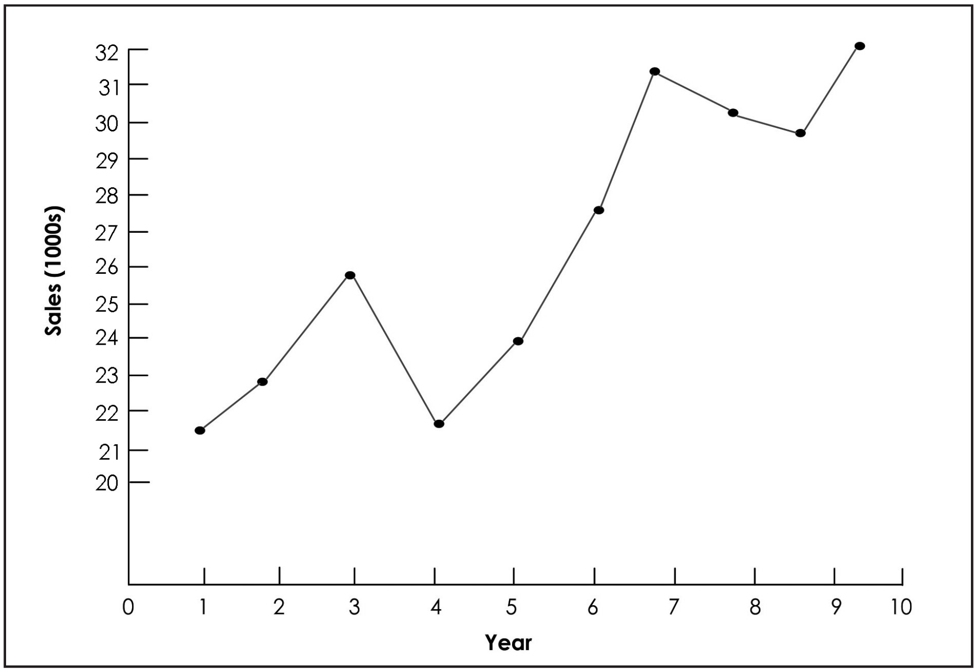


Fig. 2.4.3 Bicyle Sales Time Series

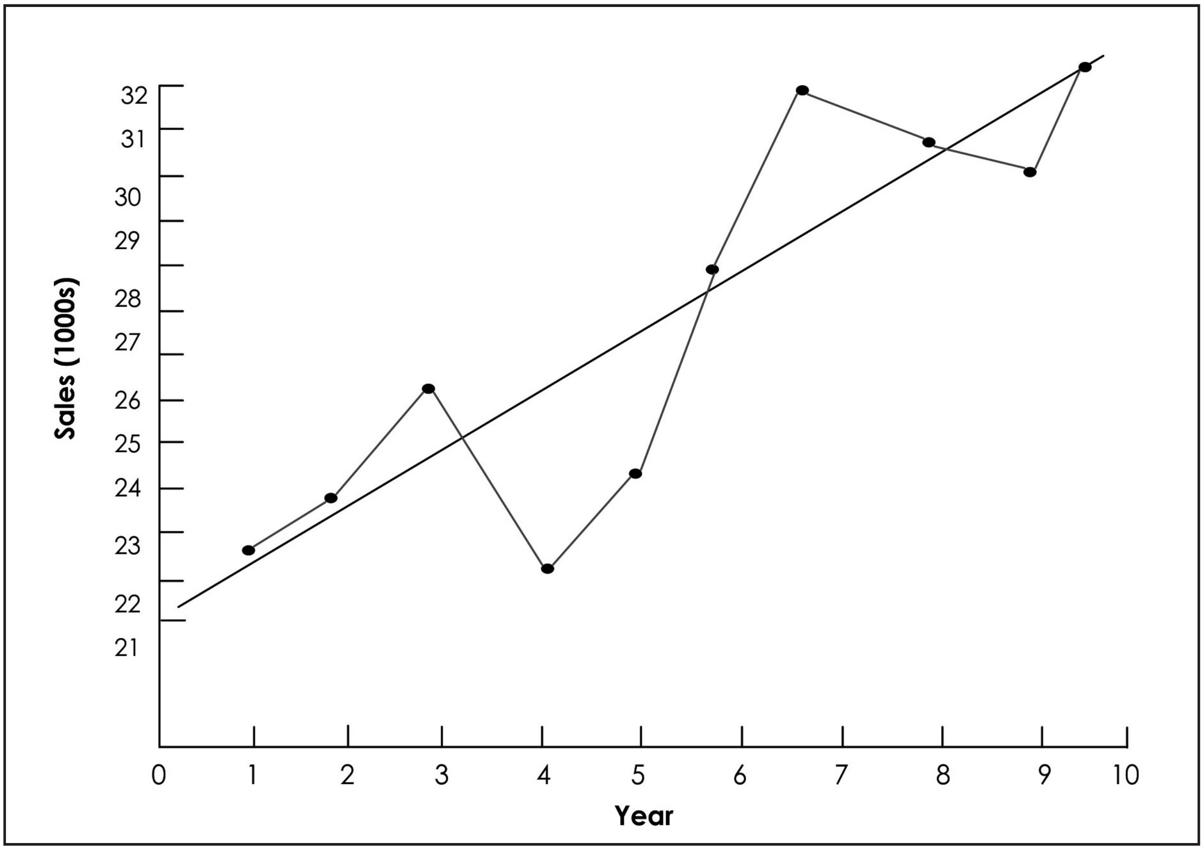


Fig. 2.4.4 Trend Represented by a Linear Function for Bicycle Sales

The estimeated regression equation describing a straight line relationship between an independent variable x and a dependent variable y is written —

$$\hat{y} = b_0 + b_1 x \quad \textbf{[Equation 2.4.3]}$$

To emphasize the fact that, in forecasting, the independent variable is time, we will use t in **equation 2.4.3** instead of x; in addition, we will use T, in place of $\hat{y}$. Thus, for a linear trend, the estimated sales volume expressed as a function of time can be written as follows.

Equation for Linear Trend

$$T_t = b_0 + b_1 t \quad \textbf{[Equation 2.4.4]}$$

Where, T_t = Trend value of the time series in period t

b_0 = intercept of the trend line

b_1 = slope of the trend line

t = time

In **equation 2.4.4**, we will let t = 1 for the time of the first observation on the time series data, t = 2 for the time of the second observation, and so on. Note that for the time series on bicycle sales, t = 1 corresponds to the oldest time series value and t = 10 corresponds to the most recent year's data. Formulas for computing the estimated regression coefficients (b_1 and b_0) in equation (2.4.4) follow.

COMPUTING THE SLOPE (b_1) AND INTERCEPT (b_0)

$$b_1 = \frac{\sum t Y_t - (\sum t \sum Y_t)/n}{\sum t^2 - (\sum t)^2/n} \quad \textbf{[Equation 2.4.5]}$$

$$b_0 = \bar{Y} - b_1 \bar{t} \quad \textbf{[Equation 2.4.6]}$$

Where,

Y_t = Value of the time series in period t

n = Number of periods

$\bar{Y}$ = Average value of the time series; that is, $\bar{Y} = \sum Y_t / n$

$\bar{t}$ = Average value of t; that is, $\bar{t} = \sum t/n$

Using equations and the bicycle sales data of Table 2.4.6, we can compute b_0 and b_1 **Table no. 2.4.4**:

Table No. 2.4.4

t	Y_t	tY_t	t^2
1	21.6	21.6	1
2	22.9	45.8	4
3	25.5	76.5	9
4	21.9	87.6	16
5	23.9	119.5	25
6	27.5	165.0	36
7	31.5	220.5	49
8	29.7	237.6	64
9	28.6	257.4	81
10	31.4	314.0	100
55	264.5	1545.5	385

$$\bar{t} = \frac{55}{10} = 5.5$$

$$\bar{Y} = \frac{264.5}{10} = 26.45$$

$$b_1 = \frac{1545.5 - (55)(264.5)/10}{385 - (55)^2/10} = 1.10$$

$$b_0 = 26.45 - 1.10\ (5.5) = 20.4$$

Therefore,

$T_t = 20.4 + 1.1t$ **[Equation 2.4.7]**

is the expression for the linear trend component for the bicycle sales time series.

The slope of 1.1 indicates that over the past 10 years the firm experienced average growth in sales of about 1100 units per year. If we assume that the past 10-year trend in sales is a good indicator of the future, equation can be used to project the trend component of the time series. For example, substituting t = 11 into equation yields next year's trend projection, T_{11}.

$T_{11} = 20.4+ 1.1(11) = 32.5$

Thus, using the trend component only, we would forecast sales of 32,500 bicycles next year. The use of a linear function to model the trend is common. However, as we discussed previously, sometimes time series have a curvilinear, or nonlinear.

Moving average values tend to "smooth out" both the seasonal and irregular fluctuations in the time series. The moving average values computed for four quarters of data do not include the fluctuations due to seasonal influences because the seasonal effect has been averaged out. Each point in the centered moving average represents the value of the time series as though there were no seasonal or irregular influence.

By dividing each time series observation by the corresponding centered moving average, we can identify the seasonal irregular effect in the time series. For example, the third quarter of year 1 shows 6.0/5.475 = 1.096 as the combined seasonal irregular value. **Table 2.4.6** summarizes the seasonal irregular values for the entire time series.

Consider the third quarter. The results from years 1,2, and 3 show third-quarter values of. 1.096,1.075, and 1.109, respectively. Thus, in all cases, the seasonal irregular value appears to have an above-average influence in the third quarter. With the year-to-year fluctuations in the seasonal irregular value attributable primarily to the irregular component, we can average the computed values to eliminate the irregular influence and obtain an estimate of the third-quarter seasonal influence.

$$\text{Seasonal effect of third quarter} = \frac{1.096 + 1.075 + 1.109}{3} = 1.09$$

We refer to 1.09 as the seasonal index for the third quarter. In **Table 2.4.7** we summarize the calculations involved in computing the seasonal indexes for the television set sales time

Table 2.4.5: Centered Moving Average Calculations for the Television Set Sales

Year	Quarter	Sales ('000s)	Four-quarter moving average	Centered moving average
1	1	4.8		
	2	4.1		
			5.350	
	3	6.0		5.475
			5.600	
	4	6.5		5.738
			5.875	
2	1	5.8		5.975
			6.075	
	2	5.2		6.188
			6.300	
	3	6.8		6.325
			6.350	
	4	7.4		6.400
			6.450	

Year	Quarter	Sales ('000s)	Four-quarter moving average	Centered moving average
3	1	6.0		6.538
			6.625	
	2	5.6		6.675
			6.725	
	3	7.5		6.763
			6.800	
	4	7.8		6.838
			6.875	
4	1	6.3		6.938
			7.000	
	2	5.9		7.075
			7.150	
	3	8.0		
	4	8.4		

series. Thus, the seasonal indexes for the four quarters are: quarter 1, 0.93; quarter 2, 0.84; quarters, 1.09; and quarter 4, 1.14.

Table 2.4.6: Seasonal Irregular Values for the Television Set Sales Time Series

Year	Quarter	Sales ('000s)	Centered moving average	Seasonal irregular value
1	1	4.8		
	2	4.1		
	3	6.0	5.475	1.096
	4	6.5	5.738	1.133
2	1	5.8	5.975	0.971
	2	5.2	6.188	0.840
	3	6.8	6.325	1.075
	4	7.4	6.400	1.156
3	1	6.0	6.538	0.918
	2	5.6	6.675	0.839
	3	7.5	6.763	1.109
	4	7.8	6.838	1.141
4	1	6.3	6.938	0.908
	2	5.9	7.075	0.834
	3	8.0		
	4	8.4		

Table 2.4.7: Seasonal Index Calculations for the Television Set Sales Time Series

Quarter	Seasonal Irregular Component Values ($S_t I_t$)	Seasonal Index (S_t)
1	0.971, 0.918, 0.908	0.93
2	0.840, 0.839. 0.834	0.84
3	1.096,1.075,1.109	1.09
4	1.133,1.156,1.141	1.14

1.00. and hence this type of adjustment is not necessary. In other cases, a slight adjustment may be necessary. To make the adjustment, multiply each seasonal index by the number of seasons divided by the sum of the unadjusted seasonal indexes. For instance, for quarterly data multiply each seasonal index by 4/(sum of the unadjusted seasonal indexes). Some of the exercises will require this adjustment to obtain the appropriate seasonal indexes.

Deseasonalizing the Time Series

The purpose of finding seasonal indexes is to remove the seasonal effects from a time series. This process is referred to as deseasonalizing the time series. Economic time series adjusted for seasonal variations (deseasonalised time series) are often reported in publications such as the Survey of Current Business, The Wall Street Journal, and Business Week. Using the notation of the multiplicative model, we have

$Y_t = T_t \times S_t \times I_t$

By dividing each time series observation by the corresponding seasonal index, we remove the effect of season from the time series. The deseasonalized time series for television set sales is summarized in **Table 2.4.8**. A graph of the deseasonalized television set sales time series is shown in **Figure 2.4.5.**

Using the Deseasonalized Time Series to Identify Trend

Although the graph in **Figure 2.4.5** shows some random up and down movement over the past 16 quarters, the time series seems to have an upward linear trend. To identify this trend, we will use the same procedure as in the preceding section; in this case, the data are quarterly deseasonalized sales values. Thus, for a linear trend, the estimated sales volume expressed as a function of time is

$T_t = b_0 + b_1 t$

where

T_t = trend value for television set sales in period t

b_0 = intercept of the trend line

b_1 = slope of the trend line

As before, t = 1 corresponds to the time of the first observation for the time series, t = 2 corresponds to the time of the second observation, and so on. Thus, for the deseasonalized

Table 2.4.8: Deseasonalized Values for the Television Set Sales Time Series

Year	Quarter	Sales ('000s) (Y_t)	Seasonal Index (S_t)	Deseasonalised Sales
1	1	4.8	0.93	5.16
	2	4.1	0.84	4.88
	3	6.0	1.09	5.50
	4	6.5	1.14	5.70
2	1	5.8	0.93	6.24
	2	5.2	0.84	6.19
	3	6.8	1.09	6.24
	4	7.4	1.14	6.49
3	1	6.0	0.93	6.45
	2	5.6	0.84	6.67
	3	7.5	1.09	6.88

Year	Quarter	Sales ('000s) (Y_t)	Seasonal Index (S_t)	Deseasonalised Sales
	4	7.8	1.14	6.84
4	1	6.3	0.93	6.77
	2	5.9	0.84	7.02
	3	8.0	1.09	7.34
	4	8.4	1.14	7.37

television set sales time series, t = 1 corresponds to the first deseasonalized quarterly sales value and t = 16 corresponds to the most recent deseasonalized quarterly sales value. The formulas for computing the value of b_0 and the value of b_t follow.

$$b_1 = \frac{\sum t\, Y_t - (\sum t \sum Y_t)/n}{\sum t^2 - (\sum t)^2/n}$$

$$b_0 = \bar{Y} - b_1 \bar{t}$$

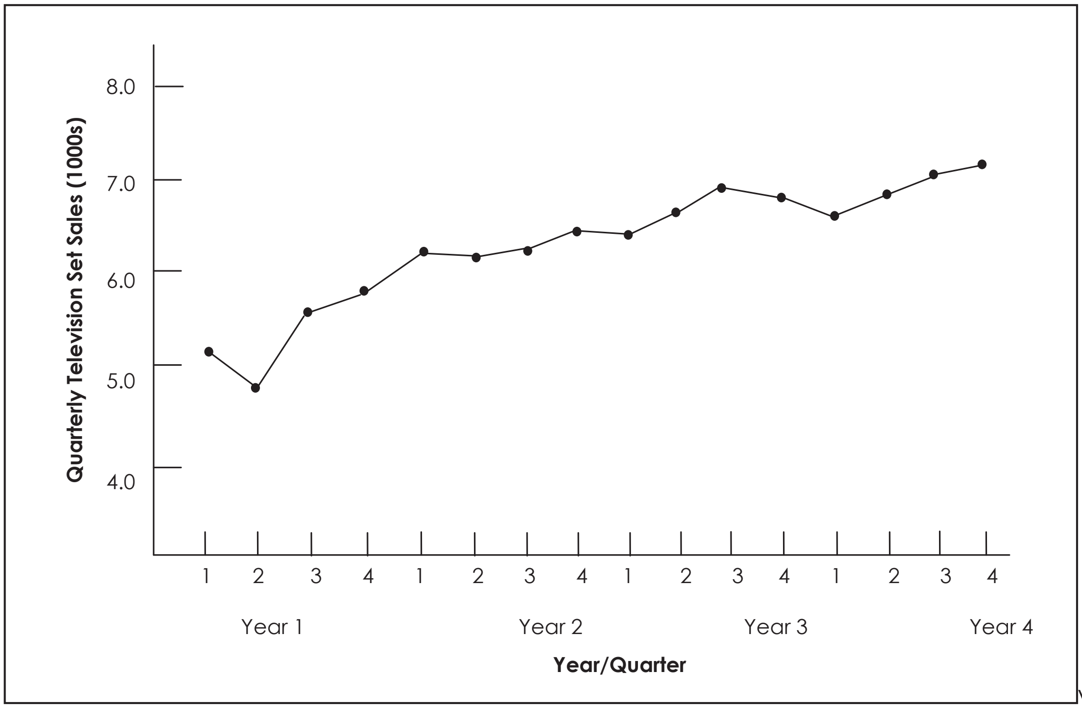


Fig. 2.4.5 Deseasonalized Television Set Sales Time Series

Note, however, that Y_t now refers to the deseasonalized time series value at time t and not to the actual value of the time series. Using the given relationships for b_0 and b_1 and the deseasonalized sales data of **Table 2.4.9**, we have the following calculations:

t	Y_t (Deseasonalized)	t Y_t	t^2
1	5.16	5.16	1
2	4.88	9.76	4
3	5.50	16.50	9
4	5.70	22.80	16

t	Y_t (Deseasonalized)	t Y_t	t^2
5	6.24	31.20	25
6	6.19	37.14	36
7	6.24	43.68	49
8	6.49	51,92	64
9	6.45	58.05	81
10	6.67	66.70	100
11	6.88	75.68	121
12	6.84	82.08	144
13	6.77	88.01	169
14	7.02	98.28	196
15	7.34	110.10	225
16	7.37	117.92	256
Totals 136	101.74	914.98	1496

Where,

$$\bar{t} = \frac{136}{16} = 8.5$$

$$\bar{Y} = \frac{101.74}{16} = 6.359$$

$$b_1 = \frac{914.98 - (136)(101.74/16)}{1496 - (136)^2/16} = 0.148$$

$$b_0 = 6.359 - 0.148(8.5) = 5.101$$

Therefore,

$$T_t = 5.101 + 0.148t$$

is the expression for the linear trend component of the time series.

The slope of 0.148 indicates that over the past 16 quarters, the firm averaged deseasonalized growth in sales of about 148 sets per quarter. If we assume that the past 16-quarter trend in sales data is a reasonably good indicator of the future, this equation can be used to project the trend component of the time series for future quarters. For example, substituting t = 17 into the equation yields next quarter's trend projection, T_{17}.

T_{17} = 5.101 + 0.148(17) = 7.617

Table 2.4.10: Quarterly Forecasts for the Television Set Sales Time Series

Year	Quarter	Trend Forecast	Seasonal Index (see Table 2.4.11)	Quarterly Forecast
5	1	7,617	0.93	(7,617)(.93) = 7,084
	2	7,765	0.84	(7,765)(.84) = 6,523
	3	7,913	1.09	(7,913)(1.09) = 8,625
	4	8,061	1.14	(8,061)(1.14) = 9,190

Thus, the trend component yields a sales forecast of 7,617 television sets for the next quarter. Similarly, the trend component produces sales forecasts of 7,765, 7,913, and 8,061 television sets in quarters 18, 19, and 20, respectively.

Seasonal Adjustments

The final step in developing the forecast when both trend and seasonal components are present is to use the seasonal index to adjust the trend projection. Returning to the television set sales example, we have a trend projection for the next four quarters. Now we must adjust the forecast for the seasonal effect. The seasonal index for the first quarter of year 5 (t = 17) is 0.93, so we obtain the quarterly forecast by multiplying the forecast based on trend (T17 = 7,617) by the seasonal index (0.93). Thus, the forecast for the next quarter is 7,617(0.93) = 7,084. **Table 2.4.10** gives the quarterly forecast for quarters 17 through 20. The high-volume fourth quarter has a 9,190-unit forecast, and the low-volume second quarter has a 6,523-unit forecast.

Models Based on Monthly Data

In the preceding television set sales example, we used quarterly data to illustrate the computation of seasonal indexes. However, many businesses use monthly rather than quarterly forecasts. In such cases, the procedures introduced in this section can be applied with minor modifications. First, a 12-month moving average replaces the four-quarter moving average; second, 12 monthly seasonal indexes, rather than four quarterly seasonal indexes, must be computed. Other than these changes, the computational and forecasting procedures are identical.

Cyclical Component

Mathematically, the multiplicative model of can be expanded to include a cyclical component.

$$Y_t = T_t \times C_t \times S_t \times I_t \qquad \textbf{[Equation 2.4.8]}$$

The cyclical component, like the seasonal component, is expressed as a percentage of tread. This component is attributable to multiyear cycles in the time series. It is analogous to the seasonal component, but over a longer period of time. However, because of the length of time involved, obtaining enough relevant data to estimate the cyclical component is often difficult. Another difficulty is that cycles usually vary in length. We leave further discussion of the cyclical component to texts on forecasting methods.

Regression Analysis

In the discussion of regression analysis**,** we showed how one or more independent variables could be used to predict the value of a single dependent variable. Looking at regression analysis as a forecasting tool, we can view the time series value that we want to forecast as the dependent variable. Hence, if we can identify a good set of related independent, or predictor, variables we may be able to develop an estimated regression equation for predicting or forecasting the time series.

The approach we used in to fit a linear trend line to the bicycle sales time series is a special case of regression analysis. In that example, two variables—bicycle sales and time were shown to be linearly related. The inherent complexity of most real-world problems necessitates the consideration of more than one variable to predict the variable of interest. The statistical technique known as multiple regression analysis can be used in such situations.

Recall that to develop an estimated multiple regression equation, we need a sample of observations for the dependent variable and all independent variables. In time series analysis the n periods of time series data provide a sample of n observations on each variable that can be used in the analysis. For a function involving k independent variables, we use the following notation.

Y_t = value of the time series in period t

x_{1t} = value of independent variable 1 in period t

x_{2t} = value of independent variable 2 in period t

x_{kt} = value of independent variable k in period t

The n periods of data necessary to develop the estimated regression equation would appear as shown in the following table.

Period	Time series (Y_t)	Value of Independent Variables						
		x_{1t}	x_{2t}	x_{3t}	.	.	.	x_{kt}
1	Y_1	x_{11}	x_{21}	x_{31}	.	.	.	x_{k1}
2	Y_2	x_{12}	x_{22}	x_{32}	.	.	.	x_{k2}
.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.
n	Y_n	x_{1n}	x_{2n}	x_{3n}	.	.	.	x_{kn}

As you might imagine, several choices are possible for the independent variables in a forecasting model. One possible choice for an independent variable is simply time. It was the choice made when we estimated the trend of the time series using a linear function of the independent variable time. Letting $x_{1t} = t$, we obtain an estimated regression equation of the form

$$\hat{Y}_t = b_0 + b_1 t$$

where Y_t is the estimate of the time series value Y_t, and where b_0 and b_1 are the estimated regression coefficients. In a more complex model, additional terms could be added corresponding to time raised to other powers. For example, if $x_{2t} = t_2$ and $x_{3t} = t_3$, the estimated regression equation would become

$$\hat{Y}_t = b_0 + b_1 x_{1t} + b_2 x_{2t} + b_3 x_{3t}$$

$$= b_0 + b_1 t + b_2 t^2 + b_3 t^3$$

Note that this model provides a forecast of a time series with curvilinear characteristics over time.

Other regression-based forecasting models have a mixture of economic and demographic independent variables. For example, in forecasting sales of refrigerators, we might select the following independent variables.

x_{1t} = price in period t

x_{2t} = total industry sales in period t - 1

x_{3t} = number of building permits for new houses in period t - 1

x_{4t} = population forecast for period t

x_{5t} = advertising budget for period t

According to the usual multiple regression procedure, an estimated regression equation with five independent variables would be used to develop forecasts.

Whether a regression approach provides a good forecast depends largely on how well we are able to identify and obtain data for independent variables that are closely related to the time series. Generally, during the development of an estimated regression equation, we will want to consider many possible sets of independent variables. Thus, part of the regression analysis procedure should be the selection of the set of independent variables that provides the best forecasting model.

We stated that the causal forecasting models use other time series related to the one being forecast in an effort to explain the cause of a time series' behavior. Regression analysis is the tool most often used in developing such causal models. The related time series become the independent variables, and the time series being forecast is the dependent variable.

In another type of regression-based forecasting model, the independent variables are all previous values of the same time series. For example, if the time series values are denoted Y_1, Y_2,……, Y_n, then with a dependent variable Y_t, we might try to find an estimated regression equation relating Y_t, to the most recent times series values Y_{t-1} , Y_{t-2} , and so on. With the three most recent periods as independent variables, the estimated regression equation would be $|\hat{Y}_t = b_0 + b_1 Y_{t-1} + b_2 Y_{t-2} + b_3 Y_{t-3}|$

Regression models in which the independent variables are previous values of the time series are referred to as auto regressive models.

Finally, another regression-based forecasting approach incorporates a mixture of the independent variables. For example, we might select a combination of time variables, some economic/demographic variables, and some previous values of the time series variable itself.

Illustration 9 :

The wages of certain factory workers are given as below. Using 3 yearly moving average indicate the trend in wages.

Year	2005	2006	2007	2008	2009	2010	2011	2012	2013
Wages	1,200	1,500	1,400	1,750	1,800	1,700	1,600	1,500	1,750

Solution :

Table : Calculation of Trend Values by method of 3 yearly Moving Average

Year	Wages	3 yearly moving totals	3 yearly moving average i.e. trend
2005	1,200	—	—
2006	1,500	4,100	1,366.67
2007	1,400	4,650	1,550
2008	1,750	4,950	1,650
2009	1,800	5,250	1,750
2010	1,700	5,100	1,700
2011	1,600	4,800	1,600
2012	1,500	4,850	1,616.67
2013	1,750	—	—

Illustration 10 :

Calculate 4 yearly moving average of the following data—

Year	2006	2007	2008	2009	2010	2011	2012	2013
Wages	1,150	1,250	1,320	1,400	1,300	1,320	1,500	1,700

Solution :

First Method :

Table : Calculation of 4 year Centered Moving Average

Year (1)	Wages (2)	4 yearly moving total (3)	2-point moving total of col. 3 (centred) (4)	4 yearly moving average centred (5) [col. 4/8]
2006	1,150	—	—	—
2007	1,250	—	—	—
		5,120		
2008	1,320		10,390	1,298.75
		5,270		
2009	1,400		10,610	1,326.25
		5,340		
2010	1,300		10,860	1,357.50
		5,520		
2011	1,320		11,340	1,147.50
		5,820		
2012	1,500			
2013	1,700			

Second Method :

Table : Calculation of 4 year Centered Moving Average

Year	Wages	4 yearly moving total (3)	4 yearly moving average (4)	2 year moving total of col. 4 (centred) (5)	4 year centred moving average (col. 5/2)
2006	1,150	–	–	–	–
2007	1,250	–	–	–	–
		5,120	1,280	–	–
2008	1,320			2,597.75	1,298.75
		5,270	1,317.5		–
2009	1,400			2,652.5	1,326.25
		5,340	1,335	–	
2010	1,300			2,715	1,357.50
		5,520	1,380		
2011	1,320			2,835	1,417.50
		5,820	1,455	–	–
2012	1,500				
2013	1,700				

Illustration 11 :

Calculate five yearly moving averages for the following data—

Year	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Value	123	140	110	98	104	133	95	105	150	135

Solution :

Table: Computation of Five Yearly Moving Averages

Year	Value ('000 ₹)	5 yearly moving totals ('000 ₹)	5 yearly moving average ('000 ₹)
2004	123	—	—
2005	140	—	—
2006	110	575	115
2007	98	585	117
2008	104	540	108
2009	133	535	107
2010	95	587	117.4
2011	105	618	123.6
2012	150	—	—
2013	135	—	—

Decomposition Methods

These methods of time-series analysis are based on the belief that the demand can be separately and distinctly broken down into its components, viz. trend, cycle, seasonality and randomness. Thus, demand usually is considered as a product of these components:

D = T x C x S x R

Where

T = Trend value

C = Cyclical factor as an index

S = Seasonality index

R = Randomness as an index

D = Demand observed

(all these are for a period 't').

The decomposition methods assume that the seasonality for a particular period of the seasonal cycle can be more or less treated as constant, in contrast to the smoothing methods which constantly update the seasonal ratios. Again, while the decomposition methods determine a particular linear or non-linear trend in the data and use this relationship in all future forecasting, the smoothing methods constantly track and update the trends (up and down) in every period. Similarly the decomposition methods attempt to determine the cyclical factor (expressed as a percentage or index) and use it across the board. The basic difference between the smoothing and the decomposition methods is therefore that unlike the latter, the former (a) continually tracks and modifies the demand components and (b) does not isolate the demand components but gives the corrections (which are, modified from period to period) in the forecasting procedure.

For an item with a more stable demand pattern over a long period of time, the decomposition methods may find better use. However, if the demand patterns are changing relatively more rapidly, the smoothing methods may be more suitable. The utility of a particular forecasting method depends upon the situation in which it is used; its complexity has little relation to its accuracy in use.

A. Simple Decomposition Procedure - Given a history of demands, we may take a moving average of the demands, the number of periods in the moving average being equal to the seasonal cycle. This procedure helps in removing/suppressing the seasonality and also the randomness to some extent. Thus, the average series is now composed of mainly T x C (as S x R is removed). Therefore, if we take the ratio of demand to the moving average (MAV), we get:

$$\frac{D_t}{MAV_t} = \frac{T_t \times C_t \times S_t \times R_t}{T_t \times C_t} = S_t \times R_t$$

where MAV_t = Moving average for period 't'.

Some methods adopt a further 3x3 MAV procedure for the obtained series so as to completely eliminate the randomness. However, simpler methods may not go through any such procedure and assume that D_t / MAV_t gives the seasonal indices (S_t).

Now $\frac{D_t}{S_t} = T_t \times C_t \times S_t$

Therefore, a plot of (D_t/S_t) over the historical time periods is made in order to reveal the 'Trend-cum-Cycle' (T x C) relationship with time. The plot also helps us to remove the randomness.

Cyclical factors are always a ticklish issue, as they depend upon the prevailing economic and industrial activity. Simpler methods will generally take $C_t \times R_t$ as around 1.00. The problem of forecasting thus reduces to computing S_t and T_t (or $T_t \times C_t \times R_t$). Forecasting procedure, therefore, consists of

(a) Finding seasonal indices

(b) Finding trend relationship, e.g.

$D_t = y + x_t$ or $D_t = m\ (D_{t-1})$

where y, x and m are constants.

(c) Applying the trend-relationship (as found in (b)) to the deseasonalised demand and thus obtaining the trend-value of demand for the period for which the forecasting is being done.

(d) Multiplying the value (called trend-value) obtained by the seasonal index corresponding to that period in the seasonal cycle. The result is the forecast.

A simple decomposition method is illustrated by the following set of solved problems.

Curve Fitting

Curve fitting is the process of finding a linear or non-linear, relationship between the dependent variable (which is usually the demand in forecasting) and an independent variable. It is helpful in causal methods where the demand is said to depend upon some factor(s), as also in the decomposition methods of time-series analysis where a trend-line is to be obtained prior to forecasting/estimating the demand in a future time period. We shall take up here the least squares method of curve fitting.

Least Squares Method of Curve Fitting:

Let us consider two different cases —

(i) Straight line: $Y = a_0 + a_1 X$

(ii) Parabola or quadratic curve: $Y = a_0 + a_1 X + a_2 X^2$

In case of a straight line: If there are N points $(X_1, Y_1), (X_2, Y_2), \ldots (X_N, Y_N)$, then the constants, a_0 and a_1 are determined by solving the simultaneous equations

$\sum Y = a_0 N + a_1 \sum X$ and $\sum XY = a_0 X + a_1 \sum X^2$

which are called the normal equations for the least square line.

In case of a quadratic curve: If there are N points $(X_1, Y_1), (X_2, Y_2), \ldots (X_N, Y_N)$, then the constants, a_0 , a_1 and a_2 are determined by solving simultaneously the normal equations for the least square parabola:

$$\sum Y = a_0 N + a_1 \sum X + a_2 \sum X^2$$

$$\sum XY = a_0 \sum X + a_1 \sum X^2 + a_2 \sum X^3$$

$$\sum X^2 Y = a_0 \sum X^2 + a_1 \sum X^3 + a_2 \sum X^4$$

Illustration 12 :

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 2014 and 2015.

Year	No. of items ('000)
2005	13
2006	20
2007	20
2008	28
2009	30
2010	32
2011	33
2012	38
2013	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 $\sum X$, $\sum Y$, $\sum XY$ and $\sum X^2$. If we arrange X in such a way that $\sum X = 0$, it will simplify our calculations. Therefore, we call the year 2009 as 0, 2009 as -1 and 2010 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
$\sum X = 0$	$\sum Y = 257$	$\sum X^2 = 60$	$\sum XY=204$

The normal equations are:

$\sum Y = a_o N + a_1 \sum X$

$\sum XY = a_0 \sum X + a_1 \sum X^2$

As $\sum X = 0$ and $\sum Y = a_o N$ and $\sum XY = a_1 \sum X^2$

Therefore,

$$a_0 = \frac{\sum Y}{N} = \frac{257}{9} = 28.56$$

$$a_1 = \frac{\Sigma XY}{\Sigma X^2} = \frac{204}{60} = 3.4$$

The equation of a straight line fitting the data is:

$Y = a_o + a_1 x$

$28.56 + 3.40\ x$

(a) Forecast for 2013, (i.e., X = 5): Y = 28.56 + 3.40 (5) = 45.56

(b) Forecast for 2014, (i.e., X = 6): Y = 28.56 + 3.40 (6) = 48.96

Illustration 13 :

The demand for colour TV sets has been rising rapidly since colour transmission was introduced in 2003. The following data are for one of the metropolitan cities. Fit a quadratic curve to the data and forecast the demand during years 2012, 2013, 2014, 2015 and 2016.

Year	Demand ('000)
2003	25
2004	35
2005	50
2006	65
2007	85
2008	115
2009	150
2010	205
2011	285

Solution:

As in the earlier example, let us call demand as Y and years as X. Let us arrange X so that the middle year is zero and $\sum X = 0$.

With this we have $\sum X = 0$ and $\sum X^3 = 0$

The normal equations for the quadratic curve are

$\sum Y = a_0 N + a_2 \sum X^2$ (1)

$\sum XY = a_1 \sum X^2$ (2)

$\sum X^2 Y = a_0 \sum X^2 + a_2 \sum X^4$ (3)

In order to solve these, the following table is constructed :

Year	X	Y	X^2	X^4	XY	X^2Y
2003	- 4	25	16	256	- 100	400
2004	- 3	35	9	81	- 105	315
2005	- 2	50	4	16	- 100	200
2006	- 1	65	1	1	- 65	65
2007	0	85	0	0	0	0
2008	1	115	1	1	115	115
2009	2	150	4	16	300	600
2010	3	205	9	81	615	1845
2011	4	285	16	256	1140	4560
	0	1015	60	708	1800	8100

Therefore from Eq. (2)

$1800 = a_1 (60)$ or $a_1 = \frac{1800}{60} = 30$

From Eq. (1) and (3)

$1015 = a_0 (9) + a_2 (60)$ and $8100 = a_0 (60) + a_2 (708)$

Solving these equations, we get

$a_0 = 83.92$ and $a_2 = 4.33$

The equation for the parabolic (quadratic) curve is therefore

$Y = 83.92 + 30 X + 4.33 X^2$

Using the above equation, the forecast for 2012 is

$Y = 83.92 + 30(5) + 4.33 (5)^2 = 342.17$

Similarly, forecasts for years 2013, 2014, 2015 and 2016 are

$Y_{2013} = 83.92 + 30 (6) + 4.33 (6)^2 = 419.80$

$Y_{2014} = 83.92 + 30 (7) + 4.33 (7)^2 = 506.09$

$Y_{2015} = 83.92 + 30 (8) + 4.33 (8)^2 = 601.04$

$Y_{2016} = 83.92 + 30 (9) + 4.33 (9)^2 = 704.65$

CAUSAL METHODS

Instead of examining the historical demand pattern with time, the causal methods try to identify the factors which cause the demand to vary and try to fit a relationship between the demand and these factors. For example, the increase in demand for an item may be related to the increase in population or in disposable income per household. It may also be related to the amount of competition in an inverse or negative way. Some of the causal methods are:

(a) Regression and correlation analysis

(b) Econometric models

(c) Input-output analysis

(d) End-use analysis

However we shall study only method (a).

Correlation - If all the values of the variable satisfy a regression equation exactly, then the variables are said to be perfectly correlated. But, this is mostly not the case and the data points are scattered about the line (or plane) which is fitted to the data. In all such cases we need to describe the fit with a measure of correlation.

If Y is the data value of the dependent variable, Yest is its estimate based on the curve line fitted, and $\overline{Y}$ is the mean value of Y:

The total variation of Y is defined as $\sum (Y - \overline{Y})^2$.

The total variation can be expressed as a sum of two terms:

$\sum (Y - \overline{Y})^2 = \sum(Y - Yest)^2 + \sum(Yest - \overline{Y})^2$

The first term (on the right) is called the unexplained variation and the second term the explained variation.

If there were no correlation, our best estimate of Y (the dependent variable) given any value of X (the independent variable) would be $\overline{Y}$ (the mean value of Y). However, if X and Y were perfectly correlated, we would expect all the values of Y to lie on the line fitted. Therefore, the regression line which has been fitted seems to explain as to why (accordingly) the estimated value viz. Yest (for a given value of X) should be different from $\overline{Y}$. The variation is unexplained in terms of the regression line, when the actual value of dependent variable is different from the estimated value.

The square root of the ratio of explained variation to the total variation is called the coefficient of correlation, r. It is a dimensionless quantity with $-1 \le r \le 1$.

$$r = \pm\sqrt{\frac{\text{Explained variation}}{\text{Total variation}}} = \pm\sqrt{\frac{(Yest - \overline{Y})^2}{(Y - \overline{Y})^2}}$$

The ratio of explained variation to the total variation, which is r^2, is called the coefficient of determination. This is the fraction of the variation in the dependent variable that is explained by the regression line which has been fitted to the data.

Both the coefficients, r and r^2, are used as measures of correlation, the latter signifying the proportion of the explained variation and the former signifying the sign (- ve or + ve) of the correlation.

Illustration 14 :

Apply the above concepts to Illustration 12. Find out whether the line gives-a good fit.

Solution:

Let us calculate values of Yest for the years in the data. The following table gives these values.

(e.g. for year 2005, i.e. X = - 4, the Yest = 28.56 + 2.77(- 4) = 17.48

Year	X	Yest	Y	(Yest - $\bar{Y}$)	(Yest - $\bar{Y}$)^2	(Y-$\bar{Y}$)	(Y- $\bar{Y}$)^2
2005	- 4	17.48	13	-11.08	122.77	- 15.56	242.11
2006	- 3	20.25	20	- 08.31	69.06	- 08.56	73.27
2007	- 2	23.02	20	.-05.54	30.69	- 08.56	73.27
2008	- 1	25.79	28	- 02.77	7.67	- 00.56	0.31
2009	0	28.56	30	0	0	+ 01.44	00.00
2010	1	31.33	32	2.77	7.67	+ 03.44	2.07
2011	2	34.10	33	5.54	30.69	+ 04.44	11.83
2012	3	36.87	38	8.31	69.06	+ 09.44	19.71
2013	4	39.64	43	11.08	122.77	+ 14.44	89.11
							208.51
			$\bar{Y} = \frac{257}{9}$ = 28.56		$\sum$ = 460.38 Explained Variation		$\sum$ = 720.19 Total Variation

Therefore, the coefficient of correlation.

$$r = \sqrt{\frac{460.38}{720.19}} = 0.7995$$

The r value is fairly high. The line thus gives a fair fit.

Illustration 15 :

Find coefficient of determination for the earlier problem of colour TV sets (Illustration 13).

Solution:

The regression equation obtained for the Illustration 13 was

Y = 83.92 + 30X + 4.33X^2

The estimated values of Y i.e. Yest are calculated from the above equation and these are given in the following table:

Year	X	Y	X^2	Yest	(Yest- Y)	(Yest- Y)^2	(Y- $\bar{Y}$)^2
2003	- 4	25	16	33.20	- 79.58	6,333	7,705
2004	- 3	35	9	32.89	- 79.89	6,382	6,050
2005	- 2	50	4	41.24	- 71.54	5,118	3,941
2006	- 1	65	1	58.25	- 54.53	2,974	2,283
2007	0	85	0	83.92	- 28.86	0833	772
2008	1	115	1	118.25	05.47	30	5
2009	2	150	4	161.24	48.46	2,348	1,385
2010	3	205	9	212.89	100.11	10,022	8,505
2011	4	285	16	273.20	160.42	25,735	29,660
		Σ Y = 1050 $\bar{Y}$ = 112.78				Σ = 59775	Σ = 60306

Therefore, Coefficient of determination = r = $\frac{\Sigma(\text{Yest} - \bar{Y})^2}{\Sigma(Y - \bar{Y})^2} = \frac{59775}{60306} = 0.991$

This means 99.1 per cent of the total variation of the Y's can be attributed to the relationship with X. However, any strong correlation must not be mistaken for a direct cause-effect relationship. Increasing years do not directly cause the increase in TV sales. It should not also be inferred that in the year 2046 the demand for TV sets will be almost 100 times higher than in the year 2011.

While the regression analysis along with the determination of correlation coefficients seems like a technique which has taken care of the causal factors and the 'fit' of the relationship between the dependent and independent variables, a few words of caution, while forecasting, may be necessary:

1. The regression or the relation is valid only within the range of the observed values that is, a regression line should be used, strictly speaking, only for the range of values it was developed from.
2. Such an analysis also assumes that the variations around the regression line fitted are deviations due to random causes and therefore, is not sensitive to any cyclical and/or seasonal changes. In such cases, an additional time-series analysis may be necessary.
3. In a regression analysis, all the observations, recent as well as past, are given equal consideration or weightage which may not be proper in several situations.
4. It may be fallacious to interpret high values of the correlation coefficient as implying cause and effect relationship.

Illustration 16 :

Following is the data obtained from the Bureau of Industrial Costs and Prices. Have the prices kept pace with the rising costs?

	2004	05	06	07	08	09	10	11	12
Costs per unit of output	203	216	223	239	248	253	279	301	311
Price of final output	225	242	250	271	275	277	295	318	329

Solution:

Let us call costs as X and prices as Y as shown in the following table :

X	Y	$x = X - \bar{X}$	$y = Y - \bar{Y}$	x^2	xy	y^2
203	225	- 49.6 .	50.8	2460	2520	2581
216	242	- 36.6	33.8	1340	1237	1142
223	250	- 29.6	25.8	876	764	666
239	271	- 13.6	04.8	185	65	23
248	275	- 04.6	00.8	21	4	1
253	277	- 00.4	1.2	0	0	1
279	295	26.4	19.2	697	507	369
301	318	48.4	42.2	2343	2042	1781
311	329	58.4	53.2	3411	3107	2830
$\sum X = 2273$	$\sum Y = 2482$			$\sum x^2 = 11333$	$\sum xy = 10246$	$\sum y^2 = 9393$

$\therefore\ \bar{X} = 252.60\ \therefore\ \bar{Y} = 275.80$

For a linear regression, the coefficient of correlation between the variables X and Y is given by:

$$r = \frac{\sum xy}{\sqrt{\sum x^2}\ \sqrt{y^2}}$$

where, as already noted, $x = X - \bar{X}$ and $y = Y - \bar{Y}$

This is called product-moment formula. Accordingly,

Accordingly,

$$r = \frac{10246}{\sqrt{(11333)\,(9393)}} = \frac{10246}{10318} = 0.99$$

Therefore, there is a close correlation between costs and prices.

Another Method:

This method uses the relative ranks between the data of each of the variables. The correlation coefficient so obtained is called Rank Correlation Coefficient.

Let us, then, write the X's and Y's in terms of their relative ranks (ranks increase as the values of X or Y increase). The least value of X is given the rank of 1, the next higher value a rank of 2, the next higher to the latter a rank of 3 and so on. The same ranking is done for the variable Y. Refer to the table given below:

	2004	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
Relative rank of costs, X	1	2	3	4	5	6	1	8	9
Relative rank of prices, Y	1	2	3	4	5	6	1	8	9
Differences in ranks of X and Y, D	0	0	0	0	0	0	0	0	0

Now, the coefficient of rank correlation is given by

$$r_{rank} = 1 - \frac{6\sum D^2}{N\ (N^2\ -\ 1)}$$

where N = number of data points.

In the present case, however, $\sum D^2 = 0$. Therefore, $r_{rank} = 1$, which indicates a perfect correlation between the variables.

Since the rank correlation coefficient is based purely on the ranks, it is a more rough estimate of the correlation between the variables.

Illustration 17:

Bangalore Beijing Beauticians (BBB) estimate that their customers on any day depend upon the number of women visiting the shopping complex in which BBB is located. The relationship is expressed as:

C = (W/50) - 10

where C = no. of customers

W = no. of women visiting the complex

The total variation and the explained variation are 3200 and 2626, respectively.

(a) What is the coefficient of correlation?

(b) What is the coefficient of determination?

(c) On a certain day, 2,900 ladies visited the shopping complex. How many customers should have been expected at BBB?

Solution:

(a) Coefficient of correlation,

$$r = \sqrt{\frac{\text{Explained variation}}{\text{Total variation}}} = \sqrt{\frac{2,626}{3,200}} = 0.905884$$

(b) Coefficient of determination is, in the case of simple regression, $r^2 = 0.820625$

(c) C = (W/50) - 10

Now, W = 2900

Therefore, C = (2900/50) - 10 = 48

The number of customers expected on that day is 48

METHOD I WHEN ACTUAL VALUES ARE TAKEN

The regression equation of Y on X is expressed as follows:

$Y_c = a+bX$

Where *a* and *b* can be found out by solving the following two normal equations simultaneously:

$$\sum Y = Na + b\sum X$$

$$\sum XY = a\sum X + b\sum X^2$$

The regression equation of X on Y is expressed as follows:

$X_c = a + bY$

Where *a* and *b* can be found out by solving the following two normal equations simultaneously:

$$\sum X = Na + b\sum Y$$

$$\sum XY = a\sum Y + b\sum Y^2$$

Illustration 18 : From the following table find :

(1) Regression Equation of X on Y.

(2) Regression Equation of Y on X.

X	10	12	18	22	25	9
Y	15	18	21	26	32	8

Solution : Table : Calculation of Regression Equations

X	y	x^2	Y^2	XY
10	15	100	225	150
12	18	144	324	216
18	21	324	441	378
22	26	484	676	572
25	32	625	1024	800
9	8	81	64	72
$\Sigma X = 96$	$\Sigma Y = 120$	$\Sigma X^2 = 1758$	$\Sigma Y^2 = 2754$	$\Sigma XY = 2188$

Regression equation of X on Y is given by :

X = a + bY

Where a & b can be found out be solving the following 2 equations simultaneously –

$\Sigma X = Na + b\,\Sigma Y$

$\Sigma XY = a\Sigma Y + b\Sigma Y^2$

Substantly the alones obtained from the table above, we get

96 = 6a + 120 b ….(1)

2188 = 120a + 2761b ….(2)

Multiply equation 1 by 20 & subtract equation 2 from it.

1920	=	120a + 2400 b
+2188	=	120a + 2761 b
- 268	=	0 - 351 b

$$b = \frac{-268}{-351}$$

b = 0.76

Put this value of b in eq .... (1)

96 = 6a + 120 x 0.76

96 = 6a + 91.3

6a = 96 – 91.3

$$a = \frac{4.8}{6} = 0.8$$

Put the value a & b in the regression equation of X on Y

X = a + by

X = 0.8 + 0.7bY

Regression equation of Yon X is given by

Y = a + bX

Where constants *a* and *b* can be found out by solving the following 2 normal equations simultaneously—

$\Sigma Y = Na + b\Sigma X$

$\Sigma XY = a\Sigma X + b\Sigma X^2$

Substituting the value obtained from the above table, we get

$120 = 6a + 96b$ ....(1)

$2188 = 96a + 1758b$ ....(2)

Multiply e.g. 1 by 16 & subtract equation 2 from it

$$\begin{array}{rl} & 1920 = 96a + 15366 \\ - & 2188 = 96a + 17586 \\ \hline & -268 = 0 + -222b \end{array}$$

$$b = \frac{268}{222} = 1.21$$

Put the value of b in equation 1

$120 = 6a + 96 \times 1.21$

$120 = 6a + 116.16$

$6a = 120 - 116.16$

$6a = 3.84$

$$a = \frac{3.84}{6} = 0.64$$

Put the value of *a* and 6 in the regression equation of Y on X

$Y = a + bX$

$Y = 0.64 + 1.21X$

There is an alternative method of finding the regression equations. Instead of the normal equations, deviations from the respective arithmetic mean or assumed mean are considered :

METHOD II WHEN DEVIATIONS ARE TAKEN FROM ACTUAL MEAN

Regression equation of X and Y is given by

$$X - \bar{X} = b_{XY}(Y - \bar{Y})$$

where $\bar{X}$, $\bar{Y}$ are actual mean of X & Y series respectively

$$b_{XY} \frac{\sum XY}{\sum Y^2}$$

ΣXY = Sum of product of deviations taken from actual mean of X & Y.
ΣY^2 = Sum of sequare of deviations from actual mean of Y.
Regression equation of an X is given by

$$Y - \bar{Y} = b_{yx}(X - \bar{X})$$

Where $b_{YX} = \dfrac{\sum XY}{\sum X^2}$

$\sum XY$ = Sum of product of deviations taken from actual mean of X & Y

$\sum X^2$ = Sum of square of deviations from actual mean of X.

Illustration 19 : From the ill-18 find the two regression equation by taking deviations from actual mean.

Solution :

Table : Calculation Regression Equations

X	Y	$X-\bar{X}=x$	$Y-\bar{Y}=Y$	x^2	Y^2	XY
10	15	-6	-5	36	25	30
12	18	-4	-2	16	4	8
18	21	2	1	4	1	2
22	26	6	6	36	36	36
25	32	9	12	81	144	108
9	8	-7	-12	49	144	84
$\sum X = 96$	$\sum Y = 120$	0	0	$\sum X^2 = 222$	$\sum Y^2 = 354$	$\sum XY = 268$

$$\bar{X} = \frac{96}{6} = 16$$

$$\bar{Y} = \frac{120}{6} = 20$$

Regression equation of x on Y

$$X - \bar{X} = b_{XY}(Y - \bar{Y})$$

Where $b_{XY} = \dfrac{\sum XY}{\sum Y^2}$

$$b_{XY} = \frac{268}{354} = 0.76$$

putting the value of b_{YX} in the above equation & also put $\bar{X} = 16$ & $\bar{Y} = 20$

X – 16 = 0.76 (Y – 20)

X – 16 = 0.76Y – 15.2

X = 0.76Y – 15.2 + 16

X = 0.76Y + 0.8

Regression equation of Y on X

$$Y - \overline{Y} = b_{YX}(x - \overline{x})$$

Where $b_{YX} = \frac{\sum XY}{\sum x^2}$

$$b_{YX} = \frac{268}{222} = 1.21$$

Putting the value of b_{YX} in above equation & also put $\overline{Y} = 20$ & $\overline{X} = 16$

Y - 20 = 1.21(X - 16)

Y - 20 = 1.21X - 1.21X16

Y - 20 = 1.21X -19.36

Y = 1.21X -19.36+ 20

Y = 1.21X +0.64

METHOD III WHEN DEVIATIONS ARE TAKEN FROM ASSUMED MEAN

In case the actual mean of the respective series are not an integer but are in decimals, it becomes cumbersome to calculate deviations from actual mean as all the values so calculated would also be in points. In such a case deviations are taken from assumed mean to simplify the calculations.

Regression equation of X on Y is given by

$$X - \overline{X} = b_{XY}(Y - \overline{Y})$$

Where $b_{XY} = \frac{\sum d_X d_Y - \sum d_X \sum d_Y}{\sum d_X^2 \frac{\left(\sum d_Y\right)^2}{N}}$

Regression equation of Y on X is given as

$$Y - \overline{Y} = b_{YX}(X - \overline{X})$$

Where $b_{YX} = \frac{\sum d_X d_Y - \sum d_X \sum d_Y}{\sum d_X^2 \frac{\left(\sum d_X\right)^2}{N}}$

Illustration 20 :

Calculate 2 regression equations from the following table—

X	10	12	15	19	15
Y	12	15	25	35	14

Solution : Table : Calculation Regression Equations

X	Y	d_x	d_y	d_x^2	d_y^2	$d_x d_y$
10	12	-5	-13	25	169	65
12	15	-3	-10	9	100	30
15	25	0	0	0	0	0
19	35	4	10	16	100	40
15	14	0	-11	0	121	0
$\Sigma X = 71$	$\Sigma Y = 101$	$\Sigma d_X = -4$	$\Sigma d_Y = -24$	$\Sigma d_X^2 = 50$	$\Sigma d^2_Y = 490$	$\Sigma d_X d_Y = 135$

$$\bar{X} = \frac{71}{5} = 14.2$$

$$\bar{Y} = \frac{101}{5} = 20.2$$

Since $\bar{X} \& \bar{Y}$ are not an integer we would solve it by taking assume mean of 15 from X series, and 25 from Y series

REGRESSION EQUATION OF X ON Y

$$X - \bar{X} = b_{XY}(Y - \bar{Y})$$

$$b_{XY} = \frac{\sum d_X d_Y - \sum d_X \sum d_Y}{\sum d_Y^2 \; \frac{\left(\sum d_Y\right)^2}{N}}$$

By putting the values from the above table we get

$$b_{XY} = \frac{135 - (-4)x(-24)}{490 - \frac{(-24)^2}{5}}$$

$$= \frac{135 - 96}{490 - \frac{576}{5}}$$

$$= \frac{39}{490 - 115.2} = \frac{39}{374.8} \quad 0.104$$

$$X - \bar{X} = b_{XY}(Y - \bar{Y})$$

$X - 14.2 = 0.104 (Y - 20.2)$

$X - 14.2 = 0.104Y - 2.10$

$X = 0.104Y - 2.10 + 14.2$

$X = 0.104Y + 12.1$

Regression equation of Yand X

$$Y - \bar{Y} = b_{YX}(x - \bar{x})$$

$$\text{Where } b_{YX} = \frac{\sum d_X d_Y - \sum d_X \sum d_Y}{\sum d_X^2 \ \frac{\left(\sum d_X\right)^2}{N}}$$

$$b_{YX} = \frac{135 - (-4)(-24)}{50 - \frac{(-4)^2}{5}}$$

$$= \frac{135 - 96}{50 - \frac{16}{5}}$$

$$= \frac{39}{50 - 3.2} = \frac{39}{46.8} = 0.83$$

$$Y - \bar{Y} = b_{YX}(X - \bar{X})$$

$$Y - 20.2 = 0.83\ (X - 14.2)$$

$$Y - 20.2 = 0.83\ X - 0.83\ X\ 14.2$$

$$Y = 0.83X - 11.78 + 20.2$$

$$Y = 0.83X + 8.42$$

2.5 CAPACITY PLANNING

Introduction

Capacity of a facility is referred to as its capability to produce. What should be the capacity of a facility is a complex but important issue. Capacity should be able to meet the present and future demand. The customer satisfaction is related to the service given by the facility. The customer should get the service in a reasonable time. Waiting too long for the service would result in loss of interest of the customer in the organization and he is likely to go to another organization to meet his requirement even if it amounts to a higher price. A valued customer always expects a prompt response. In case of his urgent requirements he expects a preferential treatment over other customers to see that his needs are met quickly.

Capacity planning is a scientific work and should be done very cautiously and carefully. Creation of capacity needs investment. It is necessary to calculate the return on the investment, which is linked with the capacity decision. Capacity planning decision involves the following considerations:

- What is the present capacity?
- What is the expected future capacity needs in the projected planning period? This could be in terms of product, manpower or technological factors.
- What are the options to meet the demand and how the capacity could be modified to meet the need?
- Evaluation of various options of capacity from financial, economical and technological considerations.
- Selection of the most appropriate option for the capacity to achieve the objectives.

Capacity planning helps to meet both the present and future demands and to some extent the sudden demands too. The characteristics of finished goods have also to be considered while planning the capacity. For example, cement has a shelf life of about six months and cannot be stored for long due to fear of its setting and loosing strength on prolonged storage. A correct assessment of the capacity assumes great importance in such situations. Further, capacity planning ensures that too much inventory of finished goods are not kept in store.

Definition of Capacity

Capacity is the rate of output from an operating system per unit time. Capacity is based on the output that the system can produce, store, and transport. For example, a cement plant could be capable to produce 3000 tons per day (tpd) of cement. Output could be also measured on the basis of resources available. The availability of resources can be in terms of number of machine hours, number of labour hours, number of tools, and square meters of the area. In case of a cement plant of 3000 tpd capacity, it could be said that there is one kiln of 3000 tpd capacity or there are two kilns of 1500 tpd capacity each to produce the cement. Output is also measured in terms of number of products that could be produced from the process.

Classification of capacity

Capacity is classified in many ways such as budgeted, dedicated, productive, protective, rated, safety, standing, and demonstrated. Mainly, the classification of capacity is talked in terms of:

- Designed or rated capacity
- Planned capacity
- Demonstrated capacity

Designed or Rated Capacity

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

The designed capacity of a process is calculated by taking into account the following:

- Number of machines available
- Capacity of each machine
- Number of shifts operated
- Duration of each shift
- Number of workdays in the period under consideration.

Capacity of the process is expressed in terms of above factors as shown below:

Capacity of the process = $CN_1N_2N_3H$

Where C = Capacity of machine per hour

N_1 = Number of machines

N_2 = Number of shifts per day

N_3 = Number of days in the time period

H = Hours in each shift

The above capacity calculations are based on the following assumptions:

- The workers performing the job are working with the same efficiency.
- There is no loss of time during product changeover.
- The process does not face machine breakdown or low rate of production during machine operation.
- Preventive or planned shutdowns are not included in the process time.
- No overtime is included.
- Workers are working at a normal rate.
- No loss of time due to worker problems.

In real life situations, these assumptions are not possible to maintain, as there are deviations from the above ideal situations. Therefore, the actual capacity of a process is normally lesser than the theoretical output capacity. The maximum capacity can be changed by changing the basic parameters. The maximum capacity is increased by the following actions:

- Increase the number of machines
- Increase the number of operating hours in the shift
- Increase the number of shifts, if possible
- Deploy trained manpower
- Avoid loss due to scrap or damages
- Control waste of time by workers
- Give incentives to workers to perform at a higher rate
- Outsource part of the workload.

Planned Capacity

Planned capacity is the capacity, which is maintained or achieved in normal operations. Production plans and schedules are worked out based on planned capacity. Planned capacity is usually less than the designed capacity due to the following reasons:

- Unexpected demand comes from some customers. Important customers often ask for shorter delivery to meet their urgent requirements, which need quick response and disturbs the planned programme.
- Preventive and predictive maintenance need time and influence the available time for production. Any variation in the time taken in completing the preventive and predictive maintenance would adversely affect the planned capacity. Preventive and predictive maintenance are important for uninterrupted work as the possibilities of breakdowns are reduced.
- Corrective repairs need time to take care of the unexpected breakdowns, which adversely affect the capacity of the process.
- Running at maximum capacity could be sustained for short time as both men and machines are strained, if they have to operate at the maximum capacity. If it is not taken care, the effect is harmful to both men and the machines. Therefore a reasonable efficiency is taken into consideration while determining the planned capacity. Normally it is 85 to 90 percent. However, attempts are made to keep the efficiency high.

The efficiency measures the ratio of planned resource allocation for a process and the actual resource consumed by the process. Planned resources are the resources needed in the form of labour time, machine time, tool, etc. Planned resource is compared with the standard performance or standard time.
Efficiency is calculated as:

Efficiency = Standard time/Actual time

Besides efficiency, there is another important factor in determining the planned capacity. This factor is known as 'Utilization Factor'. Utilization is the percentage of a resource's maximum capacity, which is expected to involve in production. For example, it is not expected by an employee to work effectively for every minute in an 8 hour shift. All workers including devoted employees need breaks to attend to their personal needs.

Utilization is expressed as:

Utilization = Actual hours/Scheduled available hours

Utilization factor and efficiency are both assumed to develop realistic and feasible plans. Unlike the utilization factor, efficiency, can exceed 100 percent, if the rate of work is higher than the standard performance as it happens in the case of an experienced and trained worker, who is able to produce more than the output of a normal performing employee. Efficiency can also be lower than 100% if untrained or inexperienced workers are deployed to perform the task.

Planned capacity is therefore calculated by determining the designed capacity and multiplying the same with the utilization factor and efficiency.

Planned capacity = Designed capacity × Efficiency × Utilization factor

It is also to be noted that a process could produce only as much output as that of the activity with the lowest capacity.

Illustration 1:

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

Solution:

$$\text{Utilization} = \frac{\text{Hours worked}}{\text{Hours available}}$$

$$= \frac{7 \text{ hours}}{8 \text{ hours}} \times 100$$

$$= 87.5\%$$

Illustration 2:

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

(a) Worker completes the job in 10 hours.

(b) Worker completes the job in 6 hours.

Solution:

(a) Worker completes have work in 10 hours

$$\text{Efficiency} = \frac{\text{Standard hours}}{\text{Actual hours}}$$

$$= \frac{8 \text{ hours}}{10 \text{ hours}} \times 100 = 80\%$$

(b) Worker completes the work in 6 hours

$$\text{Efficiency} = \frac{\text{Standard hours}}{\text{Actual hours}}$$

$$= \frac{8 \text{ hours}}{6 \text{ hours}} \times 100 = 133.3\ \%$$

Illustration 3:

A workshop operates on 2 shifts of 8 hours per day. It has 10 machines. It works for 5 days in a week. Machine utilization is 90% and the efficiency of the machines is 85%. Calcutta the designed/ rated capacity of the workshop in standard hours.

Solution:

Rated capacity of the workshop = No. of shifts x No. of hour's in each shift x No. of days /week x No. of Machines x Utilization factor x Efficiency

$= 2 \times 8 \times 5 \times 10 \times 0.90 \times 0.85$

= 612 Standard hour per week

Demonstrated Capacity

The actual level of output for a process over a period of time is known as the demonstrated capacity. Demonstrated capacity deals with the actual production over a time rather than the calculated designed capacity or planned capacity. Demonstrated capacity is determined by averaging the recorded figures of actual output over a period of time. It might differ from both the designed and the planned capacities for various reasons, such as:s

- Product mix
- Operator skill and experience
- Health of equipment or machines
- Type of jobs

- Quality of materials
- Inaccurate standards for process performance
- Idle time
- Blockages
- Rejection due to poor quality
- Training time of the operators
- Other factor

Illustration 4:

An assembly line of an item A has the following output in a 10 week period:

Week No	Standard hours produced
1	350
2	375
3	380
4	400
5	300
6	325
7	340
8	370
9	390
10	350

Calculate the demonstrated capacity of the assembly line per week.

Solution:

Demonstrated capacity is the average of the total standard hours produced over a number of periods.

Total number of weeks = 10

Total standard hours produced = 3,580 standard hours

Average per week = 3,580/10 = 358 standard hours

Illustration 5:

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

Solution:

Productivity = Efficiency x Utilization

$$\text{Efficiency} = \frac{\text{Standard time allowed}}{\text{Actual hours used}}$$

$$= \frac{7}{8} \times 100 = 87.5\%$$

$$\text{Utilization} = \frac{\text{Actual time worked}}{\text{Hours available}}$$

$$= \frac{8}{12} \times 100 = 66.67\%$$

Productivity = Efficiency x Utilization

= 87.5% x 66.67% = 58.83%

$$\text{Also productivity} = \frac{\text{Standard hours of output}}{\text{Clock time scheduled}}$$

$$= \frac{7}{12} \times 100 = 58.33\%$$

Units of Measure for Capacity

Capacity is expressed by a particular unit. The choice for a particular unit differs based on the business or on the product. Unit of measure for production of cement in a cement plant would be tones/day (tpd) or tones per year (tpy) whereas the unit of measure for oil refinery is barrels per day. We see that different units of measures are adopted for different purposes.

Capacity is also measured in terms of the inputs or the outputs of the conversion process. Table 2.5.1 shows examples of units of measure based on input and output in different facilities.

Table 2.5.1 Units of measures in different facilities based on input and output

Base	Facilities	Unit of Measure
Output	1. Cement Plant	i. Tonnes per day tpd)/tones per year (tpy)
	2. Electric supply company	ii. Mega watts
	3. Cycle factory	iii. Number of cycles
	4. Dairy plant	iv. Liters of milk
Input	5. College	v. Number of students enrolled Number of courses provided Number of faculty members
	6. Research organization	vi. Number of scientists
	7. Aeroplane	vii. Number of seats
	8. Aerodrome	viii. Number of passengers handled
	9. Rail network	ix. KM of rail line
	10. Roads	x. KM of road.

Unit of measure is linked with the level at which the details are discussed. For example, the capacity of a workstation in a workshop is given by the number of jobs completed. But at the level of the Board, the capacity of the workstation is given in terms of Rupees in Lakhs/Crores. Standard hours are normally used for planning the schedule of production of the workstation.

There should be one criterion for selecting the unit of capacity, which is common across the mix of units produced in that facility. In this way, it is possible for a unit of measure to allow all the products to be stated in comparable terms.

Capacity Measurement Over Time Spans

Capacity available and capacity required are measured in the following time spans:

- Short-term Capacity Requirement Plans.
- Intermediate term Rough Cut Capacity Plans.
- Long-term Resource Requirement Plans.

In real life situations, it is difficult to get a realistic measure of the capacity due to day variations.

Capacity Management

In normal circumstances, designed capacity is higher than the planned and demonstrated capacities and planned capacity is higher than demonstrated capacity. However, in real life situation different situations are encountered.

There are situations of excess capacity as well as insufficient capacity in plant operations. When a firm is able to produce more with the existing resources or more than the customer's demand, the process is underutilized and presents an excess capacity. This situation is not desirable as the organization could be incurring costs for idle machines.

In another situation, the firm could face a situation of insufficient capacity due to some resource constraints. These include lack of adequate machines, facilities or tools, which result in lower output as compared to the level that the firm needs to satisfy demand. This problem is tackled by adding new capacity in the form of new facilities, procuring additional equipment or by drawing more heavily from suppliers. These initiatives would help in matching with the designed capacity.

The biggest challenge before the management in relation to the capacity is how to optimize the use of existing capacity. Ineffective use of capacity is due to various reasons, such as:

- Current organization of productive resources.
- Unnecessary tasks being carried out in the process.
- Frequent breakdown of equipment.
- Poor quality of materials from suppliers.
- Delays in lead time for material supplies resulting in delay in deliveries.
- Absenteeism of staff.
- Incorrect process design.

The existing capacity could be optimally utilized by identifying and eliminating the problems. It is essential to diagnose the problem and correct the situation, which might not even need any additional investment. Even if some additional investment is needed it would be a very nominal expense. Energy audit and technical audit studies are steps in third direction. At times, organization needs the help of external consultations of consulting organizations to identify the problems and advice solutions.

Management encounters three situations as follows:

➢ Designed capacity > Planned capacity > Demonstrated capacity

➢ Designed capacity > Demonstrated capacity > Planned capacity

➢ Designed capacity = Demonstrated capacity > Planned capacity

Designed capacity > Planned capacity > Demonstrated capacity

In this situation, demonstrated capacity falls short of planned capacity and occurs due to problems with inputs or with the available level of capacity. Various reasons for low demonstrated capacity are:

- Too many setups needed for large number of products.
- Inadequate skill and experience or operators.
- Excessive breakdowns of machine.
- Trials for new materials or for new products.
- Material problems.
- Blockages.
- Rejections and rework.
- Other reasons such as power failures, strike etc.

The shortage of demonstrated capacity in comparison to the designed capacity is taken care of by examining the input problems to avoid any idle running of the facilities.

Designed capacity > Demonstrated capacity > Planned capacity

Demonstrated capacity is more than the planned capacity due to the following:

- Optimum product mix does not require setups.
- Deployment of well trained and experienced staff on the job help in high capacity outputs.
- Quality of incoming material is monitored.
- Less rejection rate, scrap and rework.

Designed capacity = Demonstrated capacity > Planned capacity

In this situation, the system produces more than the production plans demand using all its available capacity. If the situation continues for long, it shows the threat of insufficient capacity and could be responded to in the following manner:

- Add capacity: For long term solution add physical resources to add the capacity. For short term measures, addition of capacity is achieved by giving overtime or arranging additional shift.
- Change the Process: It may need analysis and evaluation of process flow and necessary modification of the process in use. Even sub-contracting to suppliers would help the situation.
- Reduce the input rate at which the orders enter the process. Another way may be to refuse new orders or quote longer delivery time. However, this would adversely affect the interest of the customers of the organization.

In few cases, the demonstrated capacity is found to be more than the designed capacity. This is observed especially when the process is improved by combining or eliminating unnecessary steps.

Calculation of Capacity

Following steps are taken in the calculation of capacity:

- Prepare a flow chart for the process. Stream line the operation or plan parallel operations as needed.
- Assign time for every activity in the process over the same time period for which the capacity of the process is to be measured; say year, month, week or a day.
- Use a common unit of measurement for the entire process.
- Determine the designed capacity of the process. Designed capacity of individual activity as well as the overall capacity of the process should be worked out. This would require consideration of operation whether in sequence or in parallel.
- Work out planned capacity for the overall process based on utilization factor and efficiency.
- Determine the demonstrated capacity based on the observed results over time.
- Compare demonstrated, planned and designed capacities and decide on:
    - Reducing the input rate.
    - Adding resources to increase the upper limit on process capacity.
    - Evaluating the current uses of capacity.

The management of capacity is the key planning responsibility of operations managers. All other operations planning takes place within the framework set by capacity decisions.

Capacity management is concerned with the matching of the capacity of the operating system and the demand placed on that system.

A system has capacity if it has at least some of each of the types of resources which are needed to perform its function. For example, a taxi service has capacity to transport a person if it has a vacant cab, a driver, fuel, etc., and a manufacturing system has capacity to produce if it has equipment, raw materials, labour, etc. Some of each of the necessary resources must exist if capacity is to exist. However, in measuring capacity we shall often refer only to the principal, or most costly, or most greatly used, or most commonly used resource in the operating system. **Table 2.5.2** identifies some of the resources and some of the measures which might be used to describe the capacity of different types of systems.

Table 2.5.2 The capacity of operating systems: measurement of capacity

Operating system	Measure of capacity
Manufacture	
Electricity generation	Megawatt capacity
Steel manufacture	Number of mills or blast-furnaces
Craft manufacture	Labour force
Transport	
Airline	Number of seats
Taxi service	Number of cabs
Telecommunications	Number of lines
Service	
Hospital	Number of beds
Library	Number of books/journals
Restaurant	Number of tables
Supply	
Warehouse	Volume
Retail shop	Shelf area
Petrol station	Number of pumps

Demand forecasting

In most situations the first step in capacity planning will be demand forecasting.

The length of the forecast period will depend largely on the nature of system resources and the nature of the market. Capacity plans may involve periods in excess of five years where there is sufficient stability or predictability of the nature of demand. A long-term view may be essential where there is a long lead time on the provision or replacement of resources. In contrast, a shorter-term view would be appropriate where the nature of demand is less stable or less predictable, where resources are more readily provided or replaced, or where the manner in which the function is accomplished may change, through, for example, technological advances.

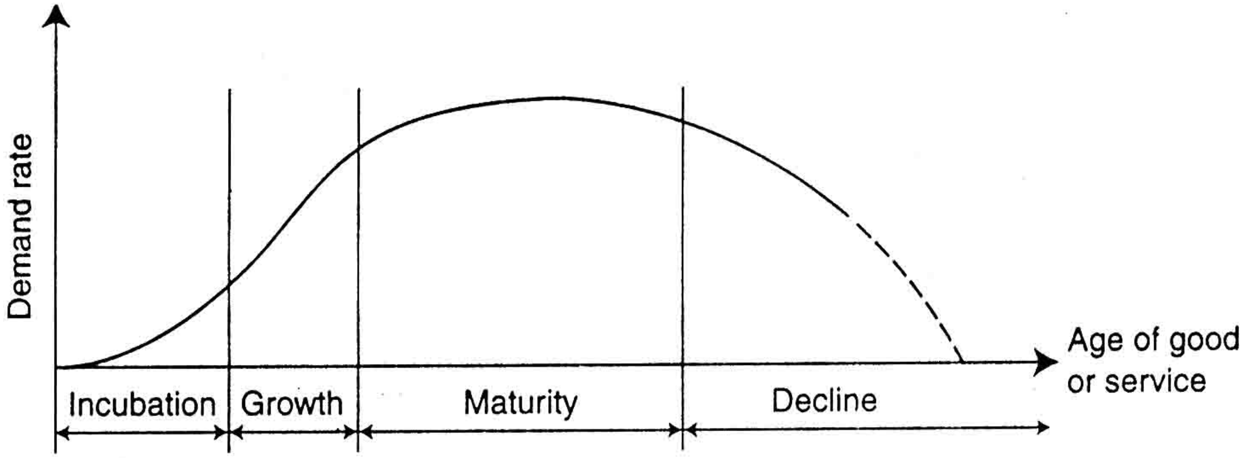


Fig. 2.5.1 A life-cycle curve for a single good or service

The demand life-cycle

In forecasting demand for goods or services it is appropriate to recognize that in many cases demand is a function of age. The classic life-cycle curve shown in **Figure 2.5.1** illustrates this relationship. This curve will normally apply in the case of goods or services consumed directly by the public (e.g. domestic appliances, sport and leisure facilities). The time-scale will depend on the nature of the product or service. While there is a tendency to assume continued growth for goods and services such as raw materials, basic services and transport (e.g. steel, fuel, medical care, rail and air transport), a similar life-cycle relationship may in fact exist, although the time-scale may be considerable.

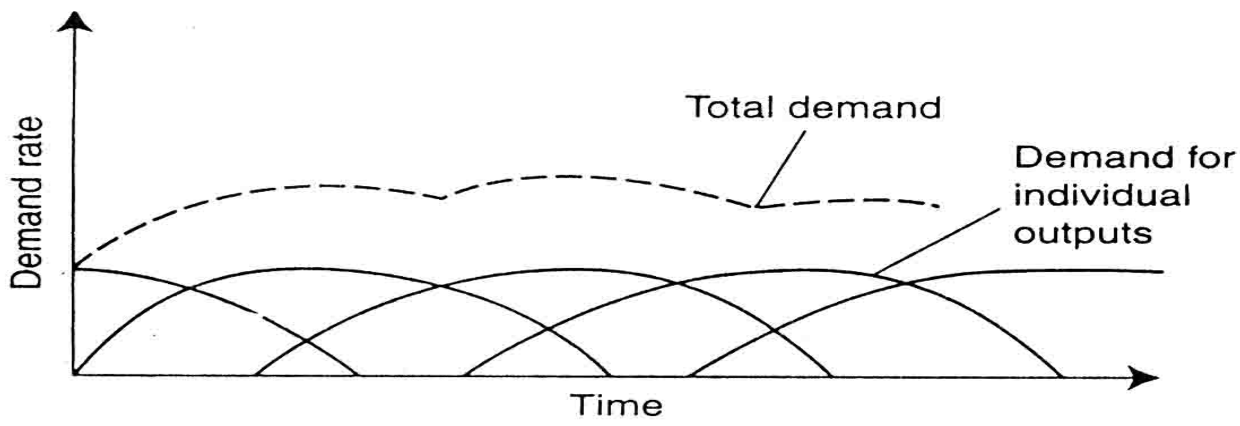


Fig. 2.5.2 Combination of individual demand curves

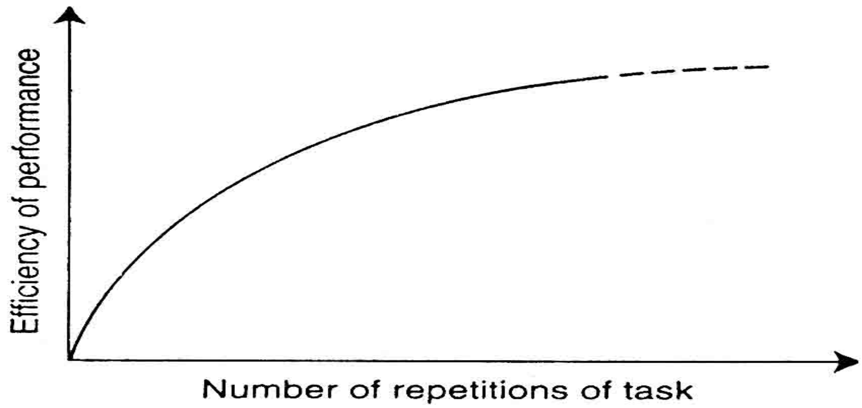


Fig. 2.5.3 A learning curve

Various policies might be employed for the provision of capacity to satisfy such demand. At one extreme, sufficient capacity to meet all expected demand might be provided from the outset, with attendant benefits of economies of scale in ordering, acquisition, training, etc. Alternatively, capacity might be matched to demand by incremental change over time, with benefits in utilization, etc. Systems providing several outputs from common resources might, despite the life-cycle characteristics, expect relatively steady total demand. **Figure 2.5.3** illustrates this.

Some factors affecting the capacity of resources

Given a forecast of demand for a future period, the next step in capacity planning is to decide what overall or general level of capacity to provide for that period.

Before proceeding further we must recognize that a given quantity of resources does not necessarily provide a fixed level of capacity. For example, in one situation a labour force of ten people may provide a greater capacity than in another. The absence of a fixed relationship between a quantity of physical resources and capacity is a result of a variety of factors.

Dealing with Demand Fluctuations -Capacity Management Strategies

Faced with fluctuating and uncertain demand levels there are two basic capacity planning strategies which might be employed: (1) providing for efficient adjustment or variation of - system capacity; and (2) eliminating or reducing the need for adjustments in system capacity.

Table 2.5.3 Means available for capacity adjustment (capacity strategy 1)

Resources	Capacity increases	Capacity reductions
All	Subcontract some work Buy rather than make (manufacture only)	Retrieve some previously subcontracted work [(Make rather than buy (manufacture only)]
Consumed	Reduce material content	
Material	Substitute more readily available materials Increase supply schedules Transfer from other jobs	Reduce supply schedules Transfer to other jobs
Fixed	Scheduling of activities ,i.e. speed and load increases	

Resources	Capacity increases	Capacity reductions
Machines	Scheduling of maintenance, i.e. defer, hire or transfer from other functions	Scheduling of maintenance ,'i.e. advance Subcontract or transfer to other functions
Labour	Hours worked, i.e. overtime rearrangement of hours, shifts, holidays' Workforce size ,i.e. staffing levels Temporary labour transfer from other areas	Hours worked, i.e. short time rearrangement of hours, shifts, holidays Workforce size, i.e. layoffs, transfer to, other areas

Table 2.5.4 Methods for eliminating or reducing the need for capacity adjustment (strategy2)

Method		Relevance for:	
		Dealing-with demand increases	Dealing with demand decreases
(a)	Eliminate adjustment by: Maintaining sufficient excess capacity	Yes	Not directly relevant
(b)	Reduce/minimize adjustment by		
(i)	Some excess capacity, together with: Loss of trade and/or	Yes (ignore some demand)	Not directly relevant
	Customer queing	Yes (increase queue)	Yes (reduce queue)
(ii)	Output stocks	Yes (reduce stock)	Yes (increase stock)

Capacity Planning Procedures

In this section we shall describe some of the procedures which may be used in capacity planning. Before going into detail two general points will be made.

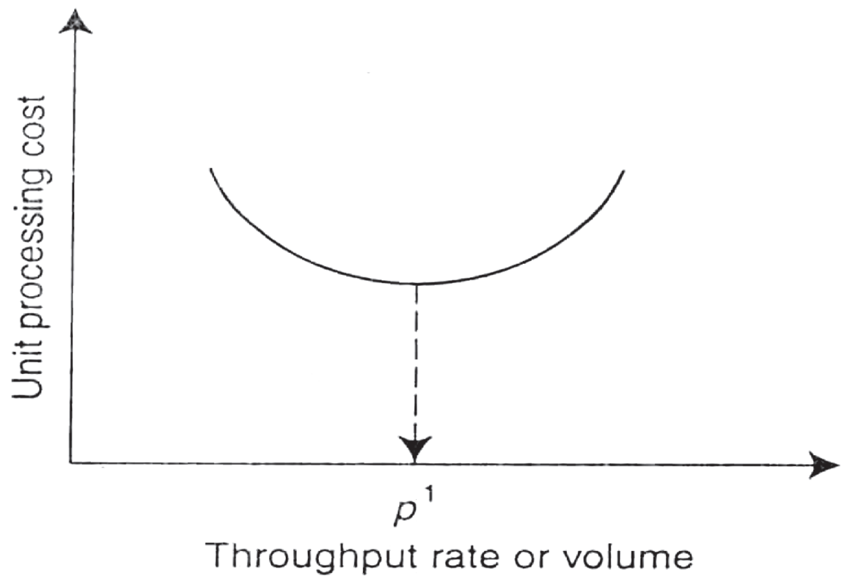


Fig. 2.5.4 Unit cost/volume relationship

Aggregation

The term aggregate planning is often employed in the capacity context. The implication is that such planning is concerned with total demand, i.e. all demands collected together. This is of relevance in operating systems where different goods or services are provided. In such cases capacity planning will seek to estimate or measure all demands and express the total in such a way as to enable enough of all resources (or total capacity) to be provided. Demand for all outputs must therefore be expressed in common capacity-related units such as the number of resources or resource hours required.

Economic operating levels

Figure 2.5.4 shows the relationship between the unit cost of processing and the throughput rate for a hypothetical situation. It will be evident from the figure that the economic throughput rate is p^1 since this is the rate at which the unit cost is least. The use of a higher throughput rate involves higher unit costs, as does a lower throughput rate. Such a situation will often exist, especially where an operating system has been designed specifically to process items or customers at a particular rate. For example, in a flow processing system involving a series of interdependent facilities, the entire system must be designed to provide a particular output or throughput rate. If the output rate is reduced, then costs will increase because of facility idle time, etc., and if the output rate is increased, then subcontracting, overtime work, duplicate facilities, etc. will be required, all of which will contribute to the unit output costs.

If it is now considered appropriate to increase the level of resources in order to provide for a greater throughput rate, then it may be possible to shift the entire curve as shown in **Figure 2.5.5.** This implies that the facilities have been rearranged or set up in a different manner so that the intended rate is now p^2. Again, departures from this throughput rate p^2 can incur increased unit costs.

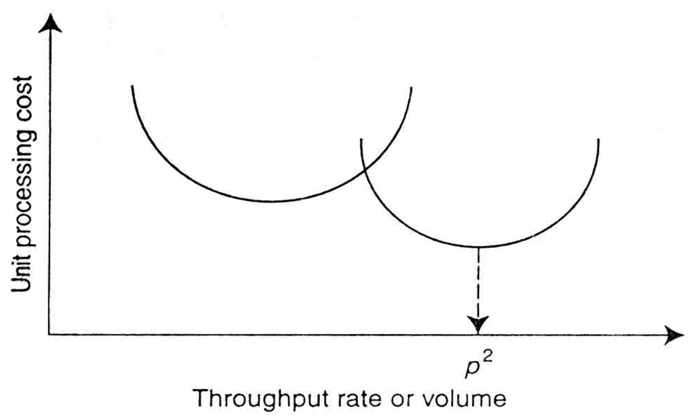


Fig. 2.5.5 Unit cost/volume relationships

This concept of an 'economic operating level' is relevant in many situations and is of value in capacity planning since, where curves such as those shown in **Figures 2.5.4** & **2.5.5** are available or can be approximated, the cost of changing capacity through the adoption of capacity planning strategy 1 can be established for different magnitudes of change.

Notice that in some situations the cost-throughput rate relationship is not a 'smooth' one. For example, in some situations a throughput rate can be increased only incrementally. However, whatever the nature of the relationship, provided it is known or can be approximated, the economic level of operations can be found and the cost of capacity changes above or below a particular level can be obtained.

Most of the available procedures are relevant only in particular situations and deal only with particular types of capacity planning problems. In introducing each of the procedures below we shall first try to indicate where the approach might be employed and for what particular purpose.

Cumulative graphs

This is a procedure for comparing alternative capacity plans for a period, particularly where there is a need to balance the costs of changing capacity against cost of insufficient or extra capacity. The capacity provided to satisfy estimated demand will, as shown above, be influenced by the strategy employed for meeting demand fluctuations. Graphical representation on the following data:

Table 2.5.5 Estimated monthly demand

Month	Working days	Cumulative days	Estimated demand (in resource hours)	Cumulative estimated demand
Jan.	20	20	500	500
Feb.	18	38	650	1,150
Mar.	22	60	750	1,900
Apr.	18	78	900	2,800
May	21	99	700	3,500
June	20	119	500	4,000
July	20	139	300	4,300
Aug.	10	149	300	4,600
Sept.	20	169	450	5,050
Oct.	21	190	500	5,550
Nov.	20	210	550	6,100
Dec.	18	228	300	6,400

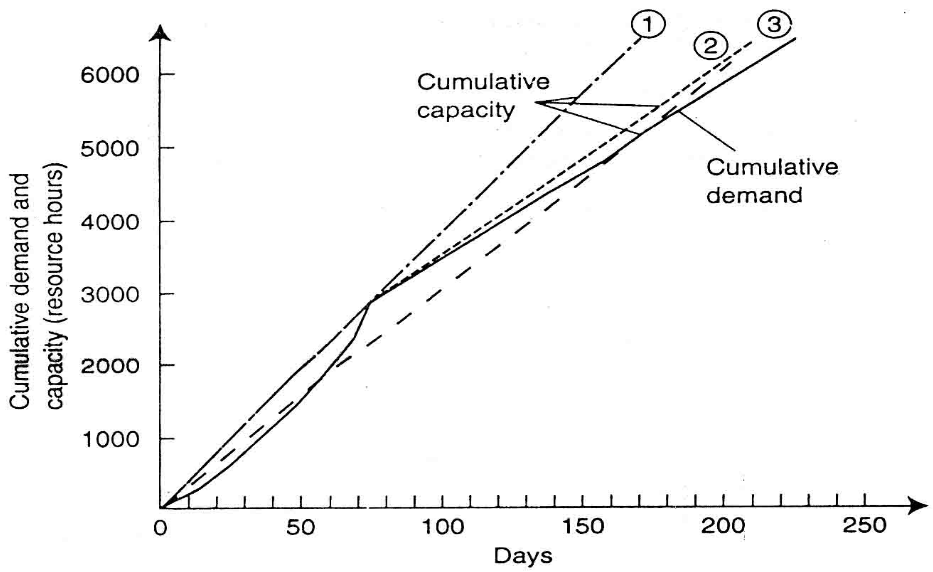


Fig. 2.5.6 Cumulative demand and capacity curves

Linear programming

This approach provides a means of allocating available capacity and inventories against a forward demand in such a way as to balance these costs and smooth the level of operations.

Various linear programming methods have been used in this context. Here we shall concentrate on the use of the 'transportation' algorithm. The 'transportation' method of linear programming provides a means of minimizing a combination of capacity and inventory costs. Various alternative means of providing capacity are recognized, typically normal working, overtime working and subcontracting. The use of the method requires that demands for each of several periods are satisfied from inventory and/or from the use of normal plus, if necessary, additional capacity in such a manner that total costs are minimized. The approach has one major disadvantage in that it is static, i.e. it is a method for formulating policy for a given period assuming no changes in circumstances, etc. during that period. Repeated recalculations for a forward period will overcome this to some extent, but there is a danger of sub-optimization.

Heuristic methods

These methods are largely concerned with workforce or capacity smoothing. They may be of relevance where there is a need to balance costs of capacity change with costs of inventories, A 'heuristic' method provides a good, but not necessarily the best, solution. In reality most operations management decisions are heuristic or, more colloquially, 'rules of thumb'.

The management coefficients model uses a simplified version of the workforce production level decision rules incorporated in the linear decision rule method. Coefficients for these rules are determined by regression analysis on historical performance, i.e. managers' actual past behaviour. The equation is then used to indicate the future decisions as with the linear decision rules.

An alternative approach involves a search of feasible solutions to establish the coefficients for the linear decision rule method. The coefficients are established to minimize total cost and the two equations are then used for planning purposes. Two approaches have been developed. The parametric production planning model deals with inventory, workforce changes, overtime costs and customer queuing. The search decision rule is of a similar nature.

Queuing theory methods

Such approaches may be of relevance in determining the capacity required in service and transport systems and/or in deciding levels of utilization of capacity and customer service levels. Transport and service systems depend on an input provided by the beneficiary of the service and 'processing' cannot take place until that is available. Because of this time dependence, capacity planning is constrained and such systems cannot usually achieve the same levels of resource productivity as manufacture or supply systems.

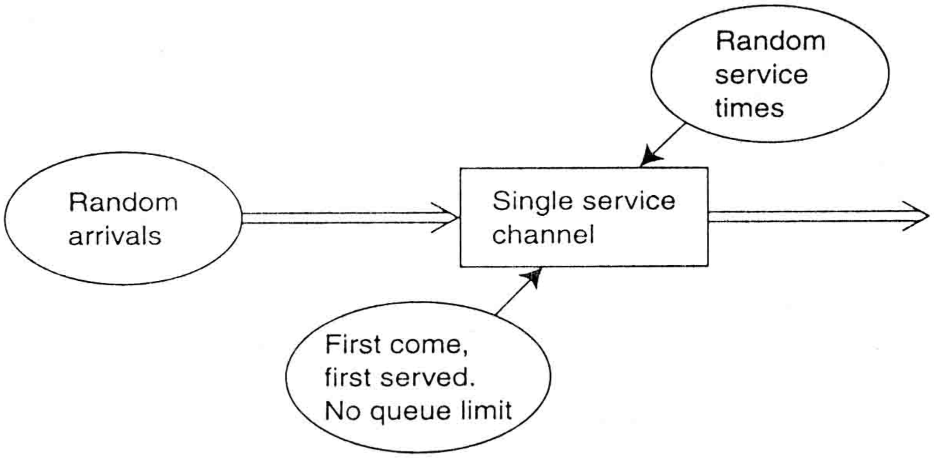


Fig. 2.5.7

However, some such systems improve utilization by scheduling inputs, i.e. by controlling them (e.g. appointments systems for GPs, dentists, etc., and certain types of transport system). In other situations (e.g. roads, hospitals, shops), since there is little control of input arrival rate, adequate capacity must be provided to meet peak demand without excessive 'customer' waiting time. Outside peak demand periods, low utilization must be tolerated unless alternative services can be provided. Queuing theory may be used in capacity planning in such situations.

Although input 'arrivals' may follow specific patterns, the overall pattern in many cases is random. This gives rise to queuing situations. The methods used to describe and analyse queuing situations depend on the form of the system, in particular:

(a) number of servicing units;

(b) configuration of servicing units, i.e. whether in parallel or in series;

(c) queue discipline;

(d) distribution of arrival times;

(e) distribution of service times.

The simplest case is shown in **Figure 2.5.7.**

Let,

P_n = probability of n units in system (i.e. queue + one being serviced)

L = average number of units in system

L_q = average number of units in queue

W = average time units spend in system

W_q = average time units spend in queue

where:

λ = average arrival rate (units/period of time)

μ - average service rate (units/period of time)

p = utilization parameter = $\frac{\lambda}{\mu}$

$\mu > \lambda$

If there are λ arrivals/h and the system has a capacity of μ/h, the system will be busy $\frac{\lambda}{\mu}$ proportion of time and idle $\left(1-\frac{\lambda}{\mu}\right)$ proportion of time. Thus:

P_0 (probability of no units in system) = $1-\frac{\lambda}{\mu}$

It can also be shown that:

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

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

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

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

N.B. L_q does not equal L - 1 since for some of the time the service channel is empty; the average number being served $\neq 1$.

A Systematic Approach to Capacity Decisions

Although each situation is somewhat different, a four-step procedure generally can help managers make sound capacity decisions. In describing this procedure, we assume that management has already performed the preliminary step of determining existing capacity.

1. Estimate future capacity requirements.
2. Identify gaps by comparing requirements with available capacity.
3. Develop alternative plans for filing the gaps.
4. Evaluate each alternative, both qualitative and quantitative, and make a final choice.

Step 1: Estimate Capacity Requirements

The foundation for estimating long-term capacity needs is forecasts of demand, productivity, competition and technological changes that extend well into the future.

The demand forecast has to be converted to a number that can be compared directly with the capacity measure being used. Suppose that capacity is expressed as the number of available machines at an operation. When just one product (service) is being processed, the number of machines required, M, is

Number of machines required =

$$\frac{\text{Processing hours required for year's demand}}{\text{Hours available from one machine per year after deducting desired cushion}}$$

$$M = \frac{Dp}{N\left[1 - \left(\frac{C}{100}\right)\right]}$$

Where D = number of units (customers) forecasts per year

p = processing time (in hours per unit or customers)

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

C = desired capacity cushion

The processing time, p, in the numerator depends on the process and methods selected to do the work. Estimates of p come from established work standards. The denominator is the total number of hours, N, available for the year, multiplied by a proportion that accounts for the desired capacity cushion, C. The proportion is simply 1.0 - C, where C is converted from a percentage to a proportion by dividing by 100.

If multiple products or services are involved, extra time is needed to change over from one product or service to the next. Setup time is the time required to change a machine from making one product or service to making another. Setup time is derived from process decisions, as is processing time. The total setup time is found by dividing the number of units forecasts per year, D, by the number of units made in each lot, which gives the number of setups per year, and then multiply by time per setup. For example, if the annual demand is 1200 units and the average lot size is 100, there are 1200/100 = 12 setups per year. Accounting for both processing and setup time when there are multiple products (services), we get.

Number of machines required =

$$\frac{\text{Processing and setup hours required for year's demand, summed over all products}}{\text{Hours available from one machine per year after deducting desired cushion}}$$

$$M = \frac{\left[Dp + \left(\frac{D}{Q}\right)s\right]_{product\,1} + \left[Dp + \left(\frac{D}{Q}\right)s\right]_{product\,2} \ldots. + \left[Dp + \left(\frac{D}{Q}\right)s\right]_{product}}{N\left[1 - \left(\frac{C}{100}\right)\right]}$$

Where Q = number of units in each lot P = Processing time

s = setup time (in hours) per lot

Always round up the fractional part unless it is cost efficient to use short-term conditions such as overtime or stockouts to cover any shortfalls. Now considered an example given below:

A copy center in an office building prepares bound reports for two clients. The center makes multiple copies (the lot size) of each report. The processing time to arrange and bind each copy depends on, among other factors, the number of pages. The center operates 250 days per year, with one eight-hour shift. Management believes that capacity cushion of 15 percent is best. Based on the following table of information, determine how many machines are needed at the copy center.

Item	Client X	Client Y
Annual demand forecast (copies)	2,000	6,000
Standard processing time (hour/copy)	0.5	0.7
Average lot size (copies per report)	20	30
Standard setup time (hours/lot)	0.25	0.40

Solution:

$$M = \frac{\left[Dp + \left(\frac{D}{Q}\right)s\right]_{\text{product 1}} + \left[Dp + \left(\frac{D}{Q}\right)s\right]_{\text{product 2}} .... + \left[Dp + \left(\frac{D}{Q}\right)s\right]_{\text{product}}}{N\left[1 - \left(\frac{C}{100}\right)\right]}$$

$$= \frac{[2000(0.5) + (2000/20)(0.25)]_{\text{client X}} + [(6000(0.7) + (6000/30)(0.40)]_{\text{client Y}}}{[(250 \text{ days / year})(1 \text{ shift / day})(8 \text{ hours / shift})(1.0 - 15/100)}$$

$$= \frac{5305}{1700} = 3.12$$

Rounding up to the next integer gives a requirement of four machines.

Step 2: Indentify Gaps

A capacity gap is any difference (positive or negative) between projected demand and current capacity. Identify gaps requires use of the correct capacity measurement. Complications arise when multiple operations and several resource inputs are involved. For example, in the early 1970s, airline executives incorrectly concluded that airlines having the larger share of seats flown attract a larger share of total passengers. In other words, fly more seats to get more passengers. Many airlines responded by buying more jumbo jets, but competitors flying smaller planes were more successful. The correct measure was the number of departures rather than the number of seats. Thus several airlines had to adjust the capacity imbalance between small and large planes by buying smaller planes and discontinuing use of some jumbo jets. Expanding the capacity of some operations may increase overall capacity. However, if one operation is a bottleneck, capacity can be expanded only if the capacity of the bottleneck operation is expanded. Let considered an example to understand this matter.

Grandmother's Chicken Restaurant is experiencing a boom in business. The owner expects to serve a total of 80,000 meals this year. Although the kitchen is operating at 100 percent capacity, the dining room can handle a total of 105,000 diners per year. Forecasts demand for the next five years is as follows.

Year 1: 90,000 meals

Year 2: 100,000 meals

Year 3: 110,000 meals

Year 4: 120,000 meals

Year 5: 130,000 meals

What are the capacity gaps in Grandmother's kitchen and dining room through year 5?

Solution:

The kitchen is currently the bottleneck at a capacity of 80,000 meals per year. Based on the demand forecast, the capacity gap for the kitchen is

Year 1: 90,000 – 80,000 = 10,000

Year 2: 100,000 – 80,000 = 20,000

Year 3: 110,000 – 80,000 = 30,000

Year 4: 120,000 – 80,000 = 40,000

Year 5: 130,000 – 80,000 = 50,000

Before year 3, the capacity of the dining room (105,000) is greater than demand. In year 3 and subsequently, there are capacity gaps for the dining room:

Year 3: 110,000 – 105,000 = 5,000

Year 4: 120,000 – 105,000 = 15,000

Year 5: 130,000 – 105,000 = 25,000

Step 3: Develop Alternatives

The next step is to develop alternative plans to cope with projected gaps. One alternative, called the base case, is to do nothing and simply lose orders from any demand that exceeds current capacity, other alternatives are various timing and sizing options for adding new capacity, including the expansionist and wait-and-see strategies. for example, BMW expanded its facility in Spartanburg, South Carolina in two stages when, in 1995, it added the Z-3 roadster production line to its already existing 325 line. Additional possibilities include expanding at a different location and using short-term options such as overtime, temporary workers, and subcontracting.

Step 4: Evaluate Alternatives

In this final step, the manager evaluates each alternative, both quantitatively and qualitatively.

Qualitative Concerns: Qualitatively, the manager has to look at how each alternative fits the overall capacity strategy and other aspects of the business not covered by the financial analysis. Of particular concern might be uncertainties about demand, competitive reaction, technological change, and cost estimates. Some of these factors cannot be quantified and have to be assessed on the basis of judgement and experience. Others can be quantified, and manager can analyze each alternative by using assumptions about the future. One set of assumptions could represent a worst case, where demand is less, competition is greater, and constructive costs are higher than expected. Another set of assumptions could represent the most optimistic view of the future. This type of "what if" analysis allows the manager to get an idea of each alternative implications before making a final choice.

Quantitative Concerns: Quantitatively, the manager estimates the change in cash flows for each alternative over the forecast time horizon, compared to the base case. Cash flow is the difference between the flow of funds into and out of an organisation over a period of time, including revenues, costs, and changes in assets and liabilities. The manager is concerned here only with calculating the cash flow attributable to the project.

Illustration 6:

You have been asked to put together a capacity plan for a critical bottleneck operation at the Surefoot Sandal Company. Your capacity measure is number of machines. Three products (men's, women's and children's sandals) are manufactured. The time standards (processing and setup), lot sizes, and demand forecasts are given in the following table. The firm operates two 8-hour shifts, 5 days per week, 50 weeks per year. Experience shows that a capacity cushion of 5 percent is sufficient.

Time Standards

Product	**Processing (hr/pair)**	**Setup (hr/lot)**	**Lot Size (pair/lot)**	**Demand Forecast (pairs/yr)**
Men's sandals	0.05	0.5	240	80,000
Women's sandals	0.10	2.2	180	60,000
Children's sandals	0.02	3.8	360	1,20,000

a. How many machines are needed?

b. If the operation currently has two machines, what is the capacity gap?

Solution:

a. The number of hours of operation per year, N, is

N = (2 shifts/day) × (8 hours/shift) × (5 × 50) days/machine-year

= 4000 hours/ machine-year

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:

$$M = \frac{\left[Dp + \left(\frac{D}{Q}\right)s\right]\text{men} + \left[Dp + \left(\frac{D}{Q}\right)s\right]\text{women} + \left[Dp + \left(\frac{D}{Q}\right)s\right]\text{children}}{N\left[1 - \left(\frac{C}{100}\right)\right]}$$

$$M = \frac{\left[80{,}000(0.05) + \left(\frac{80{,}000}{240}\right)(0.5)\right] + \left[60{,}000(0.10) + \left(\frac{60{,}000}{180}\right)2.2\right] + \left[1{,}20{,}000\ (0.02) + \left(\frac{1{,}20{,}000}{360}\right)3.8\right]}{4000\left[1 - \left(\frac{5}{100}\right)\right]}$$

$$= \frac{14{,}567 \text{ hours / year}}{3{,}800 \text{ hours machine – year}} = 3.8 \text{ or } 4 \text{ machines}$$

b. The capacity gap is 1.8 machines (3.8 – 2). Two more machines should be purchased, unless management decides to use short-term options to fill the gap.

Illustration 7:

The base case for Grand Mother's Chicken Restaurant is to do nothing. The capacity of the kitchen in the base case is 80,000 meals per year. A capacity alternative for Grandmother's Chicken Restaurant is a two-stage expansion. This alternative expands the kitchen at the end of year 0, raising its capacity from 80,000 meals per year to that of the dining area (105,000 meals per year). If sales in year 1 and year 2 live up to expectations, the capacities of both the kitchen and the dining room will be expanded at the end of year 3 to 130,000 meals per year. The initial investment would be ₹80,000 at the end of year 0 and an additional investment of ₹170,000 at the end of year 3. The pretax profit is ₹2 per meal. What are the pretax cash flows for this alternative through year 5, compared with the base case?

Solution

Table 2.5.6 shows the cash inflows and outflows. The year 3 cash flow is unusual in two respects. First, the cash inflow from sales inflow is ₹50,000 rather than ₹60,000. The increase in sales over the base is 25,000 meals (105,000 – 80,000) instead of 30,000 meals (110,000 – 80,000) because the restaurant's capacity falls somewhat short of demand. Second, a cash outflow of ₹170,000 occurs at the end of year 3, when the second-stage expansion occurs. The net cash flow for year 3 is ₹50,000 - ₹170,000 = - ₹120,000.

Table 2.5.6 Cash flows for Two-Stage Expansion at Grandmother's Chicken Restaurant

Year	Projected Demand (meals/yr)	Projected Capacity (meals/yr)	Calculation of Incremental Flow Compared to Base Case	Cash Cash Inflow (Outflow)
0	80,000	80,000	Increase kitchen capacity to 105,000 meals	= (₹80,000)
1	90,000	1,05,000	90,000 – 80,000 = (10,000 meals)(₹2/meal)	= ₹20,000
2	1,00,000	1,05,000	100,000 – 80,000 = (20,000 meals)(₹2/meal)	= ₹40,000
3	1,10,000	1,05,000	105,000 – 80,000 = (25,000 meals)(₹2/meal)	= ₹50,000
	Increase total capacity to 130,000 meals			= (₹170,000)
	The net cash flow for 3 year			(₹1,20,000)
4	1,20,000	1,30,000	120,000 – 80,000 = (40,000 meals)(₹2/meal)	= ₹80,000
5	1,30,000	1,30,000	130,000 – 80,000 = (50,000 meals)(₹2/meal)	= ₹1,00,000

Illustration 8:

Penelope and Peter Legume own a small accounting service and one personal computer. If their customers keep organized records, either of the owners can use the computer to prepare one tax return per hour, on average. During the first two weeks of April, both Legumes work seven 12-hour shifts. This allows them to use their computer around the clock.

a. What is the peak capacity, measured in tax returns per week?

b. The Legumes normally operate from 9 A.M. to 7 P.M., five days per week. What is their effective capacity, measured in tax returns per week?

c. During the third week of January, the legumes processed 40 tax returns. What is their utilization, as percentage of effective capacity?

Solution:

a. Peak capacity = (12 hours/shift) (2 shifts/day)(7 days/week)(1 return/hour)

= 168 returns/week

b. Although both Legumes may be present in the shop, the capacity is limited by the number of hours their one computer is available:

Effective capacity = (10 hours/day)(5 days/week)(1 return/hour)

= 50 returns/week

c. Utilization is the ratio of output of effective capacity:

$$\text{Utilization} = \frac{40 \text{ returns /week}}{50 \text{ returns / week}} \times 100\%$$

= 80%

Illustration 9:

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 × 4 = 1,200 hrs.
Y	400	6.0	400 × 6 = 2,400 hrs.
Z	500	3.0	500 × 3 = 1,500 hrs.
			Total = 5,100 hrs.

Step 2 : Annual production capacity of one machine in standard hours = 8 × 250 = 2,000 hours per year

Step 3 : Number of machines required = Work load per year/Production capacity per machine

= 5100/2000

= 2.55 machines = 3 machines.

Illustration 10:

A steel plant has a designed 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:

Efficiency of the plant = Actual output/ Effective Capacity

= 36,000/40,000 × 100 = 90%

Utilisation = Actual output/ Design Capacity

= 36,000 / 50,000 × 100 = 72%

Illustration 11:

An item is produced in a plant having a fixed cost of ₹ 6,000 per month, variable cost of ₹2 per unit and a selling price of ₹7 per unit. Determine

(a) The break-even volume.

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

(c) How many units should be produced to earn a profit of ₹ 4,000 per month?

Solution:

(a) Break-even-volume

Fixed cost (FC)	= ₹6,000 per month
Variable cost (VC)	= ₹2 per unit
Selling price (SP)	= ₹7 per unit

Let Q be the break even volume per month, then

Total cost	= Fixed Cost + (Variable cost / unit) × Quantity
TC	= FC + (VC × Q) = 6,000 + 2Q
Sales Revenue	= Selling price per unit × Quantity = 7Q

For Q to be break-even volume,

Sales Revenue	= Total cost
i.e., 7Q	= 6,000 + 2Q
5Q	= 6,000
Q	= 6,000/5
	= 1,200 units / month

(b) For Q = 1,000,

Profit	= Sales Revenue - Total cost
	= SR - (FC + VC × Q)
	= (7 × 1,000) - (6,000 + 2 × 1,000)
	= (7,000) - (6,000 + 2,000)
	= ₹ 7,000 - 8,000 = - ₹1,000 (i.e., loss of ₹1,000)

(c) For profit of ₹4,000, What is Q?

SR	= FC + (VC) Q + Profit
7Q	= 6,000 + 2Q + Profit
7Q - 2Q	= (6,000 + 4,000)
5Q	= 10,000
	= 2,000 units

Illustration 12:

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:

(a) Break-even point

Let QBEP be the break even point.

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

Then QBEPR = FC + (VC) QBEP

QBEP =FC/(R – VC)

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

Then, Q1 = 12,000/(50 – 20) = 12,000/30 = 400 units

(Not within the range of 0 to 300)

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

Then, Q2 = 15,000/(50 – 20) = 15,000/30 = 500 units

(within the range of 301 to 600)

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

Then, Q3 = 21,000/(50 – 20) = 21,000/30 = 700 units

(with in the range of 601 to 900)

(b) 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).

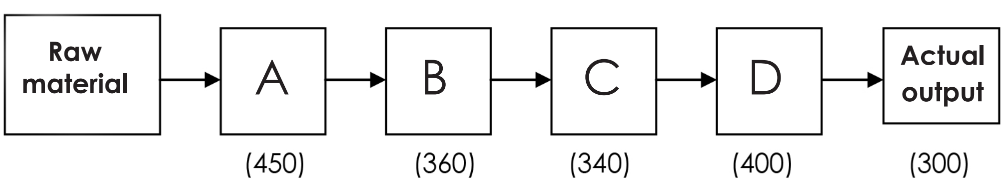
Also, the break even point for 3 machines is 700 units which is more than the upper limit of projected demand of 600 to 650 units and hence not feasible. For 2 machines option the break even volume is 500 units and volume range is 301 to 600.

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.

Illustration 13:

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) System efficiency = Actual output/ System capacity

= (300/340) × 100 (i.e., maximum possible output) = 88.23%

Illustration 14:

A firm operates 6 days a week on single shift of 8 hours per day basis. There are 10 machines of the same capacity in the firm. If the machines are utilised for 75 percent of the time at a system efficiency of 80 percent, what is the rated output in terms of standard hours per week?

Solution:

Maximum number of hours of work possible per week

= (Number of machines) × (Machine hours worked per week)

= 10 × 6 × 8 = 480 hours

If the utilisation is 75% then number of hours worked = 480 × 0.75 = 360 hours.

Rated output = utilised hours × system efficiency = 360 × 0.8 = 288 standard hours.

Illustration 15:

A manufacturing company has a product line consisting of five work stations in series. The individual workstation capacities are given. The actual output of the line is 500 units per shift.

Calculate (i) System capacity (ii) Efficiency of the production line

Workstation no.	A	B	C	D	E
Capacity/shift	600	650	650	550	600

Solution:

(i) The capacity of the system is decided by the workstation with minimum capacity/shift, i.e., the bottleneck. In the given example, the work station 'D' is having a capacity of 550 units/ shift which is a minimum.

Therefore, the system capacity = 550 units/shift.

(ii) The actual output of the line = 500 units/shift.

Therefore, the system efficiency = Actual capacity/System capacity × 100

= 500/550 × 100 = 90.91 %

2.6 PROCESS PLANNING

A process is a sequence of activities that is intended to achieve some result, typically to create added value for the customers.

Types of Processes:

(i) Conversion Processes i.e., converting the raw materials into finished products (for example, converting iron ore into iron and then to steel). The conversion processes could be metallurgical or chemical or manufacturing or construction processes.

(ii) Manufacturing Processes can be:

(a) Forming Processes, (b) Machining Processes and (c) Assembly Processes.

(iii) Testing Processes which involve inspection and testing of products (some times considered as part of the manufacturing processes).

Forming Processes include foundry processes (to produce castings) and other processes such as forging, stamping, embossing and spinning. These processes change the shape of the raw material (a metal) into the shape of the work piece without removing or adding material.

Machining Processes comprise metal removal operations such as turning, milling, drilling, grinding, shaping, boring etc.

Assembly Processes involve joining of parts or components to produce assemblies having specific functions.

Process Planning is defined as the systematic determination of methods by which a product is to be manufactured economically and competitively. It consists of selecting the proper machines, determining the sequence of operations, specifying the inspection stages, and tools, jigs and fixtures such that the product can be manufactured as per the required specification. The detailed process planning is done at each component level.

After the final design of the product has been approved and released for production, the Production Planning and Control department takes the responsibility of Process Planning and Process Design for converting the product design into a tangible product. As the process plans are firmly established, the processing time required to carryout the production operations on the equipments and machines selected are estimated. These processing times are compared with the available machine and labour capacities and also against the cost of acquiring new machines and equipments required, before a final decision is made to manufacture the product completely in house or any parts or sub assemblies must be outsourced.

In transformation of raw materials into finished products, several questions need to be answered; such as:

1. What will be the production quantity?
2. What are characteristics of the products to be manufactured?
3. The availability of equipment and what kinds of equipment are to be purchased and what will be the investment?
4. What kinds of labour are required?
5. What should be the level of automation?
6. Make or buy the components required?

Once these questions are answered, the process planning activity can be carried out with minute details as to how each component can be manufactured.

Process Planning is concerned with planning the conversion processes needed to convert the raw material into finished products. It consists of two parts - (i) Process design and (ii) Operations design.

The two terms are explained as under:

Process planning establishes the shortest route that is followed from raw material stage till it leaves as a finished part or product.

The activities that are associated with process planning are:

- List of operations to be performed and their sequence.
- Specifications of the machines and equipment required.
- Necessary toolings, jigs and fixtures.
- Gives the manufacturing details with respect to feed, speed, and depth of cut for each operation to be performed.
- It gives the estimated or processing time of operations.

All the above information is represented in the form of a document called process sheet or route sheet. The information given in the process sheet can be used for variety of activities.

- It becomes the important document for costing and provides the information on the various details like set-up and operation times for each job.
- The machine and manpower requirements can be computed from the set-up and operational times.
- Helps to carryout scheduling.
- The material movement can be traced.
- It helps in cost reduction and cost control.
- It helps to determine the efficiency of a work centre.

Factors affecting process planning

(i) Volume (quantity) of production.

(ii) Delivery dates for components or products.

(iii) Accuracy and process capability of machines.

(iv) The skill and expertise of manpower.

(v) Material specifications.

(vi) Accuracy requirements of components or parts.

Steps in Process Planning

1. Detailed study of the component drawings to identify the salient features that influence process selection, machine selection, inspection stages and toolings required.
2. List the surfaces to be machined.
3. The surfaces to be machined are combined into basic operations. This step helps in selection of machines for operation.
4. Determine the work centre, tools, cutting tools, jigs and fixtures and inspection stages and equipment.
5. Determine the speed, feed and depth of cut for each operation.
6. Estimate the operation time.
7. Find the total time to complete the job taking into account the loading and unloading times, handling times, and other allowances.
8. Represent the details on the process sheet.

Process design is concerned with the overall sequences of operations required to achieve the product specifications. It specifies the type of work stations to be used, the machines and equipments necessary to carryout the operations. The sequence of operations is determined by (a) The nature of the product, (b) the materials used, (c) the quantities to be produced and (d) the existing physical layout of the plant.

Operations design is concerned with the design of the individual manufacturing operation. It examines the man-machine relationship in the manufacturing process. Operations design must specify how much labour and machine time is required to produce each unit of the product.

Process Design-Framework

The process design is concerned with the following: (i) Characteristics of the product or service offered to the customers, (ii) Expected volume of output, (iii) Kinds of equipments and machines available in the firm, (iv) Whether equipments and machines should be of special purpose or general purpose, (v) Cost of equipments and machines needed, (vi) Kind of labour available, amount of labour available and their wage rates, (vii) Expenditure to be incurred for manufacturing processes, (viii) Whether the process should be capital-intensive or labour-intensive, (ix) Make or buy decision and (x) Method of handling materials economically.

Selection of process

Process selection refers to the way production of goods or services is analysing. It is the basis for decisions regarding capacity planning, facilities (or plant) layout, equipments and design of work systems. Process selection is necessary when a firm takes up production of new products or services to be offered to the customers.

Three primary questions to be addressed before deciding on process selections are:

- How much varieties of products or services will the system need to handle?
- What degree of equipment flexibility will be needed?
- What is the expected volume of output?

Process decisions

Major process decisions are:

Process choice :

It refers to choice of a particular process, based upon the nature of product. The operations manager has to choose from five basic process types - (i) Job shop, (ii) Batch, (iii) Repetitive or assembly line, (iv) Continuous and (v) Project.

Vertical integration :

Vertical integration is the degree to which a firm's own production system handles the entire supply chain starting from procurement of raw-materials to distribution of finished goods.

Two directions of vertical integration are:

(a) Backward integration which represents moving upstream toward the sources of raw-materials and parts, for example, a steel mill going for backward integration by owning iron ore and coal mines and a large fleet of transport vehicles to move these raw materials to the steel plant.

(b) Forward integration in which the firm acquires the channel of distribution (such as having its own warehouses, and retail outlets).

Procedure for process planning and design

1. The inputs required comprise the product design information, production system information and product strategy decisions.
2. Process planning and design starts with selection of the types of processes, determining the sequence

of operation, selection of equipment, tooling, deciding about the type of layout of facilities and establishing the control system for efficient analysing of resources to achieve most economical production of the product.

3. The outputs are specific process plans, route sheets, flow charts, assembly charts, installation of equipments, machinery, material handling systems and providing trained, skilled employees to carryout the production processes to achieve the desired results.

Process analysis and process flow design :

While analysing and designing processes to transform input resources into goods and services, certain questions need to be asked. They are:

- Is the process designed to achieve competitive advantage in terms of differentiation, response or low cost?
- Does the process eliminate steps that do not add value?
- Does the process analysing customer value as perceived by the customer?
- Will the process enable the firm to obtain customer orders?

A number of tools help production manager to understand the complexities of process design and redesign.

Some of such tools are: (i) Flow diagram, (ii) Assembly charts, (iii) Process charts and (iv) Operation and Route sheet.

Purpose of Process Charts

- Process charts can present a picture of a given process so clearly that every step of the process can be understood by those who study the charts.
- Process charts may be effective in process analysis and may help in detecting inefficiencies of the processes currently adopted.

Types of Process Charts

Process charts can be classified as operation process charts, flow process charts, worker-machine/ man-machine charts and activity charts or multiple activity charts.

Process Improvement

It is a systematic study of the activities and flows of each process to improve the process. Once the process is thoroughly understood, it can be improved.

Process improvement becomes necessary because of relentless pressure to provide better quality at a lower price. The basic techniques for analysing the processes such as flow diagrams and process charts are useful for understanding the processes and improve them. Improvements can be made in quality, through-put time, cost, errors, safety and on-time delivery.

Process improvement is necessary when:

(i) the process is slow in responding to the customer,
(ii) the process introduces too many quality problems or errors,
(iii) the process is costly,
(iv) the process is a bottleneck, with work accumulating and waiting to go through it, and
(v) the process involves waste, pollution and little value addition.

Application of BCA in the choice of machines or process

This analysis is the most convenient method for selecting the optimum method of manufacture or machine amongst the competing ones. The cost estimates of the competing methods (both fixed and variable costs) are prepared and a particular quantity N is determined at which the alternatives give the same cost.

If the quantity to be manufactured is less than N the process with lower fixed cost is selected and if the quantity to be produced is more than N the process with lower variable cost is selected.

Let F_A = the Annual Fixed Cost of Machine A

F_B = the Annual Fixed Cost of Machine B

V_A = Variable Cost per unit for Machine A

V_B = Variable Cost per unit for Machine B

N = Quantity at which costs on both machines will be equal.

$\therefore$ Total cost on machine A = Total cost on Machine B for Quantity N

i.e., $F_A + V_A.N = F_B+V_B.N$

or, $N(V_A-V_B) = F_B- F_A$

or, $N = \dfrac{F_B - F_A}{V_A - V_B}$

The alternative with lower fixed cost will be more economical for manufacturing up to N and once the quantity exceeds N, it is economical to select an alternative with lower variable cost.

PLANT LAYOUT

Meaning, Definition and Scope

A plant layout refers to the arrangement of machinery, equipment and other industrial facilities – such as receiving and shipping departments, tools rooms, maintenance rooms, employee amenities, etc., - for the purpose of achieving the quickest and smoothest production at the least cost. The subject of plant layout not only covers the initial layout of machines and other facilities but encompasses improvement in, or revisions of, the existing layout in the light of subsequent developments in the methods of production. In other words, a plant layout is a floor plan for determining and arranging the desired machinery and equipment of a plant, whether established or contemplated, in the best place to permit the quickest flow of material at the lowest cost and with the least amount of handling in processing the product from the receipt of the raw materials to the shipment of the finished products.

A more simple, clear and comprehensive definition is given by Knowles and Thompson. They say that a plant layout involves:

(i) Planning and arranging manufacturing machinery, equipment, and services for the first time in completely new plants;

(ii) The improvements in layouts already in use in order to introduce new methods and improvements in manufacturing procedures.

Factors Influencing Layout

As pointed out earlier, the pattern of layout varies from industry to industry, location to location, and plant to plant. Different types of layout are in use; and the selection of a particular type of layout to suit the requirements of a plant depends on a number of factors. Primarily, the layout of a plant is influenced by the relationship among materials, machinery and men. Other factors – such as the type of product, the type of workers, the type of industry and management policies- also influence the layout. Some of the factors which influence layout are explained in the following paragraphs:

(i) **Materials:** When it is said that materials influence plant layout, what is meant is that there is a need to provide for the storage and movement of raw materials in a plant until they are converted into finished products. Every factory should buy raw materials economically when they are available; they should be stored properly and moved through production centres efficiently for manual or mechanical operations or chemical processing.The storage and movement of raw materials require properly placed storage rooms and materials movement or handling equipment. These involve initial investment and recurring costs. The type and size of a storage , as also the type of materials equipment cranes, trolleys, pipelines, etc. depend upon:

(a) whether the raw materials are liquid or solid, light or heavy, small or large; and

(b) The availability or scarcity of materials even when this is affected by seasonal variations and market conditions.

(ii) **Product:** A layout is designed with the ultimate purpose of producing a product. The type of product - that is, whether the product is heavy or light, big or small, liquid or solid and its position in relation to the plant location influences the layout.

(iii) The layout designer should also consider the type, position and requirements of employees. If women workers are employed, the layout must be planned after keeping in mind their particular requirements. The position of employees, that is, whether they remain stationary or moving, also influences the layout.

Employee facilities, such as health and related services, feeding and related services, locker rooms and lavatories influence the layout significantly. Employee safety, too, must receive due consideration.

(iv) The type of product, the volume of its production, the type of process and management policy determines the size and type of the machinery to be installed which, in turn, influences the plant layout.

(v) **Type of industry:** The type of industry and the method of the manufacturing process exercise a significant influence on plant layout. Industries in this context may be broadly classified into four types:

(a) Synthetic;

(b) Analytical;

(c) Conditioning; and

(d) Extractive.

(vi) **Location:** The site selected for the location of a plant influences its layout in more than one way. First, the size and terrain of the site determine the type of building which, in turn, influences the layout. Second, the location of the plant determines the mode of transportation, depending upon the distances from the source of raw materials and market to the Plant.

(vii) **Managerial Policies:** Management policies significantly influence plant layout. The following are such managerial policies:

(a) The volume of production and provision for expansion;

(b) The extent of automation;

(c) Making or buying a particular component;

(d) Desire for quick delivery of goods to customers;

(e) Purchasing policy;

(f) Personnel policies.

It is obvious that many top management policies determine the plant layout objectives and the scope of the plant activities. The layout engineer must have clear and complete understanding of those top management policies that have a bearing on plant layout objectives.

Principles of Layout

The factors discussed above influence the choice of a particular type of layout. While accepting the selected layout, the layout engineer should be guided by certain principles. The layout selected in conformity with layout principles should be an ideal one. These principles are:

(i) **The Principle of Minimum Travel:** Men and materials should travel the shortest distance between operations so as to avoid waste of labour and time and minimize the cost of materials handling.

(ii) **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.

(iii) **Principle of Usage:** Every foot of available space should be effectively utilized. This principle should receive top consideration in towns and cities where land is costly.

(iv) **Principle of Compactness:** There should be a harmonious fusion of all the relevant factors so that the final layout looks well integrated and compact.

(v) **Principle of Safety and Satisfaction:** The layout should contain built in revisions 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.

(vi) **Principle of Flexibility:** The layout should permit revisions with the least difficulty and at minimum cost.

(vii) **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 facility

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;

(ii) Product layout;

(iii) Fixed position layout;

(iv) Cellular Manufacturing (CM) layout;

(v) A combination of the above.

These methods are discussed in the following paragraphs.

Process Layout

Also called the functional layout, layout for job lot manufacture on batch production layout, the process layout involves grouping together of like machines in one department. For example, machines performing drilling operations are fixed in the drilling department, machines performing casting operations are grouped in the casting department; and so on. In this way, there would be a heating department, a painting department, a machining departments etc., where similar machines 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, engine lathes will be arranged in one department, turret lathes in a second department, and milling machines in a third department.

A quantity of raw material is issued tno a machine which performs 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 this other machine for treatment. Thus, material would move long distances and along criss-crossing 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 treatment in every department, like commuters waiting for city buses in Bangalore. Thus, one rarely finds aisles which are free from partly finished goods in factories where the process, grouping of machines has been effected, as in Kirloskar Electricals Ltd., Bangalore, Larsen & Toubro Ltd ., Bangalore etc.

The process layout principles may be diagrammatically shown in **Fig. 2.6.1.**

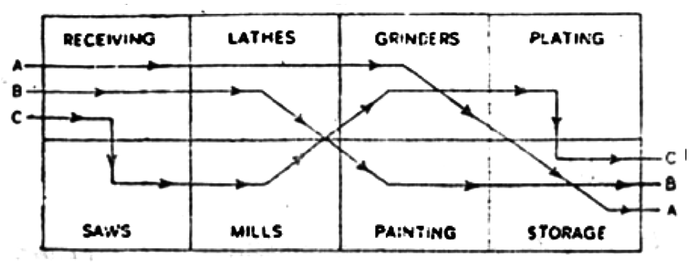


Fig. 2.6.1 Process Layout

Machines in each department in **Fig. 2.6.1** attend to any product that is taken to them. These machines are therefore, called general purpose machines. Work has to be allocated to each department in such a way that no machines are chosen to do as many different jobs as possible, i.e., the accent is on general purpose machines. The work which has to be done is allocated to the machines according to loading schedules, with the object 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 preceded product layout. It evolved from the handicraft methods of production. This type of layout is best suited for intermittent types of industries.

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

(i) The distance between departments should be as short as possible with a view to avoiding long-distance movement of materials.

(ii) Though like machines are grouped in one department, the departments themselves should be located in accordance with the principle of the sequence of operations. For example in a steel plant, the operations are melting , casting, rolling, twisting, etc. These different departments may be arranged in that order to avoid cross-overs and backtracking of materials.

(iii) Convenience for inspection.

(iv) Convenience for supervision.

Process layout may be advantageously used in light and heavy engineering industries, made-to-order furniture industries, etc.

Advantages

1. Reduced investment of machines as they are general purpose machines.
2. Greater flexibility in the production.
3. Better and more efficient supervision is possible through specialisation.
4. There is greater scope for expansion as the capacities of different lines can be easily increased.
5. This type of layout results in better utilisation of men and machines.
6. It is easier to handle breakdown of equipment by transferring work to another machine or station.

7. There is full utilisation of equipment.
8. The investment of equipment would be comparatively lower.
9. There is greater incentive to individual worker to increase his performance.

Disadvantages

1. There is difficulty in the movement of materials. Mechanical devices for handling materials cannot be conveniently used.
2. This type of layout requires more floor space.
3. There is difficulty in production control.
4. Production time is more as work-in-progress has to travel from place to place in search of machines.
5. There is accumulation of work-in-progress at different places.

Product Layout

Also called the straight-line layout or layout for serialized manufacture (the term straight-line, as applied to production, refers to the movements which do not involve backtracking or crossing of the line of movement of the product), the product layout involves the arrangement of machines in one line , depending upon the sequence of operations. Materials are fed into the first machine and finished goods travel automatically, from machine to machine, the output of one machine becoming the input of the next. It is a feast for the eyes to watch the way sugarcane, fed at one end of the plant, comes out as sugar at the other end. Similarly, in a paper mill, bamboos are fed into the machine at one end and paper comes out at the other end.A product layout is , therefore, defined in the following words: 'In the product layout, the equipment used to fabricate a given product is lined up in order of appearance. The raw material arrives at one end of the line and goes from one operation to the next quite rapidly, with a minimum of work-in-progress storage and materials handling.

The principles of product layout have been shown in **Fig. 2.6.2.**

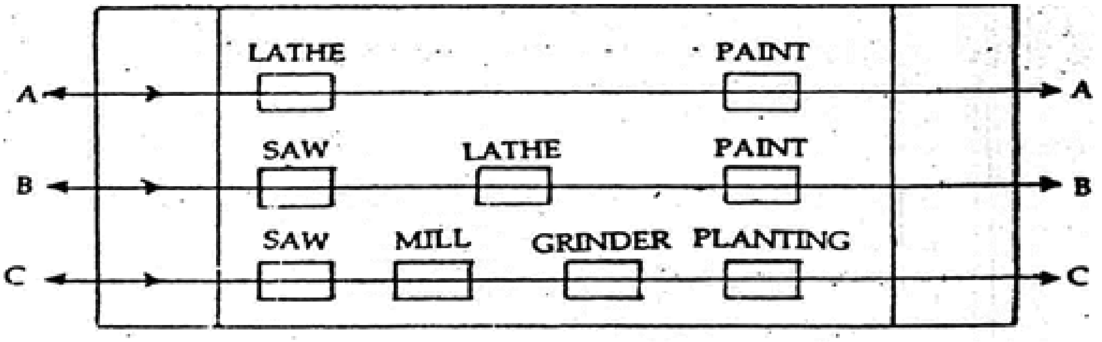


Fig. 2.6.2 Product Layout

For each line of production machines are arranged separately. Thus, if there are three lines of operation, three lines of machines have to be arranged, as is evident in **Fig. 2.6.2**. The accent in the product layout is, therefore, 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.

The grouping of machines should be done, on product line, keeping in mind certain principles. These are:

(i) All the machine tools or other items of equipment must be placed at the point demanded by the sequence of operations;

(ii) There should be no points where one line crosses another line;

(iii) Materials may be fed where they are required for assembly but not necessarily all at one point;

(iv) All the operations, including assembly, testing and packing, should be included in the 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.

Advantages

1. There is mechanisation of materials handling and consequently reduction in materials handling cost.
2. This type of layout avoids production bottlenecks.
3. There is economy in manufacturing time.
4. This type of facilities better production control.
5. This type of layout requires less floor area per unit of production.
6. Work-in-progress is reduced and investment thereon is minimised.
7. Early detection of mistakes or badly produced item is possible.
8. There is greater incentive to a group of workers to raise their level of performance.

Disadvantages

1. Product layout is known for its inflexibility
2. This type of layout is also expensive.
3. There is difficulty of supervision.
4. Expansion is also difficult.
5. Any breakdown of equipment along a production line can disrupt the whole system.

Table 2.6.1 presents relative merits of the product and the process layouts.

Table 2.6.1 Relative Merits of Product and Process Layouts

Product Layout	Process Layout
1. Mechanisation of materials handling and consequent reduction in materials handling cost.	1. Reduction in the investment on machines as they are general purpose machines.
2. Avoidance of bottlenecks.	2. Greater flexibility in production.
3. Economy in manufacturing time.	3. Better and more efficient supervision possible through specialization.
4. Better production control.	4. Better scope for expansion.
5. Less floor area required per unit of production.	5. Better utilization of men and machines.
6. Minimum investment in work-in-progress	6. Easier to handle breakdowns of equipment by transferring work to another machine or station.
7. Early detection of mistakes or badly produced items.	7. Full utilization of the plant.
8. Greater incentive to a group of workers to raise their performance.	8. Greater incentive to individual workers to raise the level of their performance.

A comparison between product and process layouts is shown in Table 2.6.2

Table 2.6.2
Comparison of Product and Process Layouts

	Characteristics	Product Layout	Process Layout
1.	Mechanisation of materials handling	√	
2.	Avoidance of bottlenecks	√	
3.	Economy in manufacturing time	√	
4.	Minimisation of investment in work in progress	√	
5.	Better production control	√	
6.	Early detection of bad workmanship	√	
7.	Greater incentive to a group of workers to raise the level of their performance	√	
8.	Reduced investment in machines	√	
9.	Flexibility in production		√
10.	Scope for expansion		√
11.	Handling of breakdowns is easy		√
12.	Greater incentive to individual workers to raise the level of their performance		√
13.	Better utilization of workers and equipment		√
14.	Specialisation in supervision		√

When should a particular layout be used? Table 2.6.3 presents the answer.

Table 2.6.3 Circumstances When Product and Process Layouts can be Used

Product Layout	Process Layout
1. One or few standard product.	1. Many types or kind of products, or emphasis on special orders.
2. Large volume of production of each item over a considerable period of time.	2. Relatively low volume of production of individual items.
3. Minimum inspection required during the sequence of operation.	3. Many inspections required during a sequence of operations.
4. Materials and products permit bulk or continuous handling by mechanical means.	4. Materials or products too bulky to permit bulk or continuous handling by mechanical means.
5. Little or no occasion to use the same machine or work station for more than one operation (minimum number of sets required).	5. Frequent need for using the same machine or work station for two or more different operation.

Fixed Position Layout

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 the fixed location layout, this type is followed in the manufacture of bulky and heavy products, such as locomotives, ships, boilers and generators. The construction of a building requires a fixed location layout because men, cement, sand, bricks, steel, wood, etc., are taken to the site of the construction. This is equally true of a brick kiln. Another example is that of a hospital, where doctors and nurses (workers) and medicines and other paraphernalia (materials) are taken to the patient (product).

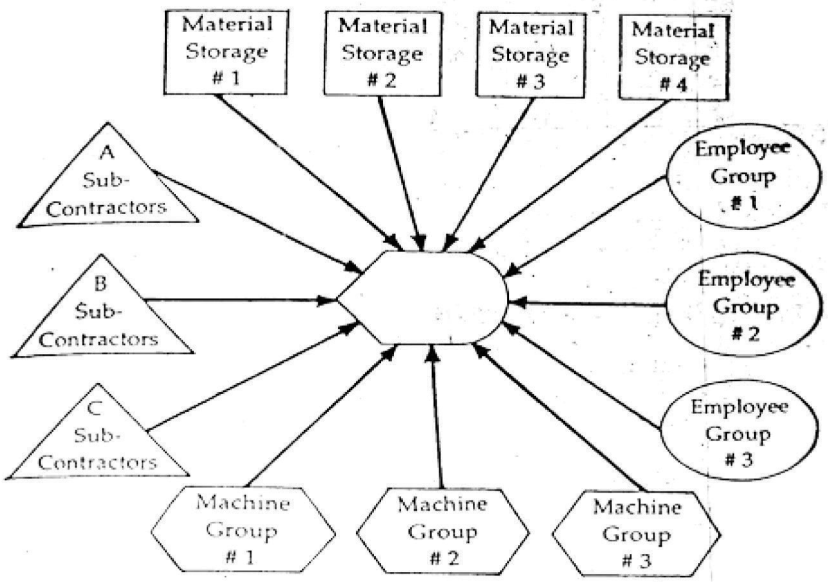


Fig. 2.6.3 Fixed Position Layout

The advantages of a fixed position layout are:

(i) Men and machines can be used for a wide variety of operations producing different products;

(ii) The investment on layout is very small;

(iii) The worker identifies himself with the product and takes pride in it when the work is complete;

(iv) The high cost of, and difficulty in transporting a bulky product are avoided.

Cellular Manufacturing (CM) Layouts

In cellular manufacturing (CM), machines are grouped into cells, and the cells function somewhat like a product layout within a larger shop or process layout. Fig 2.6.4 is an illustration of CM. Each cell in the CM layout is formed to produce a single parts family – a few parts all with common characteristics, which usually means that they require the same machines and have similar machine settings.

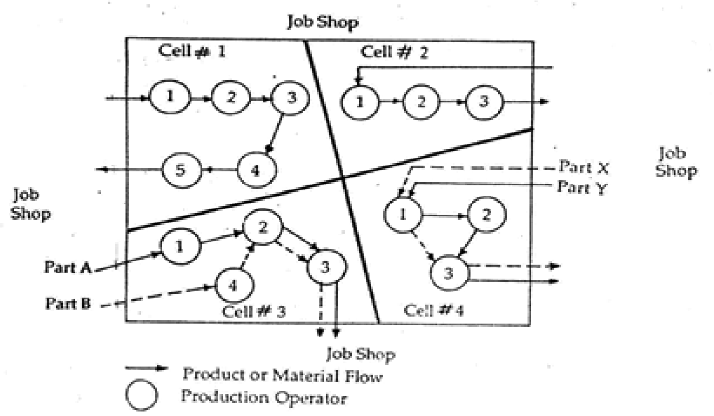


Fig. 2.6.4 Cellular Manufacturing

A distinct feature of CM is that the number of cells is relatively small and the number of production machines per cell is also small. There are also relatively few workers within cells, ranging from 2 to 15. Typical CM arrangement is 5 cells, 6 machines per cell, and 5 workers per cell.

Why CM layout is attempted? There are at least six reasons. They are:

1. Machine changeovers are simplified.
2. Training periods for workers are shortened.
3. Materials handling costs are reduced.
4. Parts can be made faster and shipped more quickly.
5. Less in-process inventory is required.
6. Production is easier to automate.

While six points stated above speak about the merits of CM, there are potential disadvantages of the system. They include reduced manufacturing flexibility and potentially increased machine downtime; (since machines are dedicated to cells and may not be used all the time); cells that become outdated as products and process change, and the disruption and cost of changing to cells.

Combined Layout

The application of the principles of product layout, process layout or fixed location 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.

In plants involving the fabrication of parts and assembly, fabrication tends to employ the process layout, while the assembly areas often employ the product layout. In soap manufacturing plants, the machinery manufacturing soap is arranged on the product-line principle but ancillary services, such as heating, the manufacturing of glycerine, the power-house, the water treatment etc, are arranged on a functional basis.

The departments are arranged according to the types of processes but the products flow through on a product layout.

To extend the logic of the combined layout, we may refer to the application of the fixed location principle in every industrial establishment. Is it not true that workers are brought from different places in buses to the factory every day? Will not materials and tools be carried to the place of manufacture every time?

To sum up: In the final analysis, the combination that produces the desired volume of products at the least total cost is preferred. Marketing is concerned with maximising income, industrial engineering is concerned with minimizing cost, and management is gambling that there is sufficient difference in its favour.

LAYOUT PLANNING

Designing and installing a layout for the first time and its subsequent revision may be looked after by the Engineering or Planning Department. Not infrequently, the services of outside consultants are engaged for the purpose. Large establishments, with branches, subsidiaries and associate companies, may have a construction company as one of their subsidiaries, which discharges the responsibility of planning and constructing the plants of its family concerns, apart from accepting orders from outside.

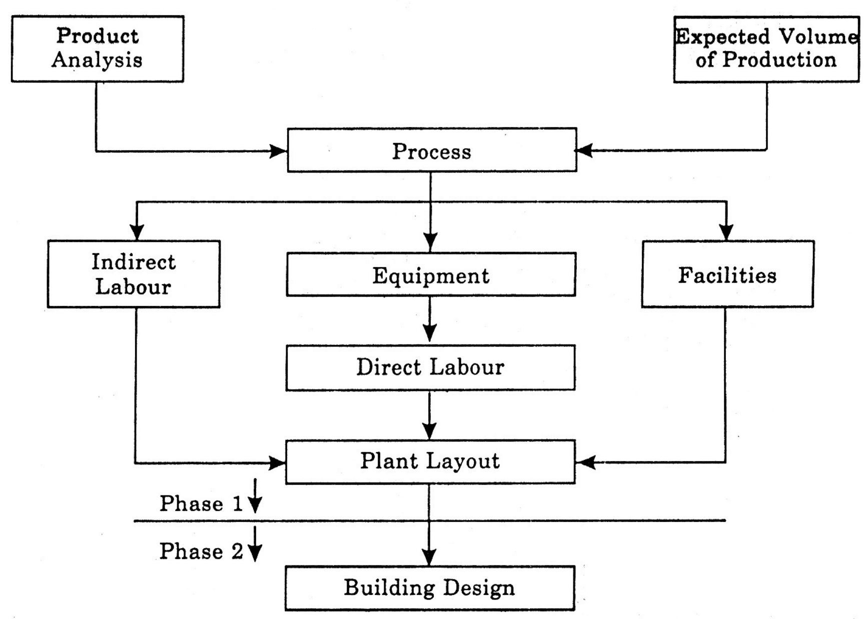
Whoever designs and installs a layout, there is no ready-made method for preparing it. The process of preparing a layout is an art as well as a science, in spite of the advances made in the use of layouts. Naturally, the final layout will be a consummation of many trials, errors, and compromises. The final layout, which emerges out of trials and errors, may not be the best.

To make the final layout as perfect as possible, the layout personnel would do well to proceed step by step in the process of layout planning. These steps are shown in **Exhibit 2.6.1.**

The layout procedure might start with an analysis of the product to be manufactured and the expected volume of its production. An analysis of the product includes a study of the parts to be manufactured and/or bought, and the stages at which they should be assembled to obtain the end product. The volume of production is estimated in terms of market and management policies.

For a given product at a stated volume of production, a process that is most appropriate must be determined. The process that is determined, like any other factor, may not be permanent because it will be influenced by changes in the volume of production, changes in the product and changes in equipment. The process which is decided upon determines the type of equipment that would be needed to manufacture a given product at a given volume. The equipment requirements of a company vary with its methods of grouping machines or the type of layout, the main consideration being an increasing use of machines and not of labour. The equipment which is selected determines the number of workers who will be required. The trend nowadays is to replace labour by machines because that results, in increased production, reduced cost, better quality and fewer labour troubles. But labour cannot be completely dispensed with; it would always be needed to switch on and switch off the machines, even if the whole plant is mechanised.

Exhibit 2.6.1 : Steps in Layout Planning and Design



At the fourth stage, product and volume have led to a process which dictates the type of equipment which would be acquired and which, in turn, would require operators. But the operators require the services of indirect labour - of material handlers, janitors, maintenance staff, quality control staff and production supervisors. The arrangement of all these facilities and personnel constitutes plant layout. Once the plant layout is designed, the layout engineer often engages the services of an architect or the construction division of the company to design the system.

Layout Tools and Techniques

Various techniques are available for planning the layout. The most commonly used technique is the use of two-dimensional templates. Other techniques depend upon the method of layout. For example, to design the process layout operations, sequence analysis is mainly used, whereas line balancing is used to design the product layout.

Templates : Templates are patterns which consist of a thin plate of wood or metal, which serves as a gauge or a guide in mechanical work. A plant layout template is a scaled representation of a physical object in a layout. This object may be a machine, materials handling equipment, a worker or even materials. The templates are fixed to plan drawing and are moved around the drawing to explore the various layout possibilities until a layout, which eliminates unnecessary handling and back-tracking of materials and offers flexibility to admit revisions at the least cost, emerges. The template method is particularly useful in developing a layout for an existing department or building or when the configuration of the building is already established through other layout techniques.

Where a layout is to be developed with no building around, other techniques, as explained below, will be useful.

Operations Sequence Analysis : Being an early approach to process layouts, operations sequence analysis develops a good scheme for arrangement of departments graphically analysing the layout problem. **Exhibits 2.6.2** and **2.6.3** illustrates the technique. The exhibits are drawn using the following data:

Number of departments - 10.

Number of products travelling among the departments - 6.

During one month, the products travel among departments as shown in the **Table 2.6.4.**

Department Code	Department Description	Grind 5	Paint 6	Drill 7	Rework 8	Glaze 9	Ship & Receive 10
1	Blow and mould	1,000	-	5,000	-	3,000	3,000
2	Heat treat	2,000	2,000	-	-	-	3,000
3	Neck	-	2,000	-	-	2,000	-
4	Package	1,000	-	4,000	-	-	5,000
5	Grind	-	2,000	-	-	-	-
6	Paint	-	-	-	-	2,000	-
7	Drill	-	-	-	1,000	-	-
8	Rework	-	-	-	-	-	1,000
9	Glaze	-	-	-	-	-	-
10	Ship & receive	-	-	-	-	-	-

Exhibits 2.6.2 shows an initial solution with circles representing departments and lines representing product travels among departments. The number of products that travel during the month among departments in written on the lines.

Exhibit 2.6.2 : Initial Solution for Layout

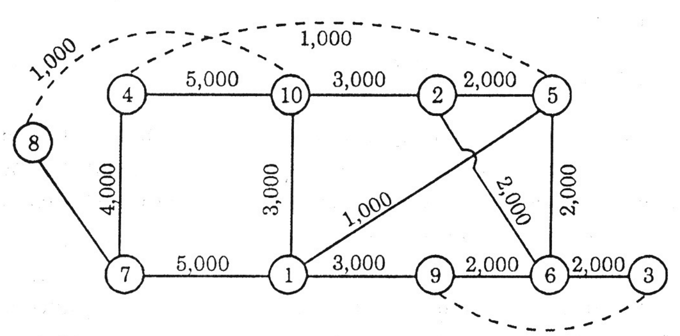
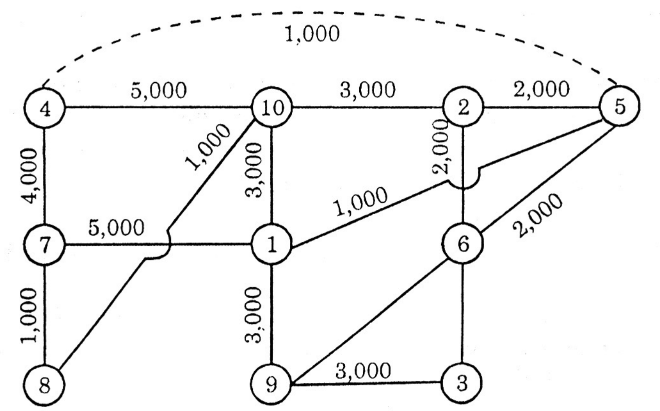


Exhibit 2.6.3 shows the restructured layout with certain departments moving closer to others. For example, Department 3 has been shifted closer to Department 9, and Departments 8, 9 and 6 have been shifted to form a rectangular shape.

Exhibit 2.6.3 : Restructured Layout



Thus, operations sequence analysis helps determine locations of operating departments relative to one another.

Line Balancing : Line balancing is the phase of assembly line study that nearly equally divides the work to be done among the workers so that the total number of employees required on the assembly line is minimised. Line balancing is not simple; in fact, there are usually many alternative ways that the work can be divided among the workers. Operation researchers have used linear programming dynamic programming and other optimal methods to study line balancing problems. Explanation of all these is beyond the scope of this text.

Analysing Layouts With Computers

As in other fields, computers have entered the field of layout engineering in a big way. Various techniques have been developed and used in layout planning. For example, in designing process layout, the analyses used are - ALDEP (automated layout design programs), CORELAP (computerised relationship layout planning) and CRAFT (computerised relative allocation of facilities technique).

These and other computer programmes can save time and effort in large and complex layout problems, but the plans they offer are only the beginning of a final layout. The layouts given by computers must be fine-tuned by hand and checked for logic, and machines and other elements of the layout must usually be hand-fitted with templates.

Layout or Building

Which comes first, the chicken or the egg? This ancient puzzle can be used to illustrate the relationship between the layout and the industrial building. Should the building be built first and the layout planned to fit it? Or should the layout be planned first and the building built around it?

The ideal procedure would be to plan the layout first and construct the building around it. But the ideal situation is not always available because of certain reasons. In the case of going concerns, some, if not all, the buildings may be in existence. To demolish the existing building to plan the layout would be very difficult and expensive. Moreover, the site selected may impose restrictions and make it difficult for one to plan the layout first and construct the building around it. In such circumstances, the building comes first, and then the layout. Plant layout will be generally a compromise between the ideal layout and the limitations of a plant site and building.

Whichever comes first, care should be taken to make the building and the layout as ideal as possible within the available facilities, for both are vital to the success of any industrial establishment. If the building is compared to the skin and bones of a human body, the layout is naturally the arrangement of heart, liver, muscles, etc., inside the skin and bones; the difference between the two is that, in the case of a factory, one comes after the other; but the human body emerges from the womb ready-made.

Criteria for Selection and Design of Layouts

Facility layouts must integrate work centre location, office, computer facilities, tool room, storage space and washrooms etc. Two of the major criteria for selecting and designing and layout are:

1. Material handling cost and
2. Worker effectiveness

Materials handling costs are minimized by using mechanised material handling equipments such as belts, cranes and conveyors to automate product flows and keeping the flow distances as short as possible by locating the work centres for sequential processing activities in adjacent areas.

Worker effectiveness is another important criteria in the layout of facilities. Good layout provides workers with a 'satisfying' job and permit them to work effectively at the highest skill level for which they are being paid. Good communication systems and well-placed supporting activity locations are critical to the success of any facility.

The various methods used for selecting the best layout among several alternatives layouts are illustrated below with example:

1. Travel Chart Method

The trave chart which is also known as from-to-chart is helpful in analysing the overall flow of material. It shows the number of moves made between departments and identifies the most active departments. A typical travel chart is shown in **Exhibit 2.6.4.**

Exhibit 2.6.4 : Facility Outline Chart and Travel Chart for a Typical Facility

1	2	3
4	5	6

(a) Facility outline chart

From	Number of moves to					
	A	B	C	D	E	F
A	–	7	–	–	–	5
B	–	–	–	4	10	–
C	–	7	–	–	2	–
D	–	–	8	–	–	–
E	4	–	–	–	–3	
F	–	6	–	–	10	–

The solution is obtained by the trial and error method which attempts to minimise non-adjacent flows by centrally locating the active departments (i.e., departments which have the maximum number of links with other departments). The work centres,are shown as circles and the connecting lines represent the loads transported during a given time. Departments next to each other or diagonally across from each other are regarded as adjacent departments.

Procedure

Step 1 : Determine which departments have the most frequent links with other departments. This can be done by totalling the number of entries in each row and column. The number of links between the departments are as below:

Department	A	B	C	D	E	F
Number of links	3	5	3	2	5	4

Step 2 : Try to locate the most active departments in the central positions in the facility outline.

In this example, departments B and E which have the maximum number of links with other departments are located at locations 2 and 5 of the facility outline.

Step 3 : By trial and error method, locate the other departments so that the non-adjacent flows are minimised.

Step 4 : If all the non-adjacent moves are eliminated, the solution is complete. If non-adjacent flows still exist, try to minimise the number of units flowing to non-adjacent areas as weighted by the distances between non-adjacent departments.

2. Load-Distance Analysis Method

Load-distance analysis is useful in comparing alternative layouts to identify the one with the least product or material travel time per period. This method helps to minimise transportation costs by evaluating alternate layouts on the basis of the total of the product of actual distance moved and the load (the units moved) for each layout alternative. Alternatively, the material handling costs can be computed directly by multiplying the number of loads by the material-handling cost per load. The layout with the lowest total (load × distance) or total (load × cost) is the best choice.

The following illustration helps in understanding the load-distance analysis method to determine the best layout alternative which minimises the total (load x distance moved).

Load-Distance Analysis

Illustration 1:

Two layout alternatives are shown below. The facility's products, their travel between departments and the distances between departments for each layout alternative are also shown below. The layout alternative that minimises the monthly product travel through the facility has to be determined.

Layout A

8	4	10	2	5
3	7	1	9	6

Layout B

7	1	9	6	3
4	10	2	5	8

Department Movement Combination	Distance between Department (feet)		Department Movement Combination	Distance between Department (feet)	
	Layout A	Layout B		Layout A	Layout B
1 - 5	30	30	3 - 9	30	20
1 - 7	10	10	4 - 5	30	30
1 - 9	10	10	4 - 7	10	10
1 - 10	10	10	4 - 10	10	10
2 - 5	10	10	5 - 6	10	10
2 - 6	20	20	6 - 9	10	10
2 - 10	10	10	7 - 8	20	50
3 - 6	40	10	8 - 10	20	30

Products	Department Processing Sequence	Number of Products Processed per month	Product	Department Processing sequence	Number of Products Processed per month
a	1-5-4-10	1,000	d	1-7-8-10	1,000
b	2-6-3-9	2,000	e	2-5-6-9	2,000
c	2-10-1-9	3,000	f	1-7-4-10	4,000

Solution:

Step 1 : Compute the total travel for each product through each layout alternative as given below:

Product	Department Processing Sequence	Distance Moved per Product	
		Layout A	Layout B
a	1-5-4-10	30 + 30 + 10 = 70	30 + 30 + 10 = 70
b	2-6-3-9	20 + 40 + 30 = 90	20 + 10 + 20 = 50
c	2-10-1-9	10 + 10 + 10 = 30	10 + 10 + 10 = 30
d	1-7-8-10	10 + 20 + 20 = 50	10 + 50 + 30 = 90
e	2-5-6-9	10 + 10 + 10 = 30	10 +10 +10 = 30
f	1-7-4-10	10 + 10 + 10 = 30	10 +10 +10 =30

Step 2 : Compute the total distance travelled per month for each product through each layout alternative as below:

Product	Products per month (load/units)	Distance per product (feet)		Load x Distance per month (units x feet)	
		Layout A	Layout B	Layout A	Layout B
a	1,000	70	70	70,000	70,000
b	2,000	90	50	1,80,000	1,00,000
c	3,000	30	30	90,000	90,000
d	1,000	50	90	50,000	90,000
e	2,000	30	30	60,000	60,000
f	4,000	30	30	1,20,000	1,20,000
			Total	5,70,000	5,30,000

Step 3 : Determine the layout alternative to be chosen based on the minimum (load x distance) per month. Layout B results in the least total (load x distance) per month and hence the choice.

3. Systematic Layout Planning

Systematic layout planning (SLP) method is used in some production systems such as service systems, where the amount of material that flows between departments may not be critical for developing a good facility layout. This method develops a chart known as "relationship chart" or Richard Muther's half-matrix, which rates the relative importance of locating one department close to another department. The importance ratings are indicated by code letters a, e, i, o, u, x is known as 'nearness codes', which indicate the following degree of importance.

Nearness code	Degree Importance
a	absolute necessary
e	very important or essential
i	important
o	ok, ordinary importance
u	unimportant
x	undesirable

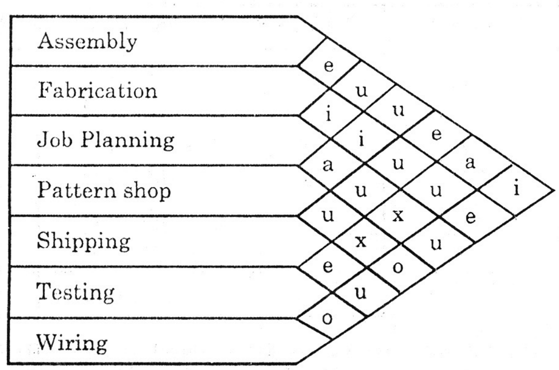
In addition to the nearness code, a reason code indicated by a number (say 1, 2 or 3) based on a variety of reasons for locating any two departments adjacent to each other, is used.

The examples of reason codes are:

Nearness code	Degree Importance
1	use of common personnel
2	noise isolation
3	safety purpose
4	ease of supervision
5	common equipment
6	type of customer

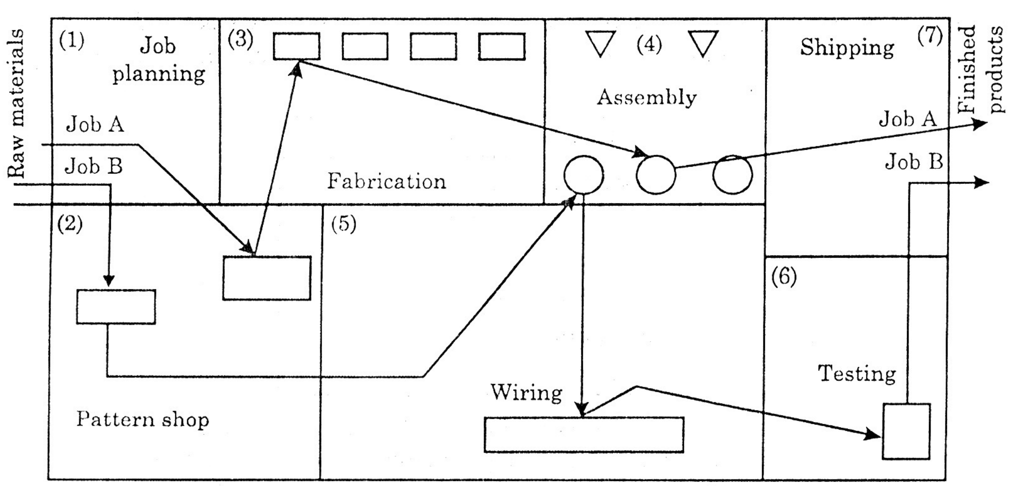
Exhibit 2.6.5 illustrates the half-matrix developed for a job-shop layout for producing a made-to-order product.

Exhibit 2.6.5 : Richard Muther's half-matrix for a Job Shop Layout (or process layout)



Based on the nearness code, the above seven departments can be arranged in the job-shop layout as shown in **Exhibit 2.6.6** below:

Exhibit 2.6.6 : Job Shop Layout as Determined by Systematic Layout Planning Method Using Richard Muther's Half-matrix Indicating Nearness Codes



Layout Design Procedure

Designing the layout of a plant is a specialised activity and should be carried out systematically. The various steps to be followed in the layout design are:

1. Statement of specific objectives, scope and factors to be considered.
2. Collection of basic data on sales forecasts, production volumes, production schedules, part lists, operations to be performed and their sequences, work measurement, existing layouts, building drawings.
3. Preparation of various kinds of charts such as flow process charts, flow diagram, string diagram, templates etc.
4. Designing the production process.
5. Planning the material flow pattern and developing the overall materials handling plan.
6. Calculation of requirement of work centres and equipments.
7. Planning individual work centres.
8. Selection of materials handling equipments.
9. Determining storage requirements.
10. Planning of auxiliary and service facilities.
11. Determination of routing, space requirements for each work station, service department, employee facilities etc.
12. Draw building specifications to fit the requirements of the layout.
13. Preparation of floor plan indicating location of doors, windows, stair case, lifts etc.
14. Preparation of tentative or drafts layout plans.
15. Preparation of detailed layout drawing and get approval of the top management.
16. Preparation of work schedule for the installation of layout.

Plant Location

Plant location may be understood as the function of determining where the plant should be located for maximum operating economy and effectiveness. The selection of a place for locating a plant is one of the problems, perhaps the most important, which is faced by an entrepreneur while launching a new enterprise. A selection on pure economic considerations will ensure an easy and regular supply of raw materials , labour force, efficient plant layout proper utilisation of production capacity reduced cost of production. An ideal location may not, by itself, guarantee success; but it certainly contributes to the smooth and efficient working of an organisation. A bad location, on the other hand, is a severe handicap for any enterprise and it finally bankrupts it. It is, therefore, very essential that utmost care should be exercised in the initial stages to select a proper place. Once a mistake is made in locating a plant, it becomes extremely difficult and costly to correct it, specially where large plants are concerned. Cases are not wanting where mistakes were committed and wrong places selected.

The need for the selection of the location may arise under any of the following conditions:

(a) When the business is newly started;

(b) The existing business unit has outgrown its original facilities and expansion is not possible; hence a new location has to be found:

(c) The volume of business or the extent of market necessiates the establishment of branches;

(d) A lease expires and the landlord does not renew the lease; and

(e) Other social or economic reasons; for instance, inadequate labour supply, shifting of the market, etc.

Whatever the reason, the selection of the location has to be made after considering all the economic factors which have a bearing on it. It may be impossible to find a place which abounds in all the facilities that are required to start a factory; but a search has to be made for a place which enjoys as many facilities as possible. The guiding principle in the search should be for a place where the cost of the raw material and of fabrication, plus the cost of the marketing of the finished product, will be minimum.

STEPS IN LOCATION

To be systematic, in choosing a plant location, the entrepreneur would do well to proceed step by step, the steps being:

(a) Within the country or outside;

(b) Selection of the region;

(c) Selection of the locality or community

(d) Selection of the exact site.

(a) Deciding on Domestic or International Location

The first step in plant location is to decide whether the facility should be located domestically or internationally.

(b) Selection of Region

The selection of a particular region out of the many natural regions of a country is the second step in plant location.

The following factors influence such selection:

i) **Availability of Raw Materials :** As a manufacturing unit is engaged in the conversion of raw materials into finished products, it is very essential that it should be located in a place where the supply of raw materials is assured at minimum transport cost. Nearness to raw materials offers such advantages as:

   (1) Reduced cost of transportation;

   (2) Regular and proper supply of materials uninterrupted by transportation breakdowns; and

   (3) Savings in the cost of storage of materials.

ii) **Nearness to the Market:** Since goods are produced for sale, it is very essential that the factory should be located near their market. A reduction in the cost of transporting finished goods to the market; the ability to adjust the production programme to suit the likes and dislikes of consumers; the ability to render prompt service to the consumers, provide after-sale services, and execute replacement orders without delay — these are some of the advantages that accrue to the entrepreneur if he establishes his factory near his market.

iii) **Availability of Power:** Power is essential to move the wheels of an industry. Coal, electricity, oil and natural gas are the sources of power. Where coal is the source of power, as in the case of the iron and steel industry, the factory has to be located near the coal fields.

iv) **Transport Facilities:** While making a study of a location, an entrepreneur considers the question of the availability of transport facilities. Transport facilities are essential for bringing raw materials and men to the factory and for carrying the finished products from the factory to the market. A place which is well connected by rail, road and water transport is ideal for a plant location.

v) **Suitability of Climate:** The climate has its own importance in the location of a plant because of two reasons. First, there are certain industries which, because of the nature of their production, require particular climatic conditions; for example, humid climate for cotton textiles and jute. Such industries have to be located in places where humid climatic conditions are available. Second, climate affects labour efficiency. Extreme climatic conditions adversely affect labour efficiency, and such places do not attract industries. It is for this reason that little industrial activity is found in tropical and polar regions, whereas there is a heavy concentration of industrial activities in cool and temperate regions.

vi) **Government Policy:** The influence of Government policies and programmes on plant location is apparent in every country, particularly in planned economies like ours. In the name of balanced regional development, many backward regions in India have been selected for the location of new industries.

The establishment of textile units in Rajasthan, Odisha, Assam and Punjab, sugar factories and distilleries in Andhra, Tamil Nadu, Karnataka and Maharashtra, steel rolling mills in Assam, Madhya Pradesh, Kerala and Bihar, and a tyre and tube factory and electric lamps factory in Kerala are all instances which show that new industries have been located in some backward states.

The Government of India has been influencing plant location in a number of ways.

Some of these are:

- Licensing policy;
- Freight rate policy;
- Establishing a unit in the public sector in a remote area and developing it to attract other industries; Institutional finance and Government subsidies.

The influence of government policies on plant location began to be felt only after Independence. But, until Independence, purely commercial considerations decided industrial location. Such has been the case with TISCO and IISCO. It was because there was no over-solicitous Government which was ready to come to the rescue of a sick unit to save it from bankruptcy, no ideologue anxious to give a face-lift to losing public sector concerns by allowing them to jack up prices, give protection and capitalise losses by converting them into equity.

vii) **Competition Between States:** States varies with each other to attract new industries. Various states offer investment subsidies and sales tax exemptions to new units. The incentives may not be of big help to big-sized plants. But for small and medium-sized plants the incentives do matter. The owners of these plants certainly consider incentives in selection of a region.

(c) Selection of a Community

Selecting a particular locality or community in a region is the third step in plant location. The selection of a locality in a particular region is influenced by the following factors:

i) **Availability of Labour:** Despite the talk of mechanisation and automation, the importance of labour on the industrial side has not been completely lost. Labour is an important factor in the production of goods. An adequacy of labour supply at reasonable wages is very essential for the smooth and successful working of an organisation.

ii) **Civic Amenities for Workers:** Besides good working conditions inside the factory, the employees require certain facilities outside it. Recreation facilities, such as clubs, theatres, parks, etc., must be provided for the employees. They require schools for their children. A place which abounds in all these facilities will naturally be preferred to another place which lacks them.

iii) **Existence of Complementary and Competing Industries :** The existence of complementary industries is favourable to the location of industries.

iv) **Finance and Research Facilities:** Adequate capital is essential for the successful working of any organisation. A place, where facilities for raising capital are available attracts new industries.

v) **Availability of Water and Fire-Fighting Facilities :** Some industries require a plentiful supply of water for their working. Some of these are: fertilizer units, rayon manufacturing units, absorbent cotton manufacturing units, leather, tanneries, bleaching, dyeing and screens printing units. These factories must be located in places where water is available in abundance. Water may be obtained from the local authority, from the canal, from a river or a lake, or by sinking a well. In any case, the supply of water should be considered with respect to its regularity, cost, purity etc.

Industrial units are exposed to fire hazards. A fire may break out either from within or from neighbouring units. In either case, adequate fire-fighting facilities must be available. Otherwise, the loss from a fire will be considerable. Though the availability of fire-fighting facilities is not a decisive factor in plant location, the fact remains that the existence of such facilities will enhance the suitability of a location.

vi) **Local Taxes and Restrictions:** Local authorities collect charges for the supply of water, electricity and other facilities. They also collect various taxes from industrial units. They impose restrictions on the location of new units in the public interest. It is natural, therefore, for industrialists to prefer an area where such taxes and restrictions are the least irksome.

vii) **Momentum of an Early Start:** The momentum of an early start exercises a considerable influence on plant location. Certain places, where one or more factories existed before, gain prominence as centres of an industrial complex with the passage of time because, around them, a number of facilities develop.

viii) **Personal Factors :** There are entrepreneurs, specially small industrialists, who locate their plants purely on personal grounds disregarding economic considerations. Such locations sometimes totally disprove the many current theories of plant location.

(d) Selection of the Site

The selection of an exact site in a chosen locality is the fourth step in plant location. The selection of the site is influenced by the following considerations:

i) **Soil, Size and Topography:** For factories producing engineering goods, the fertility or otherwise of the soil may not be a factor influencing plant location. But for agro-based industries, a fertile soil is necessary for plant location.

ii) **Disposal of Waste :** The problem of the disposal of effluents is common to many industries, particularly, chemical, sugar, steel, and leather industries and breweries. The site selected for the location of the plant should have provision for the disposal of waste. There must be enough vacant land for the dumping of solid waste. For liquid waste, satisfactory sewer connections or a river or sea should be available.

Dimensional analysis

Even if we are able to identify the various factors influencing locational choice, the problem of quantification remains. How, for example, do we determine, for various potential locations, the cost of moving or the cost of labour ? Furthermore, having quantified such factors, what weight or importance do we attach to each? Do we, for example, consider the subjective factors as being of equal importance to the fixed-cost factors? Indeed, we may even find that we are unable to attach cost figures to some of the important factors.

Consider a simple example in which we are faced with two possible locations. We have decided that the choice between these locations will be made on the basis of the following factors:

(a) the cost of land;

(b) the cost of buildings;

(c) the cost of labour (fixed investment cost for the total required labour force for a location).

We have further found that the cost associated with each of these three factors for each of the possible locations is as shown in **Table 2.6.5**.

We might compare the relative merits of the two locations merely by summing the relevant costs, i.e.

Total for A = ₹50,000

Total for B = ₹55,000

Using this method of comparison we would choose location A, since it is the cheaper of the two. This method assumes that each of the factors is of equal importance, which may be

Table 2.6.5

Factor	Location A ₹	Location B ₹
Land	10,000	15,000
Building	25,000	30,000
Labour	15,000	10,000

far from true. For example, suppose we decide that, while the costs of land and buildings are equally important to our decisions, the cost associated with labour is twice as important as the two other costs. Then we may assess the alternatives by introducing this weighting factor:

₹	₹
Location A: 10,000	Location B: 15,000
25,000	30,000
+2(15,000)	+2(10,000)
= 65,000	= 65,000

Now it appears that each location is equally attractive.

Let us take this type of argument a little further by introducing two more factors into our examination of the two locations. Now, as well as the costs associated with land, buildings and labour, we need to consider the influence of community relations and the cost of moving. We find it difficult to place an accurate cost on either of these factors for the two locations, so we settle for a system of rating using a scale 1 to 100. A rating of 1 indicates that a location scores very highly, i.e. it is the best possible result, whereas a rating of 100 is the worst possible result.

Suppose the five factors for the two locations are quantified as shown in **Table 2.6.6**; then we might again compare locations by adding together the figures to obtain the totals shown in **Table 2.6.6**. This comparison would lead us to select location A.

However, this type of analysis is quite wrong, because we have indiscriminately mixed together two dimensions: cost and ratings. To illustrate the inadequacies of the procedure, suppose we alter the scale of the first three factors and perform our calculations in ₹000s

	Location A ₹	Location B ₹
Land	10	15
Building	25	30
Labour	15	10
Community relation (Score)	60	30
Cost of moving (Score)	80	40
	190	125

Table 2.6.6

Factor	Location A ₹	Location B ₹
Land (cost)	10,000	15,000
Building (cost)	25,000	30,000
Labour (cost)	15,000	10,000
Community relations (score)	60	30
Cost of moving (score)	80	40
Total	50,140	55,070

Such an analysis would lead us to select location B, since the change of scale has distorted our analysis.

So that such an anomaly does not occur, we must take care to treat multidimensional analysis in a more satisfactory manner. Such a method is 'dimensional analysis'. Using the following notation:

$O_{i_1},\ O_{i_2},\ O_{i_3},\ \cdots O_{i_m}$ = costs, scores, etc. associated with factors

1,2,3,….m, for location i

$W_1, W_2, W_3, \ldots W_m$ = the weight to be attached to factors

1, 2, 3, …. m

The merit of the various locations should be assessed as follows:

For location i, merit = $(O_{i_1})^{W_1} \times (O_{i_2})^{W_2} \times (O_{i_3})^{W_3} \cdots \times (O_{i_m})^{W_m}$

In the case of two possible locations the merit might be compared as follows:

$$\frac{\text{Merit of A}}{\text{Merit of B}} = \left(\frac{O_{A_1}}{O_{B_1}}\right)^{W_1} \times \left(\frac{O_{A_2}}{O_{B_2}}\right)^{W_2} \cdots \left(\frac{O_{A_n}}{O_{B_n}}\right)^{W_m}$$

If > 1, select B.

If < 1, select A.

Considerations of Plant Size

However, it ought to be pointed out that the tangible or objective costs such as transport, power, labour are related to a particular volume of production. There are fixed and variable components in each of these cost categories. Moreover, these components could be different at different locations. Therefore, the entire comparison is only relevant for a stated volume of production or plant size.

Illustration 2:

A company planning to manufacture tennis racquets has to decide on the location of the plant. Three locations are being considered viz. Mysore, Bangalore and Hosur. The fixed costs at the three locations 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 tennis racquet is ₹700 per unit. Find out (a) the range of annual production/sales volume for which each location is the most suitable and (b) which one of the three is the best location at a production/sales volume of 18,000 unit.

Solution:

The total costs, at the three locations are:

(a) At Mysore: Total Cost = Fixed Cost + Variable Cost (for a volume 'x')

=30,00,000 + 300x

(b) At Bangalore: Total cost = 50,00,000 + 200x

(c) At Hosur: Total cost = 25,00,000 + 350x

We can compute and plot the total costs per annum at the three different locations for the various cases of production volumes of 5000, 10,000, 15,000, 20,000 and 25,000 units as shown as follows:

(a) At Mysore

Volume	5,000	10,000	15,000	20,000	25,000
Total Cost (₹)	=30,00,000 +300(5,000) = 45 lakh	30,00,000 +300(10,000) = 60 lakh	30,00,000 +300(15,000) = 75 lakh	30,00,000 +300(20,000) = 90 lakh	30,00,000 + 300(25,000) = 105 lakh

(b) At Bangalore

Volume	5,000	10,000	15,000	20,000	25,000
Total Cost (₹)	50,00,000 + 200(5,000) = 60 lakh	50,00,000 + 200(10,000) = 70 lakh	50,00,000 + 200(15,000) = 80 lakh	50,00,000 + 200(20,000) = 90 lakh	50,00,000 + 200(25,000) = 100 lakh

(c) At Hosur

Volume	5,000	10,000	15,000	20,000	25,000
Total Cost (₹)	25,00,000 + 350(5,000) = 42.5 lakh	25,00,000 + 350(10,000) = 60 lakh	25,00,000 + 350(15,000) = 77.5 lakh	25,00,000 + 350(20,000) = 95 lakh	25,00,000 + 350(25,000) = 112.5 lakh

It is clear that at production volumes (a) up to 10,000 units, (b) between 10,000 and 20,000 units and (c) above 20,000 units, the most suitable locations for the factory as dictated by cost considerations are Hosur, Mysore and Bangalore respectively.

Thus, at a volume of production/sales of 18,000, Mysore is the chosen location.

2.7 PROJECT MANAGEMENT - DEFINITION

Project Definitions: Project can be defined in the following ways:

Project is an organisational unit dedicated to the allotment of a goal, the successful completion of a development product in time, within specified budget, in conformance with the pre-determined performance specifications.

It is a set of finite activities that are usually prepared only once and have well designed objectives, using a combination of human and non-human resources within limits of time.

It consists of a series of non-routine, interrelated activities with a goal that must be completed with a set amount of resources and within a set time limit.

It is a proposal for investment to create and/or develop certain facilities in order to increase the production of goods and/or services in a community during a certain period of time. (UNIDO)

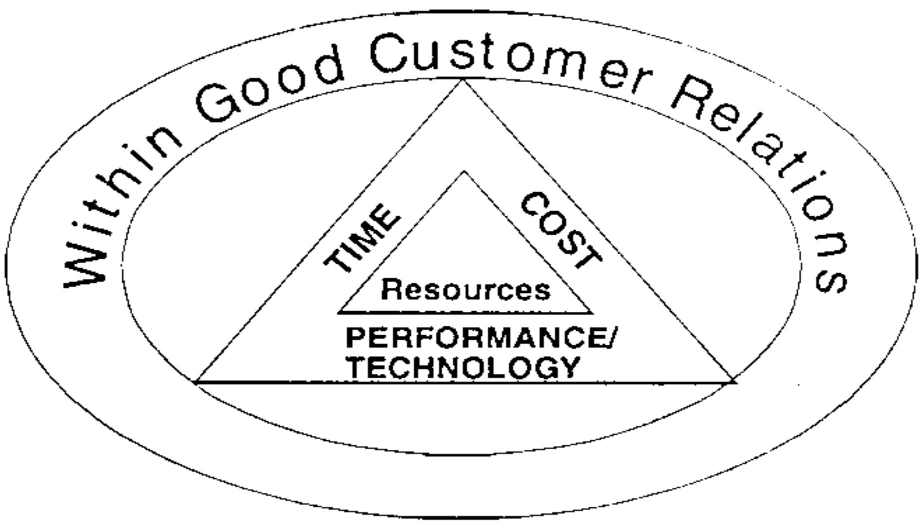


Fig. 2.7.1: Project Management Overview

Project Management is literally an 'investment of resources' to produce goods and services for consumption. Elements of a project management control include programmed objectives, policy restriction, resource constraints, government regulations, process implication, review of output, feedback and revision of objectives.

- It is a scientific way of planning, implementing, monitoring and controlling the various aspects of project, such as time, money, materials and other resources (e.g., manpower) with the intention of achieving the basic objectives or goals (technical, costs, time) while formulating a project.

Project Characteristics

The following inherent features are associated with any project:

1. **Projects have a purpose:** It is customary to use terms, such as cement projects, power projects, refinery projects (not plant), and the term project is replaced by plant as soon as the plant is operational or project is completed. All works that can be interrelated and are being performed to serve a common purpose can be grouped together and termed a project, only if it is a composite affair.

2. **Source:** Project is managed by a process of 'planning, organising, directing, staffing, monitoring and controlling'. Various starting points of a project are called **sources**. A project can have a number of sources but one end or sink.

3. **Focus:** Project has a fixed set of objectives/mission/goal. Project ceases to exist once the mission is achieved.

4. **Lifespan:** Each project is time bound through the schedules.

5. **Unique:** No two projects are alike in their execution even if the plans are duplicated and therefore involve a single time activity.

6. **Unity in Diversity:** This is a global concept for any type of project since project is considered to be a complex web of things, people and environment.

7. **Flexibility:** Change and project are synonymous. Project is dynamic in nature and therefore modifications/changes in original plans, programmes and budgets are a normal feature.

8. **Team Spirit:** This involves coming together of different individuals from varied disciplines to bestow their knowledge, experience and credence towards a total performance.

9. **Risk and Uncertainty:** Every project has risk and uncertainty associated with it. The degree of risk and uncertainty will depend on how a project has passed through its various life-cycle phases. An ill-defined project will have extremely high degree of risk and uncertainty. Risk and uncertainty are not only part and parcel of R & D projects only; there simply cannot be a project without any risk and uncertainty in a real life situation.

10. **Statement of Work (SOW):** Project planning deals with specified tasks, operations or activities, which must be performed to achieve project goals. A project starts with **statement of work**. It may be a written description of objectives (rules/regulations/ constraints/restriction) to be achieved with a brief statement of work to be done and a proposed schedule specifying the start and completion dates of the project. It could also contain certain performance measures in terms of budget, completion steps **(milestones)** and written reports to be supplied during the project completion.

11. **Implementation:** Every project needs resources or inputs where given inputs are to be converted to output through the process of implementation. The output, in short run, leads to outcomes while in the long run it should result in impact.

12. **Task:** It is further subdivision of a project. It is usually not longer than several months in duration and is performed by one group or organisation. Subtask may be used if needed to further subdivide the project into more meaningful pieces.

13. **Work Package:** It is a group of activities combined to be assignable to a single organisation of unit. The package provides a description of what is to be done, when it is to be started and completed, the budget, measures of performance and specific events to be reached at points in time (milestones). Typical milestones may be completion of design, production of a prototype, the completed testing of the prototype and the approval of pilot run.

14. **Subcontracting:** It is subset of every project without which no project can be completed unless it is proprietary firm or small in nature. The survival of a company depends on how wisely it selects

its vendors and maintains good relations with them so that project is commissioned without time over-run and cost over-run. If there are several contractors their performance is rated according to quality, delivery, price, service, etc. The activities of subcontracting include sending enquiries to subcontractor and placing order after negotiation with them on all relevant parameters.

15. Project Life Cycle: Project life cycle commences when the idea chosen is found technically feasible, economically viable, and politically suitable and investment proposal is approved. For a company executing projects, either regularly or for the first time, it would be necessary for the chief executive to issue what may be called a **project charter** soon after project manager is appointed. The charter at its minimum may define project scope, project goals, name of project manager, and his directing authority. The project reviewing authority and request for co-operation is from all concerned in the execution of the project. An elaborate effort in this direction may produce what is known as **project manual**.

These major events in projects are grouped under various heads.

- **Conception/Identification:** Acceptance of necessity, identification of objectives, project formulation
- **Planning Phase/Appraisal Phase:** Preparation of feasibility report, appraisal of feasibility report, investment decision.
- **Execution Phase of Project:** Issue of executive order, implementation of project.
- **Follow-up Phase/Monitoring Phase:** Project monitoring (data collection information gathering), preparation of Management Information System (MIS), Time management (time control) of project, cost management (cost control) of project.
- **Feedback and analysis:** Issue guidelines to future project, project clean up.

16. **Feasibility Study:** Feasibility study of the project is the most exhaustive of all the planning stage. The project is systematically examined in depth at this stage for various aspects like technical, financial, economical, commercial, social, managerial and organisational. The purpose of this study is to examine if the project objectives are realistic, recommendation in preliminary study are technically sound; beneficial from financial, economical, social point of view; feasibility from social, cultural, ecological view.

Project Objectives and Functions

Project execution must be directed to achieve the project objectives. There are three primary objectives of a project to be met, which include:

- Performance: This is to satisfy the specified standards of performance/function, reliability and safety.
- Containment of expenditure within budgets to ensure smooth running.
- Time scale: Timely implementation of project to be proven at the time of launch. The last two objectives are linked to the resources, which are limited. But this may represent an over simplification of real intent of project objectives. A project may have many objectives, which must be clear to both project manager and the owner. Prioritising the objectives is necessary for knowing the primary and secondary objectives.

Some of the typical objectives, not listed in any particular order, include:

- Quality of product,
- Avoiding unproven equipment,
- Safety during construction,
- Designing for particular project life,
- Safety for maintenance,
- Minimising start up time,
- Enhanced public image,
- Safety during operation,
- Fastest completion time,
- High level of automation,
- Lowest capital investment,
- Lowest operational costs,
- Reliability of information,
- Security of information,
- Use of local sub-contractors, and
- Use of local suppliers

Project Management Institute (PMI) identifies *six basic functions* that project management must address. These are:

1. Manage the project's scope to define-the goals and the work to be done in sufficient detail to facilitate understanding and correct performance by participants,
2. Manage the human resources involved in a project effectively,
3. Managing communications to see that appropriate parties are informed and have sufficient information to keep the project coordinated,
4. Manage time by planning and meeting schedules,
5. Manage quality so that project results are satisfactory, and
6. Manage costs to see that project is performed at the minimum possible cost and within the budget, if possible.

The following figure is the original model of project life cycle, which is suitable for any type of project.

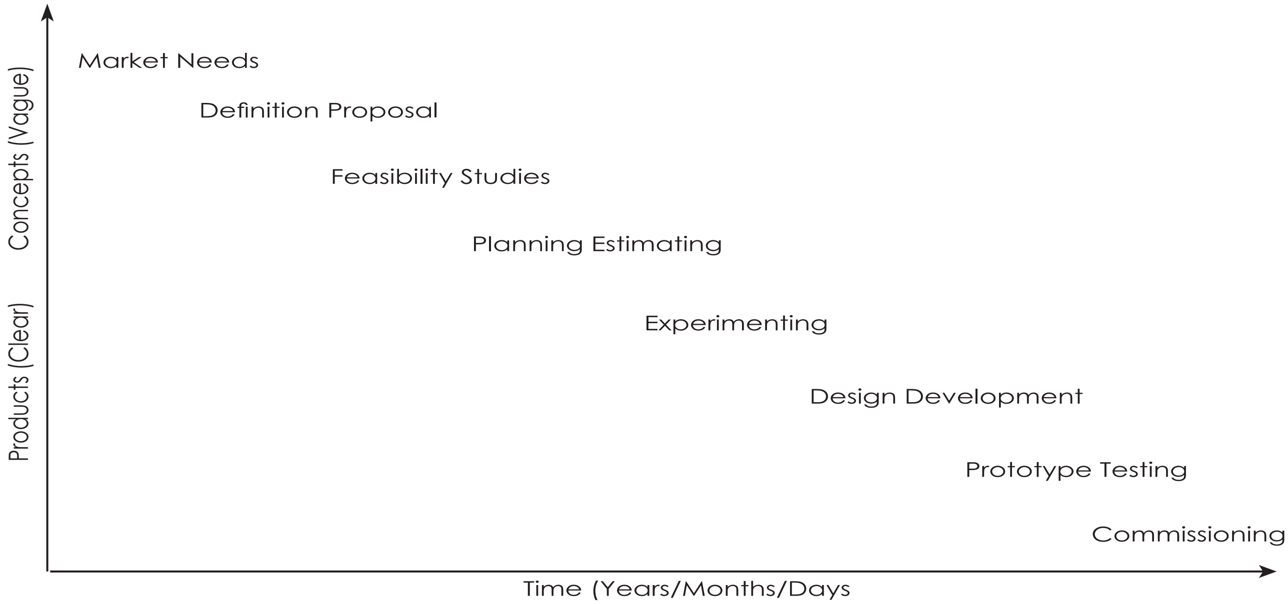


Fig. 2.7.2: Model of Project Life Cycle

Table 2.7.1: The Phases, Stages and Objectives of Various Projects

Phase	Stage	Objective
Preparation or Initiation	1. Identification of a project idea	Identification of a project idea
	2. Preliminary selection	Project objectives and preliminary global schedule and cost estimates determined.
	3. Feasibility studies	Ideas for possible solutions developed into alternative concepts; desirable technical solutions identified and classified.
	4. Evaluation and decision making (post-feasibility)	Feasibility of envisaged concepts and relevant alternatives assessed, evaluated and categorised. Decision on adoption of the most promising alternative solution; funding provided.
Implementation or construction	5. Initial project planning, scheduling, designing and engineering	All detailed drawings, specification, bills of materials, schedules, plans, cost estimates and other relevant documents checked and approved.
	6. Contracting and Procurement	Appropriate manpower, machinery, manufacturing and construction facilities, utilities, materials documentation and other relevant infrastructure components mobilised and available.
Operation	7. Facility construction and pre-operations	Complete, tested, 'debugged' and accepted product, facility or system (optimum performance, time and cost).
	8. Operations (an interface purpose and programmes continuity)	Product facility or system operational at all times and at optimum cost.

Project Life Cycle Curve

The curve below shows various phases in sequence and approximate effort involved in each phase, though in real life the phases will overlap. It can be seen that effort build up in a project is very slow but effort withdrawal is sharp. While this pattern is true for all projects, the percentage of effort in different phases will not be the same for all the projects.

The parabolic life cycle curve here represents the cumulative growth at any time. The parabolic pattern of **growth, maturity and decay** manifests itself in all phases of the project life. The knowledge of characteristic life cycle curves enables a project manager to ascertain the state of health of a particular project at any point of time. If actual progress in any of the sub-phases falls short of the qualifying work for that sub-phase, then that sub-phase is sick and requires treatment. Life cycle curve along with line of balance is very useful for management of project.

By and large, all projects have to pass through five phases, as shown in the figure. Ideally, these phases should follow one another in sequence but it rarely happens. It is possible to find the succeeding phase overlap with preceding ones or complete overlap of all phases. This overlapping may, in fact, be beneficial in compressing overall schedules.

Phases in Project Life Cycle

The five main phases are as follows:

1. Conception phase
2. Definition phase
3. Planning and organising phase
4. Implementation phase
5. Project clean-up phase

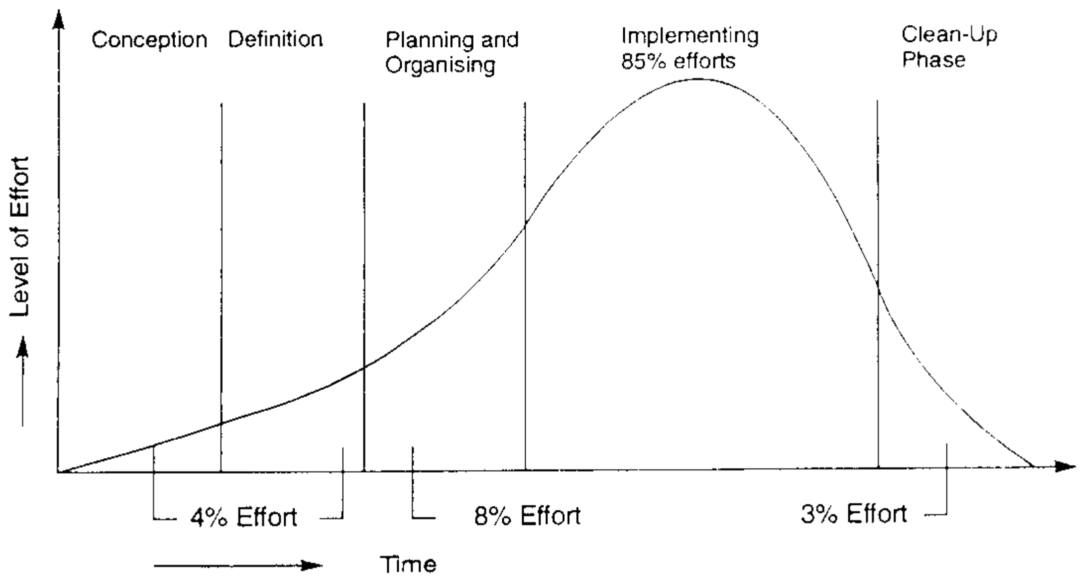


Fig. 2.7.3: Phases in Project Life Cycle

1. Conception Phase

This phase is marked by acceptance of need and identification of objectives. Identification of a goal that is bound by definite time, cost and performance target. Suitable project have to be identified first. Project identification is at the heart of the entire project management process.

It deals with the basic issue of the purpose of organisation, its long and short term goals, its strengths, its weakness, opportunities and threats (SWOT Analysis). It is a mixture of both formal and informal process. Project cannot be properly identified unless the organisation identifies its position vis-a-vis the prevailing or anticipated environment. Project ideas emerge during analysing problems conducting macro economic and social analysis, pressure from local people, etc. Project identification is followed by a broad examination of the set of identified project ideas for their physical realisability, technical soundness, market compatibility, financial availability and socio-economic impact. It is an idea generation phase in which existing problems are identified which may be non-utilisation of either the available funds, capacity of plant, expertise or unfulfilled aspirations. The ideas have to be put in black and white after examining in the light of objective and constraints. This phase, not properly addressed, may cause project failure or project becoming a liability whereas a well-conceived project will go a long way for successful implementation.

2. Definition Phase

This phase is marked by feasibility report, its appraisal and investment decision. This involves developing the idea generated during conception phase to produce documentation of details of project. These details cover all aspects necessary for customers and/or financial institutions to make up their minds on project idea. Ideally, in this phase, the bank authorities introduce strict appraisal procedure for clearance of a project funding. Various agencies may examine the feasibility report from their respective angle, e.g., government agencies give more emphasis on socio-economic aspects, Social Cost Benefit Analysis (SCBA) while financial institutions examine techno-financial viability along with managerial competence.

Project appraisal deals with accessing the absolute and relative merits of a project in order to make the critical accept or reject decision with respect to available projects.

- Market Appraisal

  Surveys, projection

- Technical Appraisal

  Product mix (optimum in nature), capacity/plant size for entire plant and equipment, process of manufacture, engineering know-how and technical collaboration

- Financial Appraisal

  Reasonableness of estimate of capital cost, reasonableness of estimate of working results, adequacy of rate of return, return on investment (ROI), sources of finance, appropriateness of financing pattern, evaluation of financial viability

- Economic Appraisal

  Economic rate of return, effective rate or protection, domestic resource cost, social cost benefit analysis (SCBA), risk/sensitivity analysis

- Managerial Appraisal

  Resourcefulness, sound understanding of project, implementation schedule clear some ambiguities of risk involved in going ahead in clear terms which help in decision of accepting/dropping at this stage itself, commitment, etc.

- Environmental

  Safeguard against damage, restoration measures

3. Planning and Organising Phase

This phase effectively starts after definition but, in actual practice, it starts immediately after conception. Generally, organisations may not formally identify this phase because of overlap. However, this phase may be marked by preparation of Project Execution Plan. Following activities are mainly involved:

- Project infrastructure and enabling service,
- System design and basic engineering package,
- Organisation and manpower,
- Schedules and budget,

- Licensing and government clearance,
- Finance,
- Identification of project manager,
- Design basis, general condition for purchase and contracts,
- Work packaging, and
- Site preparation.

4. Implementation Phase

This phase is marked by execution of project along with its controlling and monitoring. Major bulk of work (80-85%) in the project is done in this phase only. So, people want this phase to start early and finish in earliest possible time. There is greater need for co-ordination, monitoring and control with application of all techniques of project management in this phase.

This phase itself being, more or less, the whole project, every attempt is made to fast track, i.e., overlap the varying sub phases, such as engineering, procurement, construction and commissioning to maximum extent (or) parallel running of phases. Fast tracking can be improved if only agency is given the entire responsibility of design, supply and commissioning rather than different agencies.

Some of the activities involved are given below:

- Preparation of specification for equipment and machinery.
- Ordering of equipment and contracting.
- Drawing, civil construction and erection of machinery.
- Instrumentation and testing.
- Commissioning of plant.

5. Project Clean-up Phase

This phase involves handing over of the facilities built to the customer after successful guarantee (through test runs/trials) to ensure the customer satisfaction. In this phase, the following activities are completed:

- Project accounts are closed,
- Drawing, documents and manuals are catalogued and handed over,
- Outstanding payment is made and dues are collected, and
- Gradually, the project personnel are shifted to other areas.

Project Visibility

Although the proof of progress of project can be given, but it may not be possible to produce *solid evidence* for verification. Project becomes visible or gains a concrete shape only with the passage of time. It has to be realised that project is not a plant. Release of payment is sometimes linked to solid proof of progress by the financing institutions. At any point in life cycle, something will be *clearly visible, something nearly visible* but the rest will have to be imagined or projected. *So,* project is projecting all the time, to get an idea of reality.

A Framework for Project Management Issues

McKinsey and Co., management consultants, promoted a seven point framework for project management issues. The framework for classification of project management issues is given in **Table 2.7.2**.

Table 2.7.2: Framework of Project Management

Sl. No.	Element	Description
1.	Strategy	The high-level requirements of the project and means to achieve them.
2.	Structure	The organisational arrangement to carry out the project.
3.	Systems	The methods for work to be designed, monitored and controlled.
4.	Staff	Selection, recruitment, management and leadership of staff working on the project.
5.	Skills	The management and technical tools available to the project manager and the staff.
6.	Style/culture	The underlying way of working and interrelating within the work team or organisation.
7.	Stakeholders	Individuals and groups who have an interest in the project process and outcome.

The above classification of project management issues reduces the complexity of the role of project manager. In case of new situation, he knows where to find sources of help.

Elements of Project Management

The basic elements of project management include:

- Identification of the project.
- Technical and financial appraisal of the project.
- Economic or socio-economic appraisal of the project along with resources constraints. Review business justification
    - Prepare cost/benefit analysis
    - Prepare reports
- Proper formulation of project.
- Plan for implementation of the project
    - Hard plan for next stage
    - Soft plan for future stages
- Actual implementation of the project
- Monitoring the implementation to see that the project has not deviated considerably from the predefined targets, budgeted resources and time.
- Feedback and revision of objectives.
- Control action
    - Record events
    - Predict completion

    - Report progress
    - Rectification action for the deviations
- Policy restrictions
- Government regulation
- Manage staff
    - Select and train
    - Lead and manage
- Manage client relationship
    - Plan client involvement
    - Report progress
    - Resolves problems
- Evaluation either at the end of the project or few years after the completion of the project to gain an insight as to what went right or wrong vis-a-vis predefined objectives of the project and what lessons can be learned so as to transmit the same knowledge to other similar or related projects to be executed in future.

Techniques for Project Management

Project Management is not alone about Programme Evaluation and Review Techniques (PERT) or Critical Path Method (CPM). The scientific tools and techniques support and aid in the process of project management are not necessarily sufficient for its effective completion without the inputs from the human side. The scientific techniques will only tell what is right and what needs to be done, but it will require additional knowledge as to how it should be done and get it done through people through practical experience and human wisdom.

It needs to be emphasised that though techniques may be sound technically, but they may not deliver if manager is engaged in many tasks simultaneously. Throughout the life of project, the project manager has to seek a compromise between conflicting goals of technical performance, cost standard and time target. It is possible for manager to expedite actions if the priorities of management are articulated clearly. The techniques used are listed below, which will be discussed at an appropriate place.

1. **Project Selection Technique**
    - Cost benefit analysis
    - Risk and sensitivity analysis
2. **Project Execution Planning Techniques**
    - Work breakdown structure (WBS),
    - Project execution plan (PEP),
    - Project responsibility matrix, and
    - Project management manual.
3. **Project Scheduling and Co-ordinating Techniques**
    - Bar chart,
    - Project life cycle ,

- Line of balance (LOB), and
- Networking techniques (PERT/CPM).

4. **Project Monitoring and Progressing Techniques**
   - Progress measurement technique,
   - Performance monitoring technique, and
   - Updating, reviewing and reporting technique.

5. **Project Cost and Productivity Control Techniques**
   - Productivity budgeting technique,
   - Value engineering, and
   - Cost calculation using WBS.

6. **Project Communications and Clean-up Techniques**
   - Control Room, and
   - Computerised information systems.

When we talk about tools and techniques, it should be clear that mastering them all does not mean mastering project management. Besides, attempts to combine different techniques have not been fruitful because *'perfection in work and time control', 'cost control and time control'* are not agreeable. It is, therefore, no surprise that trade-offs are must and most project managers are content and obsessed with mere physical completion of project ignoring other areas of performance like time, cost or productivity. It is difficult to believe the computer based project management systems that promise to achieve everything, seeing the intricacies involved.

Roles and Attributes for Project Manager

The project manager's job is important and challenging. The manager is responsible for getting work performed but often has no direct, formal authority over most of the people who perform the job. The project manager often relies on broader knowledge of the project and skills at negotiation and persuasion to influence participants. A project manager may have the assistance of a staff if the project is large. Therefore, it is important that the project leaders have an effective means of identifying and communicating the planned activities and the ways in which they are interrelated.

Problems of project manager are:

- Project is likely to change its shape and size with time. There is always scope for change till project is finally completed.
- Those required to work on project, i.e., engineers, vendors, contractors, government bodies, etc. are almost strangers to project manager with whom he has neither worked in the past nor are likely to work in future. They are independent bodies, are neither accountable to the project manger nor are bound by corporate discipline which enables managers in all industrial organisations to get things done.

The basic roles for a Project Manager could be broadly grouped under following heads:

1. Projectising and problem solving. Projectising work as much as possible, e.g., create a number of projects such as daily, weekly, monthly, quarterly, biannually and annual package activities of entire plant.
2. Defining and maintaining integrity of a project.

3. Development of Project Execution Plan. Organisation for execution of the plan.
4. Setting of cost and time targets for each of the projects, e.g., daily, weekly, monthly activities, etc
5. Development of systems and procedures for accomplishment of project objectives and targets.
6. Line up vendors and contractors for the supply of materials and erection skills and contract management.
7. Negotiation for commitments and Man-management.
8. Non-human resource management, including fiscal matters.
9. Direction and co-ordination of project activities. Matrix and co-ordinate with other departments for preparation of drawing, specification, procurement of materials, providing skills including labour and supervision.
10. Monitor and control these projects using schedules, budgets and contracts.
11. Satisfaction of customer, government and the public.
12. Achievements of project objectives, cash surplus and higher productivity.

Attributes of a good Project Manager are:

1. Planning and organisational skills.
2. Conflict resolving capacity.
3. Ambition for achievement.
4. Personnel management skills.
5. Communication skills.
6. Change orientation.
7. Ability to solve problems in their totality.
8. High energy levels.
9. Ability to take suggestions.
10. Understanding the views of project team members and having a sympathetic attitude towards them.
11. Ability to develop alternative course of actions quickly.
12 Knowledge of project management methods, tools and technology.
13. Ability to make self evaluation.
14. Effective time management.
15. Capacity to relate current events to the project.
16. Ability to handle project management software tools and package.
17. Flair for sense of humour.
18. Solving issues/problems immediately without postponing them.
19. Initiative and risk taking ability.
20. Familiarity with the organisation.
21. Tolerance for difference of opinion, delay, ambiguity.
22. Conflict resolving capacity.

Project Planning

Planning is a primary function of management, which involves deciding in advance the future course of action. The process of project planning is to define each major task, estimate the time and resources required and provide a framework for management review and control. Planning will involve identifying and documenting scope, tasks, schedule, risks, quality and staffing needs. An adequate plan process and project plan will ensure that resources and team members will be identified so that the project will be successful. During the planning process the sequence and the logical inter-relationship between the various activities may be established. The process of project planning involves the following steps:

1. Defining the objectives and goals of the project.
2. Making forecasts for achieving the goals.
3. Identifying the various course of actions through available alternatives and assumptions.
4. Evaluating the available resources.
5. Evaluating and selecting the available course of action for achieving the desired objective under the resource constraints.

The basic tasks in planning the process include the following:

- Defining the technical approach used to solve the problem.
- Defining and sequencing the tasks to be performed and identifying all deliverables associated with the project.
- Defining the dependency relationship between tasks.
- Estimating the resources required to perform each task.
- Scheduling of all tasks to be performed.
- Defining the budget for performing the tasks.
- Defining the functional area used to execute the project.
- Estimating the duration of each task.
- Identifying the known risks in executing the project.
- Defining the process used for ensuring quality.
- Defining the process used for specifying and controlling the requirements.

Project plan is a formal, approved document used to guide both the project execution and the project control. The primary use of the project plan is document planning assumptions and decisions; to facilitate communication among stakeholders and document approved scope, cost, and schedule baselines. The project plan represents the basic tool for successfully executing a project. It forms the basis for all management efforts associated with the project. It is a record of plans that is expected to change in course of time. The project manager is responsible for bringing out the project plan, which should be accurate and complete, as far as possible, without elaborating it too much. It has to be to the point. It is a document that allows the project manager to manage the details, and not be managed by the details.

The project plan should cover the following topics:

- **General Project Information:** Points of contact, phone numbers, etc.
- **Project Executive Summary:** Business Need/Problem, Statement of work, Project objectives and approach.

- **Project Scope Statement:** It provides a documented description of the project as to its output, approach and content.
- **Critical Success Factors :** Objectives and commitments.
- **Work Breakdown Structure:** It describes a deliverable-oriented grouping of project elements, which organise and define the total scope of the project.
- **Organisational Breakdown Structure:** It provides an organisation chart that defines the communications channels, responsibilities, and the authority of each participating person/unit.
- **Cost-Benefit Analysis:** It provides the project team with information to make a balanced decision about the costs and benefits, or value, of various economic choices.
- **Resource Plan:** It describes the major resources needed to proceed with the execution of the project.
- **Project Schedule:** It provides the project schedule using a Gantt chart. The schedule must include milestones, task dependencies, task duration, work product delivery dates. quality milestones, configuration management milestones and action items.
- **Risk Plan:** It provides a description of all risks identified for the project and a plan to integrate risk management throughout the project.
- **Procurement Plan:** It identifies those needs for the project, which can be met by purchasing products or services from outside of the agency.
- **Quality Plan:** It provides a Quality Plan that defines the person(s) responsible for project quality assurance, procedures used and resources required to conduct quality assurance.
- **Communications Plan:** It defines the information needs of the project stakeholders and the project team by documenting what, when, and how the information will be distributed.
- **Configuration Management Plan:** It provides the project team with a change in management methodology for identifying and controlling the functional and physical design characteristics of a deliverable.
- **Project Budget Estimate:** It describes cost and budget considerations, including an overview, additional resource requirements, and estimated cost on completion.

Project Objectives and Policies Often, the focus of project planning is on questions like who does what and when. Before such operational planning is done, the objectives and policies guiding the project planning exercise must be articulated. The questions to be answered in this context are: What are the technical and performance objectives? What are the time and cost goals? To what extent should the work be given to outside contractors? How many contractors should be employed? What should be the terms of contract?

Well-defined objectives and policies serve as the framework for the decisions to be made by the project manager. Throughout the life of the project, he has to seek a compromise between the conflicting goals of technical performance, cost standard, and time target. A clear articulation of the priorities of management will enable the project manager to take expeditious actions.

Model for Design of a Project Management System

This involves working on different levels of interacting elements as follows:

Organisation	Man Communication Contracts Financial institution
Project hardware	Infrastructure facilities Cost Configuration Utilities Material
Resources and software	Finance Design and engineering Procurement Installation and commissioning

Work Breakdown Structure (WBS)

A WBS is a hierarchical representation of products and services to be delivered on a project. Elements of scope are decomposed to a level that provides a clear understanding of what is to be delivered for the purpose of planning, controlling and managing project scope. It is neither a schedule nor an organisational representation of the project; instead, it is a definition of what is to be delivered. Once the scope is clearly understood, the project manager must determine who will deliver it and how it will be delivered. This is one of the planning tools that must be used to ensure success of a project of any size.

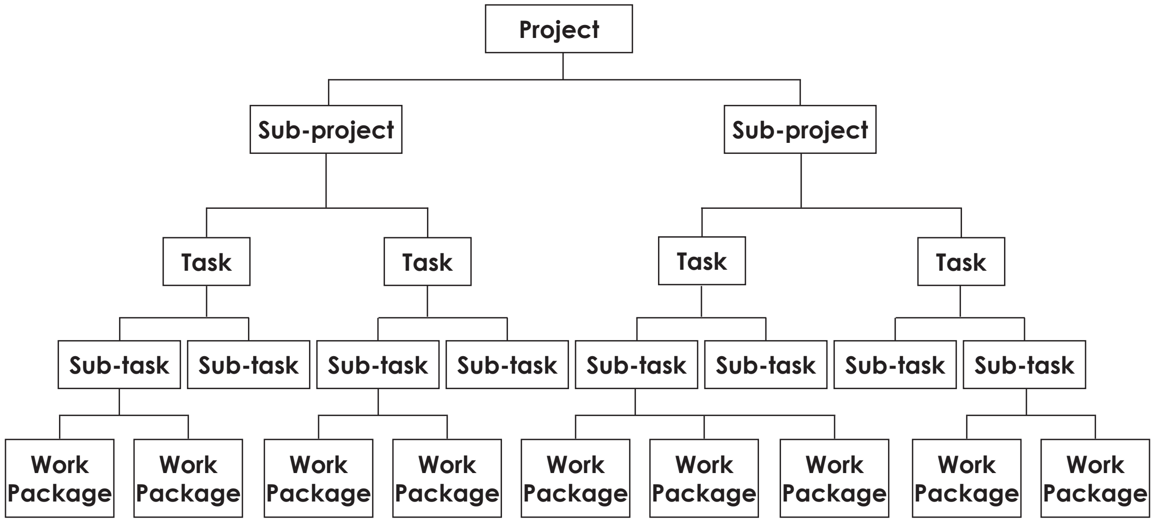


Fig. 2.7.4: Work Breakdown Structure

Development of a Work Breakdown Structure

There are certain pieces of information needed to describe the WBS deliverable and then document it in the required format:

- **WBS Element or Number**. From the WBS the agency has built
- **WBS Task Name**. From the WBS the agency has built (e.g., software).

- **Task Effort/Duration**. From the WBS the agency has built (e.g., 55 hours of efforts).
- **Resource Name**. Individuals responsible for the execution of this specific task.
- **Element or Dictionary Description**. The definition, in simple terms, of the element and what it is intended to do for the project.
- **Cost**. The total cost for the WBS element.

Decompose WBS

The WBS is decomposed into discrete products and services to be delivered during the project. Higher-level elements represent groupings of products and services to be delivered. Decomposition identifies discrete products and services. Elements are decomposed in the following way:

- A discrete product or service is identified.
- Responsibility to deliver the product or service is assigned to one individual or functional area.
- Scope is clearly understood.
- Cost is reasonably estimated.
- The element is manageable.
- Higher risk or more critical elements are decomposed to a lower level.

A coding scheme can be used to simplify the complicated structure and identify the entire elements of the family tree that make up a complete project.

Organisational Breakdown Structure (OBS)

This represents the project organisational structure arranged and coded in a hierarchical format to improve communication throughout the project. The OBS assists in reporting project attributes that are the responsibility of an agency. The hierarchical nature of the OBS provides the ability to aggregate project information to higher levels until the top level is reached. The.OBS is usually used with a WBS to ensure that all elements (scope) of a project are assigned to a responsible organisation and controlled.

Resource Planning

The resource-planning component includes the ability to plan and manage resources required to deliver a project. This starts with selection of an agency and assignment of the project team and includes the management of the resources assigned to that team. Every agency has a limited number of resources to perform tasks. A project manager's primary role is to find a way to successfully execute a project within these resource constraints. Resource planning comprises of establishing a team possessing skills required to perform the work (labour resources), as well as scheduling the tools, equipment, and processes (non-labour resources) that enable the staff to complete the project.

1. **Labour Resources:** Labour resources are also known as human resources. There are several parts to plan for the labour resource needs of a project:
    - Determining the resource pool.
    - Estimating the skill.
    - Determining the size of the project team.
    - Resource profiles.
    - Forming the team.
    - Creating resource charts.
2. **Non-labour assets:** These resources include capital, infrastructure, etc.

Schedule Development

The project activities are associated with time to create a project schedule. The project schedule provides a graphical representation of predicted tasks, milestones, dependencies, resource requirements, task duration, and deadlines. The project's master schedule inter-relates all tasks on a common time scale. The project schedule should be appropriately detailed to show breakdown of each task to be performed, name of the person responsible for completing the task, start and completion of each task, as well as expected duration of the task.

Like the development of each project plan components, developing a schedule is an iterative process. Milestones may suggest additional tasks, tasks that may require additional resources, and task completion may be measured by additional milestones. For large, complex projects, detailed sub-schedules may be required to show an adequate level of detail for each task. Once completed and approved by the project's key stakeholders, this schedule will be used to manage the project and will be known as the 'Baseline Schedule'. During the life of the project, actual progress is frequently compared with the baseline schedule, which allows for evaluation of execution activities. The accuracy of the planning process can also be assessed.

Basic efforts associated with the development of a project schedule include the following:

- Define the type of schedule.
- Define precise and measurable milestones.
- Estimate task durations.
- Define priorities.
- Determine task relationships.
- Identify lead/lag between related tasks.
- Define the critical path.
- Document assumptions.
- Identify risks.
- Review results.

The type of schedule associated with a project relates to the complexity of the implementation. For large, complex projects with a multitude of interrelated tasks, a Network Logic Diagram (commonly referred to as a 'PERT chart'— Program Evaluation and Review Technique) may be used.

Tools of Planning: The oldest formal, planning tool is the bar chart, also referred to as the Gantt chart or the multiple activity chart. In the last seven decades, network techniques have received considerable attention.

Project Scheduling

Introduction

Organizations carry out works either through normal operations or through projects. In both cases, there are some similarities as well as differences. These similarities 'and differences between operations and projects are presented in Table 2.7.3

Table 2.7.3 : Comparison between operations and projects

	Parameter	Operations	Projects
Similarities	Product	There is an end product after the operations.	There is an end product after completion of the project.
	Time	Needs time to complete the activities:	Needs time to complete the project.
	Need for people	Activities are carried out by people;	Projects need people to complete it.
	Nature	Operations are planned, executed, and controlled.	Projects are planned, executed, and controlled.
	Resources	Resource constraints are faced in execution of the work.	Resource constraints are faced in execution of the project.

	Nature	Operations are repetitive in nature	Projects are unique in nature.
Differences	Team	Operation team goes on for long until there is a change in the team due to transfer, promotion, removal from job or death of the team member.	Team members are deployed for the duration of the project only. Once the project is completed the project team is disbanned/removed from service.
	Duration of team members	Team members are regular employees of the company except in cases where a part of the activity is' sub-contracted	Team members are for a specific work requirements or for providing inputs of specific specialization in the project work
	Time frame	Time frame for operations is very long. It may continue for a period of 20-30 years or even more.	Project's time frame is limited till the results or the output of the desired product or service is achieved. Time frame depends upon the size of the project. It may be days, weeks, months or even many years.

(A) Size of Projects

Projects could be of different sizes such as small, medium, large, and very large. The size of the project could be in terms of value of the project or the time factor required for completion of the project. There could be a small project to make furniture for the office of the Chairman, which takes few weeks or about a month and might cost $10,000 to $20,000. There could be a medium size project to build a school, which could cost a few hundreds of thousand of dollars and a period of about 4 to 6 months for completion. There could be a very large size project to build an airport, a university or a very big shopping mall, which might require few years and millions of dollars. Large size projects require lots of advance planning, coordination between various agencies and close monitoring for the various resources needed. There could be projects of huge dimensions and complexities such as laying of gas pipe line in a city, inter-connecting many cities; making of metro-rail services; connecting different parts of the country by roads, airways or by waterways through a network, or making a chain of hotels in various parts of the world. These projects normally need huge amount of money and very long time, sometimes even 10 to 15 years. Many resources, expertise and lots of inter-departmental coordination are also required. Some of the power plant projects, especially hydro-electric projects take many years say even 6-10 years and drag on due to lack of planning, funds, and resources. The cost of such projects are revised many times by the time the project is completed resulting in substantial increase to the original cost of the project.

The revision of project cost often takes longer time than the initial planned time for completion of the project. Some of the projects are of vital importance, for example the defence projects like building nuclear missiles are very important for the safety, security, and sovereignty of the country. Not only the cost and time frame of these projects are very high but the aspects of confidentiality and complexities involved are also important. Thus projects are of various sizes in terms of cost, time, complexities, and importance.

Even though there are many constraints in execution of such projects, every effort is made to make the project successful. The success of a project is achieved by close monitoring and control of the progress to ensure their timely completion within the initial cost targets.

(B) Factors Influencing the Scheduling of Projects

Project management consists of identification of activities, sequencing them, estimating the duration of activities, development, and control of schedule. Scheduling of projects Js. greatly influenced by many factors, such as:

- Changes
- Uncertainties
- Database

Changes Every project undergoes lots of change by the time it is completed. As the size of the project increases, there are more chances for changes tote encountered: Changes may be in the form of' change in management decision/technology, location of the project or changes in priorities.

Uncertainties A project encounters many constraints during its execution. The constraint resulting in uncertainties could be due to the following

- Labour
- Materials
- Accidents
- Machine downtime
- Political scenario
- Natural calamities

Database Scheduling of a project is based on the database for similar projects carried out in the industry or similar projects in some other industrial sector. For example, installation and commissioning of gas turbine in a cement plant could get the guidance from the database of other cement plants or from the database of other industrial sectors like steel plants or other process plants. The information available from the database might not be applicable in all cases due to various reasons, e.g. the environmental differences. Building a housing complex in a cold country would require a different scheduling, from building the housing complex in a hot country. Correct, dependable, and reliable database is very necessary for preparing a correct schedule. Availability of power in the required quantity and quality, without power interruptions, voltage fluctuations, and frequency variations plays an important part in the execution of the project in time. Different scheduling is necessary to meet the different requirement of the project in differing scenarios of power availability.

In some cases, database is not available at all. The project planner has nothing to fall back on and estimate. Hence he largely depends on his skills to estimate the time of various activities. His experience in project management plays a very important role. A project planner working in USA is likely to fail in preparing a good plan for a project in an under developed country. The two environments are totally different for a similar type of project. The estimates prepared by him need moderation by a person having an intimate knowledge of the working environment and the resources available in an under developed country.

(C) Gantt Chart

Gantt chart is one of the oldest techniques used for planning, scheduling and controlling of projects. Gantt chart was developed by H.L. Gantt in 1917 and is in use till today. Gantt charts were used even before computer came on the scene. Even today, Gantt chart applies to manufacturing as well as service organizations.

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. In the initial days Gantt charts used the following symbols:

Symbols	**Explanation of the symbol**
[	Start of an activity
]	End of an activity
[----]	Actual progress of the activity
v	Point of time to show 'where you are'

Over a period, only bars are used to show the start, end and duration of the activity. When the Gantt chart is used as a controlling technique, the planned and actual performance of the activities are presented on the same chart by two horizontal bars with different colors or by different presentation. Table 2.7.4 presents the various tasks required to repair a large size electrical motor. The expected time to be taken by each activity as well as the relationship between different activities are also presented in Table 2.7.5. Gantt chart indicating planned schedule is presented in Fig. 2.7.5, It is seen that Activity B and D, both are dependent upon Activity A as shown on the Gantt chart.

Gantt charts are initially prepared for planning purposes. However, as the work progresses, the actual performance or progress is shown on the Gantt chart to have a clear picture of any variation from the planned time. This provides a comparison between planned-time and actual time taken in completion of an activity.

Table 2.7.4: Activities in repair of an electric motor

Sl. No.	Task	Repair Activities	Duration (Hrs.)	Analysis
1	A	Testing of motor with Megger	1	Start
2	B	Dismantling the motor and cleaning the components	2	Depends upon A
3	C	Removing the bearings from the motor shaft	1	Depends upon B
4	D	Collecting winding materials	1	Depends upon A
5	E	Rewinding of motor	8	Depends upon B, C, D
6	F	Reinstalling of the new bearings	1	Depends upon E
7	G	Assembling the motor after repairs	2	Depends upon F
8	H	Installation and testing of motor	1	Depends upon G

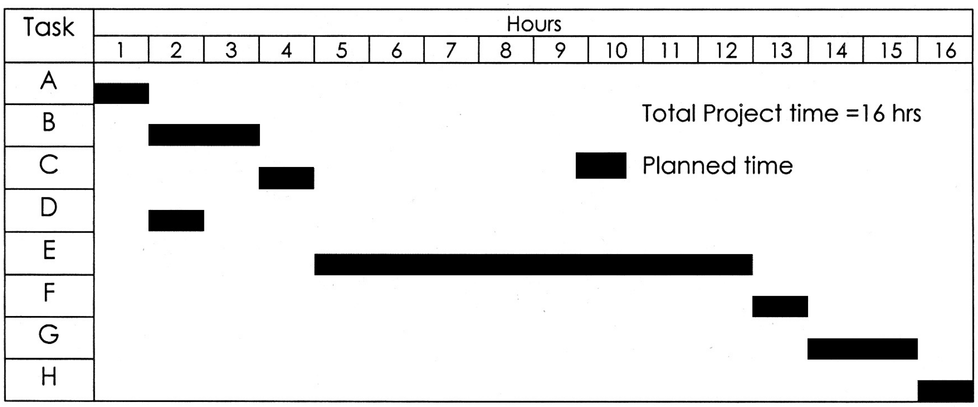


Fig. 2.7.5: Bar chart indicating the planned time for each repair activity of the electric motor

Table 2.7.5: Actual time Vs. planned time for repair of an electric motor.

Sl. No.	Task	Repair Activities	Duration (Hrs.)		Analysis
			Planned	Actual	
1	A	Testing of motor with Megger	1	1	Start
2	B	Dismantling the motor and cleaning the components	2	1	Depends upon A
3	C	Removing the bearings from the motor shaft	1	1	Depends upon B
4	D	Collecting winding naterials	1	6	Depends upon A
5	E	Rewinding of motor	8	6	Depends upon B, C, D
6	F	Reinstalling of the new bearings	1	1	Depends upon E
7	G	Assembling the motor after repairs	2	1	Depends upon F
8	H	Installation and testing of motor	1	1	Depends upon G

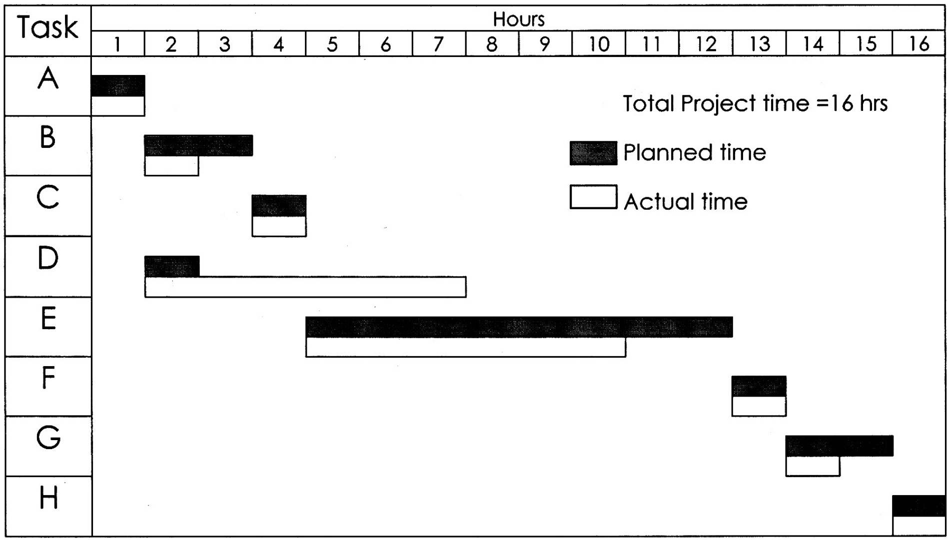


Fig. 2.7.6: Bar chart indicating the planned as well as actual time taken in each repair activity of the electric motor

Planned time of repair and actual time taken in each activity are shown in Table Activity B takes 1 hr as compared to the 2 hrs planned. Activity D has taken a longer time of 6 hrs in comparison to the planned time of 1 hr only. Similarly, there are differences in the planned and the actual time taken by the Activities E and G, as can be seen in the Table. The control Gantt chart for repair activities of the electric motor indicating both the planned as well as the actual time taken by each activity is shown in Fig. 2.7.6. Due to change in actual duration in completion of the activities as compared to the planned duration, the Gantt chart needs to be redrawn for proper linkage of various activities. This is one of the limitations of the Gantt chart as it needs frequent changes to incorporate and show the changes taking place.

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.

Network Techniques

The use of network techniques is very common for any project it helps in calculating the time of project and can be useful to optimise the overall completion time using the concept of crashing of activities. The description presented here will help the readers to control and expedite the project with optimal cost.

Transition from Gantt Chart to Network Diagram

Gantt progress chart is a bar chart that gives a comparative picture between actual performance and planned performance, i.e. how the planned performance keeps pace with the fixed targets. Due to the shortcoming or inadequacies of the bar chart in meeting the requirements of the modern day management, efforts were made to modify it by adding new elements. One important modification that forms a link in the evolution of the Gantt chart into PERT/CPM Network is called *Milestone system*.

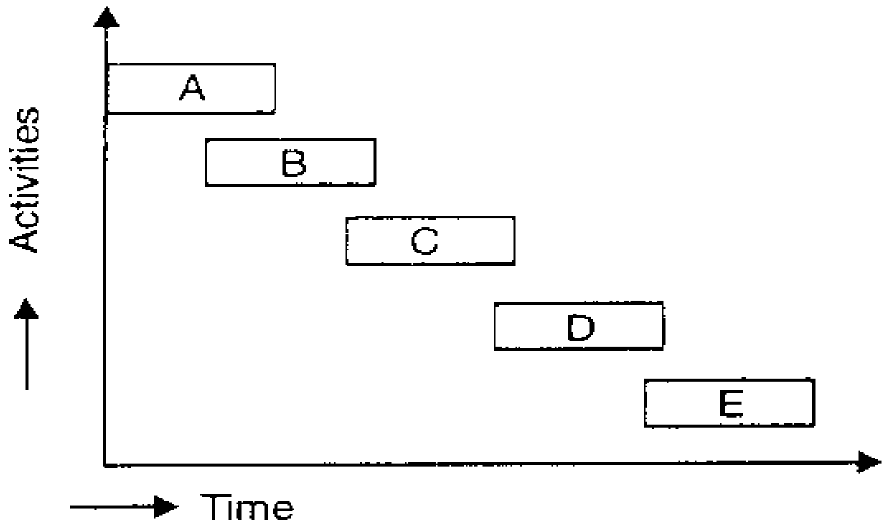


Fig. 2.7.7: Gantt Chart

Milestones are key points or events in time, which can be identified when completed as the project progresses. They act as reference points for the management. In a Gantt chart, a bar which represents a long-term job is broken down into several pieces, each of which represents an identifiable major event. While the milestone was definitely an improvement on the bar chart, it still had one great deficiency, i.e., it did not clearly show the interdependence between events. In a milestone chart, the events are in chronological order, but not in a logical sequence. A natural extension of the milestone chart was **network**, where arrows connect events in a logical sequence. This led to the evolution of network techniques.

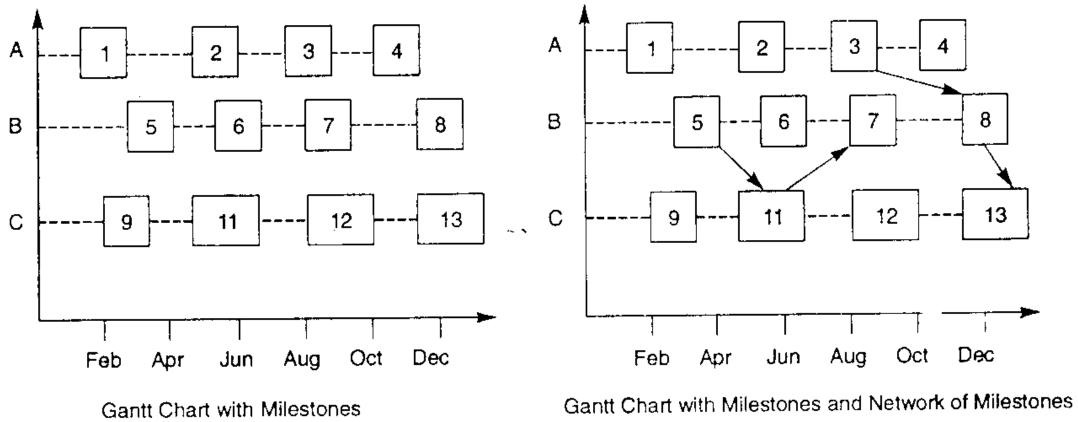


Fig. 2.7.8: Gantt Chart and Milestones

Scheduling

The network is a graphical representation of the interrelationship among all activities in the project. Developing the network forces detailed planning of the project and provides a valuable communication tool. After the activities have been identified and the network has been drawn the next step is to assign expected time duration to the activities. The expected duration depends on the planned crew size work method equipment and working hours. A particular level of resource must be assumed to be available when the work is to be performed. The following conditions may exist when the estimates are made:

- The person who is incharge of an activity or activities assumes that some customary and reasonable level of resource will be used and specify an expected duration for the activity. Some completion data is determined. This approach is in keeping with the theory of Critical Path Method (CPM).
- In some actual application, a completion time or milestone data is specified and the estimated amount of resources is adjusted so that the duration will be less than equal to the desired amount of time. This approach is in keeping with the theory of Programme Evaluation and Review Technique (PERT).

Advantages of Network Scheduling

Network based scheduling techniques can be beneficial in many ways if they are properly used. Like all other scheduling techniques, however, they are not panaceas or substitutes for judgment of good management. Since scheduling is an attempt to plan future work, and estimate the time for the required work. No technique will make poor estimates any better. Scheduling can help plan the work, but the accuracy of plans and schedules depends on the accuracy of the time estimates used in their development. Knowledgeable people and/or reliable techniques should be used to provide the time estimates.

Assuming that the estimates for a network scheduling method are as good as those for other scheduling methods, the network techniques may offer some advantages:

1. They lead to planning a project to the selected level of details so that all parts of the project and their intended order of accomplishment are known.
2. They provide a fairly accurate estimate of the length of time it will take to complete the project and activities that must be kept on time to meet the schedule.
3. They provide a graphical picture and standardised vocabulary to aid in understanding the work assignments and communicate it among the people involved in the project.
4. They provide means to track the progress on a project, i.e., show where work is with respect to the plan.
5. They identify and focus attention on potentially troublesome activities to facilitate management by exception.
6. They provide a means of estimating the time and cost impact of changes in the project plan at any stage.

Network-Based Scheduling Techniques

The biggest advance in project scheduling since the development of the *Gantt Chart* in 1917 was made between 1956 and 1958. During this period, two new scheduling techniques were developed that have much in common, although they were developed independently. These techniques are the *Program Evaluation and Review Technique* (**PERT**) and the *Critical Path Method* (**CPM**). Both are based on the use of a network or graphical model to depict the work tasks being scheduled. Both were designed to schedule long-duration projects that were to be performed only once or in low volume. Computer programs are available for both PERT and CPM, which are helpful in developing timely information about large projects, particularly those that are to be updated and revised several times before completion. Following techniques can be used to solve a problem through a network:

- Programme Evaluation and Review Technique (PERT)
- Critical Path Method (CPM)
- Resource Allocation and Multi-project Scheduling (RAMS)
- Graphical Evaluation and Review Technique (GERT)
- Multi Operation Scheduling System (MOSS)
- Critical Operating Production Allocation Control (COPAC)
- Least Cost Scheduling (LCS)
- Man Power Allocation Procedure (MAP)
- Resource Planning and Scheduling Method (RPSM)

Steps in using Network Techniques

Three major steps are involved in the use of network scheduling:

- Planning the Project
    - Analyse the project by determining all the individual activities, and
    - Show the planned sequence of these activities on a network.
- Scheduling the Project
    - Estimate how long it will take to perform each activity,
    - Perform computations to locate the critical path. This information will also provide information for scheduling, and
    - Use this information to develop a more economical and efficient schedule.
- Monitoring the Project
    - Use the plan and schedule to control and monitor progress, and
    - Revise and update the schedule throughout execution of the project so that the schedule represents the current plans and current status of progress.

Some of the Assumptions in PERT or CPM are Given Below

- Project activities can be identified as entities (there is a clear beginning and ending point for each activity).
- Project activity sequence relationships can be specified and networked.
- Project control should focus on critical path
- The activity times in PERT follow the Beta Distribution with the variance of the project assumed to equal the sum of the variances along the critical path.

Symbols Used in Network

1. Activity by → (arrow)

Arrow can have any size or slope. It starts from tail and ends at the head of arrow, e.g., assembly of parts, mixing of concrete, preparing budget, etc.

2. Dummy activity ---------> (broken arrow)

These activities consume no time. This is introduced to prevent dangling. This happens when an activity ends without being joined to end event, thus breaking continuity.

3. Event O (circle or node)

Event is represented by node. Event takes no time but it connects two or more activities. Events may be classified into three categories: merge event, burst event, merge and burst event, e.g. design completed, pipe line laid, started issue, tested.

Merge Event   Burst Event   Merge and Burst Event

Fig. 2.7.9: Events Directions

Terminologies used in networks include the following:

Network

It is the graphic representations of projects operations composed of activities and events to achieve objective of project, showing planning sequence.

Event (node)

It is a recognisable as particular instant of time and does not consume time or source. It is generally represented on network by circle, rectangle or hexagon.

Activity

It is a task or item that consumes time, money, effort, etc. It lies between preceding and succeeding events.

Float or Slack

The term **slack** time refers to an ***event-controlled network*** and ***float*** time refers to the ***activity network***.

But, generally float and slack are used interchangeably. ***Float or Slack*** is defined, as amount of time and activity can be delayed without effecting the duration of project. On a critical path, the float is zero. So, float gives an indication criticalness of an activity. An activity with little float, stands a good chance of delaying project and should be carefully monitored.

ES (a)	=	Early start time of activity 'a'
EF (a)	=	Early finish time of activity 'a'
LS (a)	=	Late start time of activity 'a'
LF (a)	=	Late finish time of activity 'a'
t	=	duration of the activity considered
TF	=	total float
FF	=	Free float
IF	=	Independent float

Total duration

Total duration of time available for any job is the difference between its earliest start time and latest finish time. If activity 1-2 is considered, then

Maximum Time Available = LF (1-2) - ES (1-2)

Earliest start time (ES)

This is the earliest occurrence time for the event from which the activity arrow originates.

Earliest finish time (EF)

This is the earliest occurrence time for the event from which activity arrow originates plus duration for the activity

EF (a) = ES (a) +t

Latest start time (LS)

This is the latest occurrence time for the node at which activity arrow terminates minus the duration for the activity

LS = LF-t

Latest finish time (LF)

This is the latest occurrence time for the node at which activity arrow terminates.

Precedence Relationships

Some activities cannot be performed until other activities have been completed. This type of requirement establishes a technical *precedence relationship*. There may sometimes be options as to the way activities may be performed, but management's prerogatives or differences in costs lead to a particular planned sequence of activities. Other activities may be performed independently. Task independence and precedence relationships should be incorporated into the job plan and indicated on the project network.

Networking Conventions: AON and AOA

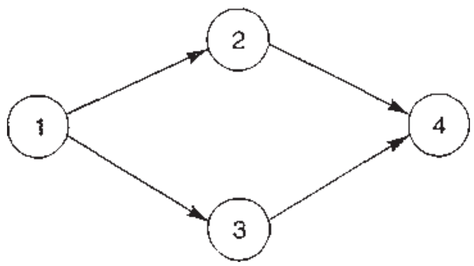
A network is a graph using circles and arrows to represent the planned relationships among the activities required to complete a project. Either of the two conventions can be used to develop a network. One uses circles to represent the project activities, with arrows linking them together to show the sequence in which they are to be performed. This is called the *activity-on-node* (AON) convention, or Precedence notation. An alternative is to show the activities as arrows and use circles to connect predecessor and successor activities. This method is called the *activity-on-arrow* (AOA) *convention*. With this convention, the circles or nodes represent events, which are points in time at which activities begin or end. An event consumes no resources, whereas an activity consumes time and other resources.

A network is drawn after all activities and their relationships have been defined. There is no proven best approach to the identification of activities. Some people start with what they believe to be logically the first activity and proceed in what they believe to be chronological order; others may start with the last activity and work backward; still others list activities in random sequence. After the activities are identified, one may ask:

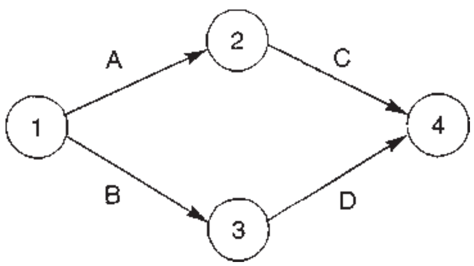
1. Which activity must immediately precede this one?
2. Which activity must immediately follow this one?
3. Can this activity be accomplished without dependence on some other activity?

The activity that must be performed just before a particular activity is its **predecessor** activity; the one that follows is its **successor** activity. Activities, which can be accomplished concurrently, are known as **concurrent** activities.

An activity in the AOA convention is often identified by numbers indicating the starting and ending events. This identification system is called *i-j* notation (i represents the number of the starting event, and; represents the number of the ending event). This notation makes it necessary for every activity to have a unique *i-j* pair. A *dummy activity* (indicated by dashed arrow) consumes no time or other resources but is used merely to indicate a precedence relationship. A dummy activity may be used to keep two activities from having the same starting and ending nodes. With the activity-on-arrow convention, dummy activities also may be needed in other instances to indicate precedence relationships. A single number or letter can identify activities in the AON convention, and there is no need for dummy activities when this convention is used. Generally, the AON convention is easier to learn because it consistently uses arrows only to indicate precedence. In contrast, some arrows (solid) are activities, and other arrows (dashed) indicate precedence requirements when the AOA convention is used. Two errors in network diagrams common to both AON and AOA method are dangling and looping which are outlined under the rules for network construction.



Activity on Node (AON)



Activity on Arrow (AOA)

Fig. 2.7.10: Comparison of AON and AOA

Rules For Network Construction

1. There should not be duplication of activities, i.e., no redundancy. Each activity is represented by one and only one arrow in the network.
2. Draw arrows in straight lines, avoid curved lines and crossing of activities.

3. Avoid looping in that, draw arrows from left to right and not in between right to left resulting in looping.
4. No hard and fast rule in numbering events. As far as possible number them in ascending order from left to right. For rigorous numbering follow Fulkerson rule (given below).
5. The length of arrow need not be scaled or proportioned to duration. This rule is necessary to avoid looping and back tracking.
6. An event cannot occur until all activities leading to it are completed and no activity can begin until its immediate preceding event has occurred.
7. Each activity must have a tail and head event. No two or more activities must have the same head and tail events.
8. Dangling must be avoided in a network diagram. It happens when an activity ends without being joined to end event, so breaking continuity because of precedence relationship not being identified.

Fulkerson Rules for Numbering Nodes

- Initial event is marked no. 1, which have arrows emerging out but none entering.
- Delete all arrows emerging from event no. 1. This will result at least one more initial event. Denote some as no. 2. Continue process till all events exhausted or numbered.
- Number at head of any arrows always greater than node number at its tail.
- No node is numbered until its all-preceding events are numbered.
- There is only one starting and one finishing node i.e., all activities are uniquely represented by one starting and one finishing event.
- There is no duplicate number for a number.

Statistical Method Of Deriving: Single Time Estimate

Looking statistically, all estimates are a prediction of probability. There are two well-known distributions considered for the analysis, viz "**Normal-Distribution**" and "**Beta-Distribution**". As per normal distribution, which is symmetric about mean the probability of occurrence can be increased by increasing standard deviation.

$$\bar{X} \pm \sigma = 68.27 \text{ Area}$$

$$\bar{X} \pm 2\sigma = 95.45 \text{ Area}$$

$$\bar{X} \pm 3\sigma = 99.73 \text{ Area}$$

However, it is assumed that expected time for an activity in PERT model follows Beta Distribution and each has its own **mean 'm'** and **standard deviation '**σ'. The estimated time for an activity can be better described by a probability distribution of activity times with the following characteristics:

- Small probability (say one in hundred) of reaching the most optimistic time (shortest time) symbol as '*a*'.
- Small probability (say one in hundred) of reaching of most pessimistic time (longest time) symbolised as '*b*'.
- One and only one most likely time symbolised as '*m*' which would be free to move between the two extremes of expected time.

- Ability to measure uncertainty in estimating

a = Optimistic Time

b= Pessimistic Time

m = Most Likely Time

Single Time Estimate (Expected Time) $t_e = \frac{(a+4m+b)}{6}$

Variance $(\sigma^2) = \left[\frac{b-a}{6}\right]^2$

Standard Deviation $(\sigma) = \sum\left[\{(b-a)/6\}^2\right]^{1/2}$

Therefore, to have all these four attributes one specific probability curve is necessary and none other than Beta distribution can be a better fit in this situation.

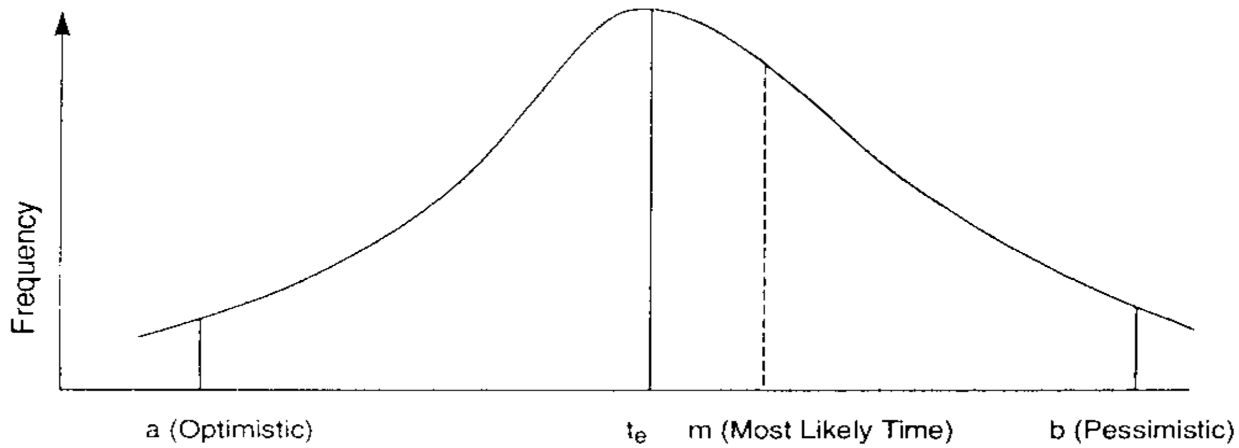


Fig. 2.7.11: Normal Distribution

If each of the activities of a network have their own 'b' (Beta Distribution) with means $\mu_1\ \mu_2 .... \mu_n$ and standard deviations $\sigma_1\ \sigma_2 .... \sigma_n$ respectively, then according to **Central Limit Theorem** distribution of time for the completion of the project as a whole will approximately be a normal distribution curve with mean and variance as given below:

Mean = $\mu_{1+}\ \mu_{2+}\ ....\ \mu_n$

Variance = $\sum\left(\sigma_1^2 + \sigma_2^2 + ...\sigma_n^2\right)$

Determination of Floats and Slack Times

Float allows some flexibility in scheduling activities. An activity can be intentionally delayed if the delay will result in a more uniform workload or provides some other advantage. Some amount of float should be retained if possible because float is like insurance. The float is useful under the following conditions: uncertain material deliveries, possible strikes, delayed drawing approvals and so on; it is wise to have a time cushion if it can be afforded.

More than one activity may require the same resources and may be planned to occur at the same time. Networking and scheduling data provided by the scheduling method will reveal such conflicts so that re-adjustments can be planned to determine the times at which various activities can occur. It is necessary to calculate the earliest date at which each activity can be performed and how much each activity can be delayed without interfering with projects scheduled completion. ES and EF of the activities are calculated in the forward direction of project. LS and LF of activities are calculated in the backward direction from the end of the project after equating the EF of the entire project and LF of the entire project.

Total float value

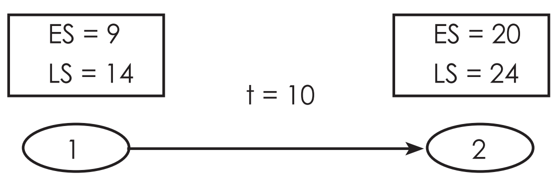
Negative	Resources not adequate
Zero	Resources just sufficient
Positive	Resources are extra, so flexibility exists for contingency delays

There are mainly three kinds of Floats:

Total Float

Amount of time by which the completion of an activity could be delayed beyond the earliest completion time without affecting the overall project duration time. It is measured by the maximum time of the difference between maximum time available to perform activity and activity duration time or the difference between latest start time and earliest start time.

$$TS(a) = LS\ (a) – ES\ (a)$$



For Activity 1-2, ES = 9 and LS = 14

Then Total Float for (1-2) = 14-9 =5

Free Float

Time by which the completion of an event can be delayed beyond the earliest finish time without affecting the earliest start of a subsequent (succeeding) activity is based on the possibility that all events occur at their earliest times, i.e., all activities start as early as possible.

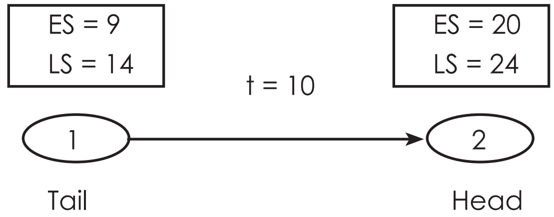
Free float for an activity is the difference between its earliest finish time and the earliest start time for its successor activity. It is that portion of the total float within which an activity can be manipulated without affecting the floats of subsequent activity. So, for all activities, the free float can take the values from ‘Total Float’ to ‘Zero’ but cannot exceed Total Float. Free float is useful for rescheduling the activities with minimum disruption of earlier plans.

FF (I-J) = (Earliest time for event ‘J’-Earliest time for event ‘I’) - Activity time for (I-J)

FS (a) = Minimum of ES times of all immediate successors of activity ‘a’- EF (a)

FF = ES (Succeeding) - EF (Activity)

FF = Total Float - Slack at Head Event



Free Float (FF) = (EF - ES) - t

= (20 - 9) - 10 = 1

Independent Float

The amount of time by which the start of an activity can be delayed without effecting the earliest start time of any immediately following activities, assuming that the preceding activity has finished at its latest finish time.

It is the portion of the total float, which an activity may be delayed for start without affecting floats of preceding activities.

Independent Float (IF_{IJ}) = (EF_J - LS_I) -t_{IJ}

Independent Float = ES (succeeding activity) — LF (activity)

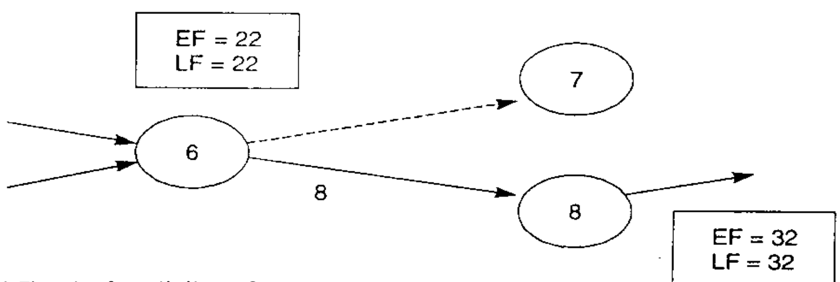
Independent Float = Free float - Slack at tail event (proceeding event)

Considering activity (1-2)

Independent Float (1-2) = (20 - 14) -10 = -4

Or, IF =FF- Slack at tail = 1-5 = -4

Considering activity 6-8 shown in the figure below shows the latest time for the job preceding 6-8 is 22 and the earliest start time for the job succeeding 6-8 is 32. The difference between them is 10, but activity takes only 8 units of time. Therefore, its independent float is 2 units of time.



Independent Float of activity = 2

The negative independent float is always taken zero. This float is concerned with prior and subsequent activities. It is observed that the relationship between the different types of floats is as follows

Independent Float	≤	Free Float	≤	Total Float

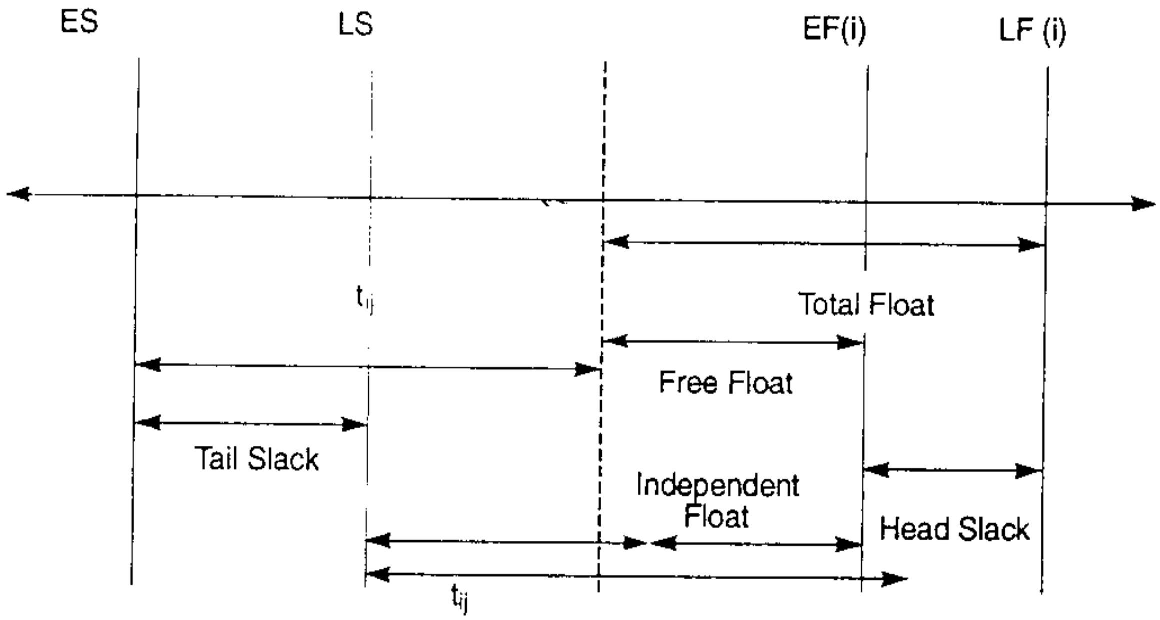
Event Slacks

For any given event the event slack is defined as the difference between the latest event and the earliest event times. For an activity (I, J); I and J are 'Head and Tail' nodes or events.

Head Event slack=	LF(J)- EF(J)
Tail Event slack=	LF(I)- EF(I)

Time Scale Representation of Floats and Slacks

The various floats and slacks for an activity (I-J) can be represented on time scale as



CRITICAL PATH

A critical path is a chain of sequential activities beginning with the project start and ending with its completion. Several or many path may exist through the network. Work may proceed on many independent path concurrently, but, of course, work may proceed on an activity only after all the necessary predecessor activities in its path have been completed. All activities, hence all paths, must be completed before the project is finished.

The path through the network that has the longest expected completion time and is expected to determine the completion date of the project is called the critical path.

Often, activities that are not on the critical path can be delayed without causing a delay in the completion of the project. On the other hand, activities on the critical path, if delayed, cause delay in the entire project. In other words, there is no float along the critical path.

(A) Forward Pass (ES, EF)

The early start and early finish for each activity are found by calculation performed in sequence from left to right in the network. This series of calculations is called *forward pass.* First, we assign a project day usually 0 to the start of the first activity to represent the ES for that activity. Then, we obtain the ES and EF for each activity by making forward pass through the network, from left to right. The duration of an activity is added to its ES to obtain the EF. The ES of an activity is set equal to the EF of its predecessor if there is only one. If an activity has more than one predecessor, its ES is equal to the latest EF of its predecessors. For example, if the early start for activity M in figure is day 10, its early finish is day 15. If the early start for activity R is day 12, its early finish day is 18. Even though one of its predecessors (activity M) is completed on day 15, activity P cannot begin until day 18 when the latest of all its predecessors is finished. The forward pass is continued until we reach the right hand side of the network. At this point, we have the EF of the final activity, which is the earliest the project can be completed (if the activities take the time that was estimated).

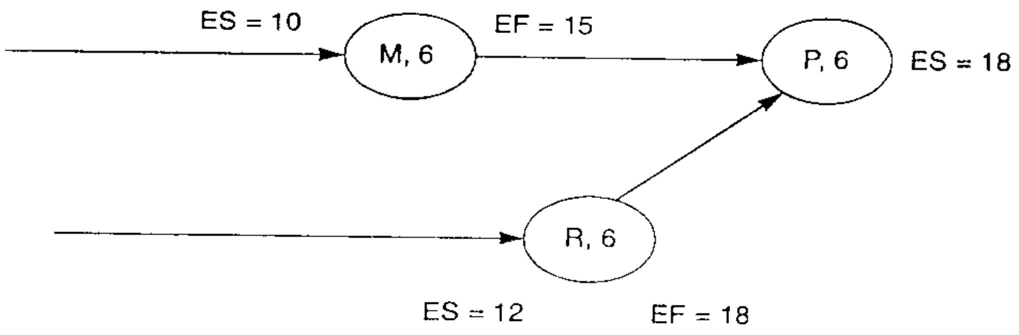


Fig. 2.7.12 Relationship

(B) Backward Pass (LF, LS)

The LF and LS dates are calculated by means of a backward pass from right to left through the network. The LF of the last activity is usually set equal to the EF of the project. Starting with the last activity subtract the activity duration form LF to obtain LS. The LF for an activity is set equal to the LS for its successors if there is only one. It is set equal to the earliest or smallest LS of all successors if there is more than one successor.

Probability of Completion Time

We assume a normal distribution table (see Appendix) for calculating probability. For this distribution Z-value tables are available. In a normal distribution curve the chances of the project being completed within the mean time is 50 per cent. This is obtained by dividing the area to the left of mean by total areas.

If T_E = mean time = 41.7 days and

Ts = Actual or Desired Time = 45 days

s = 1.2 days

$$Z = \frac{\text{Deviation}}{\text{Standard Deviation}} = \frac{(45 - 41.7)}{1.2} = 2.75$$

Standard Deviation = 1.2

This expresses area under

[X_{mean} + 2.75.s (Standard Deviation)

From Z-value table in Appendix we get

0.497 x 2 = 0.994

or Area = 99.4

So, the probability of competing project in desired time is 99.4 per cent.

Illustration 1:

Draw the network diagram for the activities of a maintenance job of a part of refinery

Table: Refinery Date

Activity	Description of Activity	Predecessor Activity
A	Dismantle the pipe line.	None
B	Disassemble other fittings.	A
C	Remove valves and check them.	B
D	Clean the valves and check them.	C,E
E	Clean the pipe lines and others.	B
F	Replace the defective items.	C, E
G	Layout of the assembly lines.	F
H	Assemble the valves.	G
I	Do the final connections.	H, D
J	Test the fittings.	I

Solution:

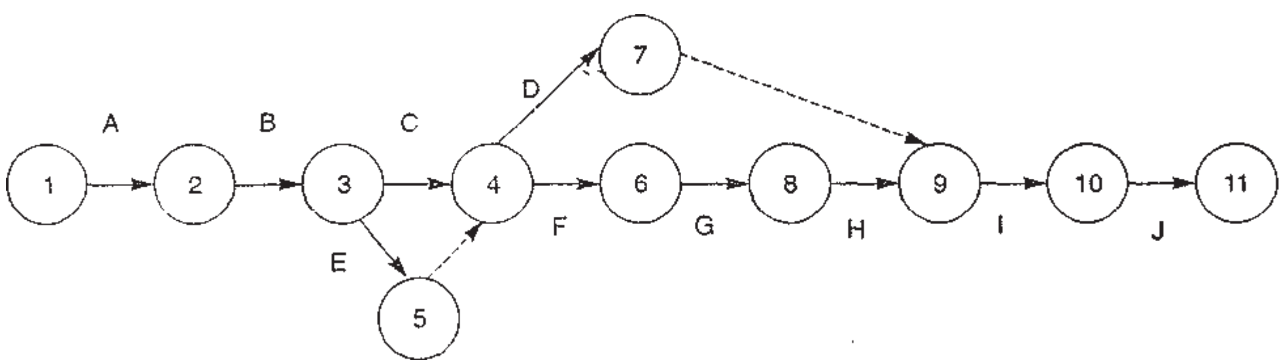


Illustration 2:

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:

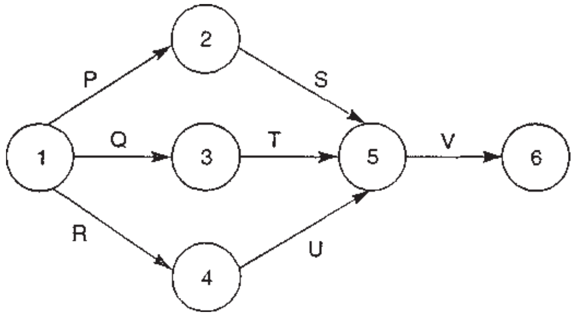


Illustration 3:

Draw the network of the project with the following situations:

P is the prerequisite for S

Q is the prerequisite for S and T

R is the prerequisite for T

S and T are the prerequisite for U

Solution:

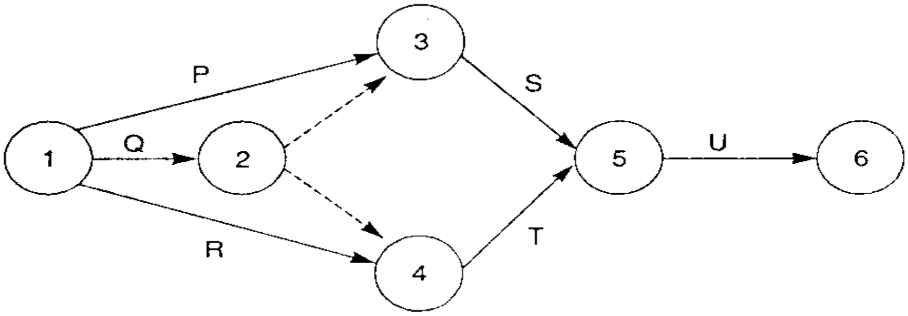


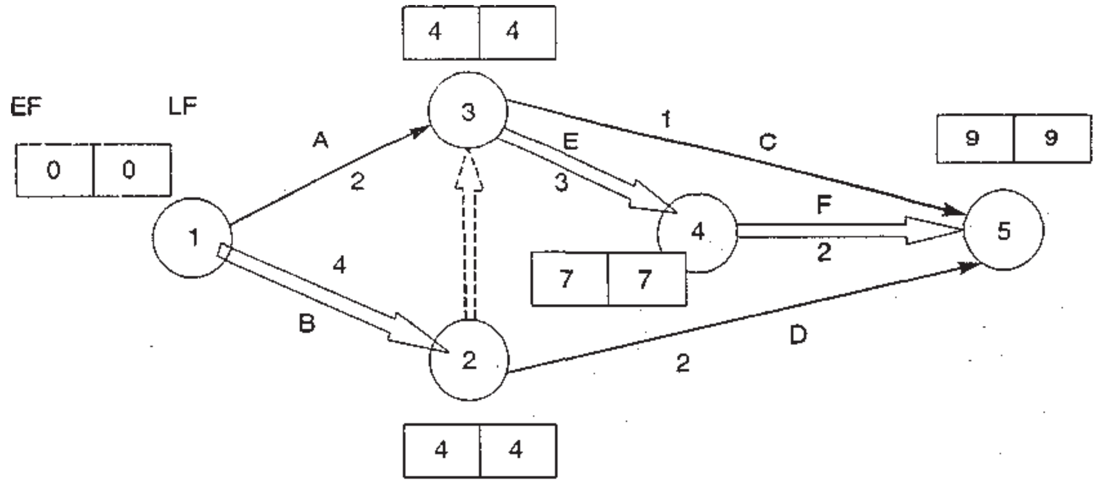
Illustration 4:

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 money and day on which it occurs above schedule.

Solution:

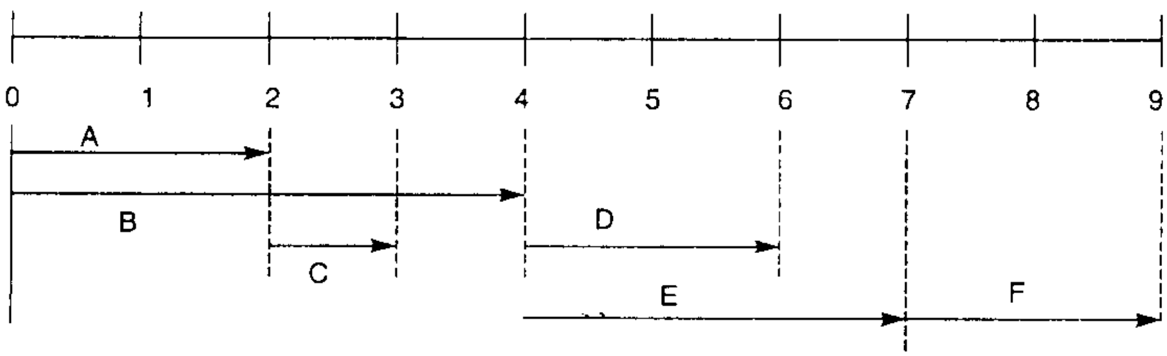


Critical Path 1-2-3-4-5

Minimum time = 9

Table: Activity Relationship

Activity	t	ES (EF- t)	EF	LS (LF- t)	LF	Event Slack (LS-ES) (LF-EF)	On Critical Path
A	2	0	2	2	4	2	No
B	4	0	4	0	4	0	Yes
C	1	4	5	8	9	4	No
D	2	4	6	7	9	3	No
E	3	4	7	4	7	0	Yes
F	2	7	9	7	9	0	Yes



Requirement of Money

Day1	Activity	A+B = 50*2
Day 2	Activity	A+B = 50*2
Day3	Activity	B+C = 50+40
Day 4	Activity	B =50
Day5	Activity	D+E = 200
Day 6	Activity	D+E = 200
Day7	Activity	E = 100
Day8	Activity	F =60
Day 9	Activity	F =60

Therefore, the peak requirement is ₹200 on day 5 and 6.

Steps in PERT Following steps are involved in the preparation of a PERT diagram:

1. **Break the project to various activities** Breaking of the project into activities depends on the extent of details of the work to be planned. For example, construction of a building is broken into broad activities like making foundation, making walls, making flooring, making ceiling, making doors and windows, doing electrical works and painting etc. Each activity could be further subdivided. For example, making foundation could involve activities such as digging, putting reinforcement steel bars, pouring concrete in the foundation arid curing of the concrete work. Foundation work could be further broken into activities such as bringing the concrete mixer, bringing the cement bags, arranging the grit, arranging water supply, mixing of cement, grit and water for making concrete etc. The breaking of activities for the construction of a building is presented in Fig. 2.7.13. The levels for breaking down the activities can be upto a workable level.

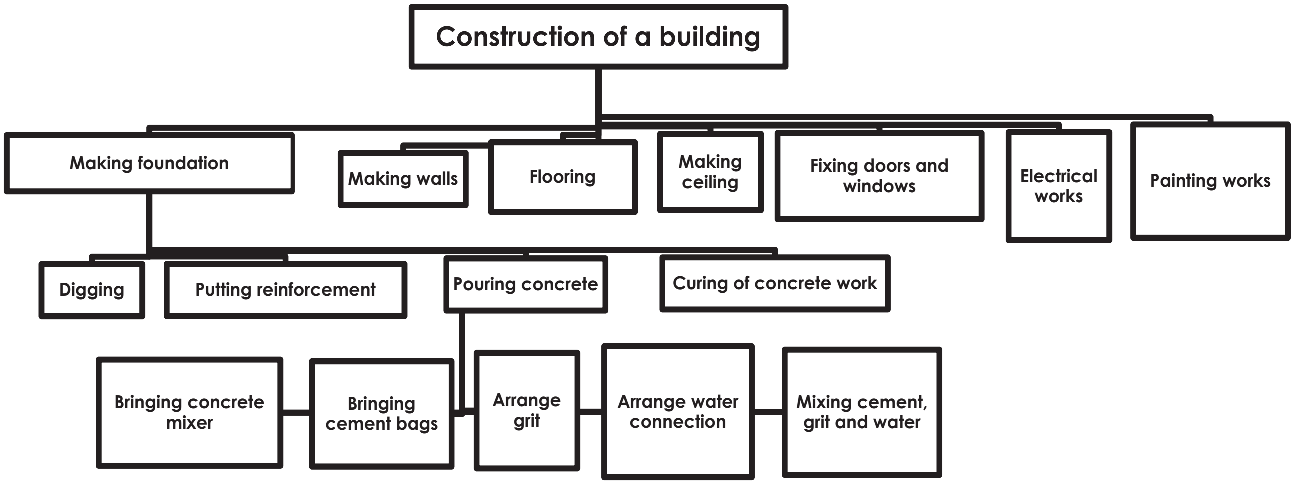


Fig. 2.7.13: Tree diagram representing breakdown of activities for construction of a building.

2. **Identify sub-activities under each activity** For example pouring concrete is a sub-activity of the activity making foundation.

3. **Determine the sequencing of the relationship between activities and sub-activities** The sequencing of activities in construction of a building is presented in Fig 2.7.14.

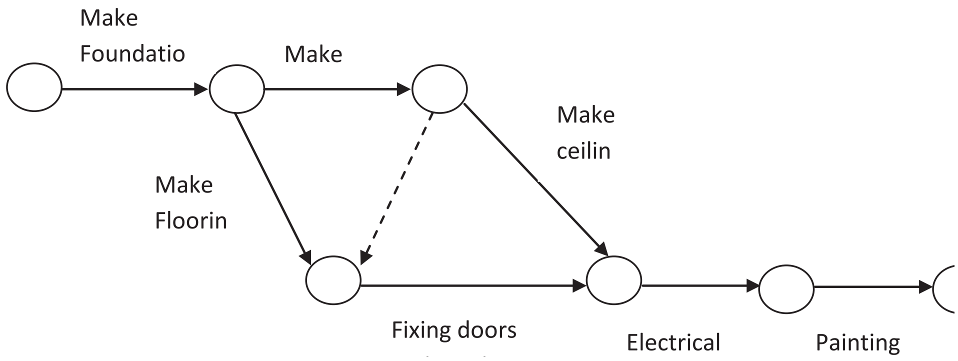


Fig. 2.7.14: Sequencing of activities in construction of building

From Fig. 2.7.14 it is seen that making walls and flooring works cannot be started until the foundation is ready. Similarly, electrical works cannot be started till the works of flooring, ceiling, fixing doors and windows are ready.

4. **Determine the estimated time (t_c)** If the most optimistic time (t_o) most likely time (t_m) and most pessimistic time (t_p)) of the activities involved in construction of building are estimated, the estimated time (t_e) can be calculated by using the formula discussed earlier. The details of calculations of these times in case of construction of a building are given in Table 2.7.6.

Table 2.7.6: Determining the estimated time of activities in construction of a building

S. No.	Activity	Time estimates (weeks)			Estimated time (t_e)= $\frac{t_0 + 4t_m + t_p}{6}$
		Most optimistic time(t_o)	Most likely time (t_m)	Most pessimistic Time (t_p)	
1	Making foundation	2	4	10	4.67
2	Make walls	3	5	8	5.17
3	Make floor	4	6	10	6.33
4	Make ceiling	1	2	4	2.17
5	Fixing doors and windows	3	5	8	5.17
6	Electrical works	2	3	6	3.33
7	Painting work	2	4	8	4.33

5. **Draw the network diagram** Calculate the critical path for the project/work. Determine the project time. These are discusssed in detail later in this chapter.

Applications of PERT

PERT is useful in the following situations:

- The project should have identifiable activities.
- The activities should have clear starting and ending points.
- Project is complicated and consists of many inter-related tasks.
- Technique is good for projects, where alternative options, sequence of activities and time period are involved.

Illustration 5:

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 and 8-9 without delaying the project. There is than a change required in the PERT network.

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)

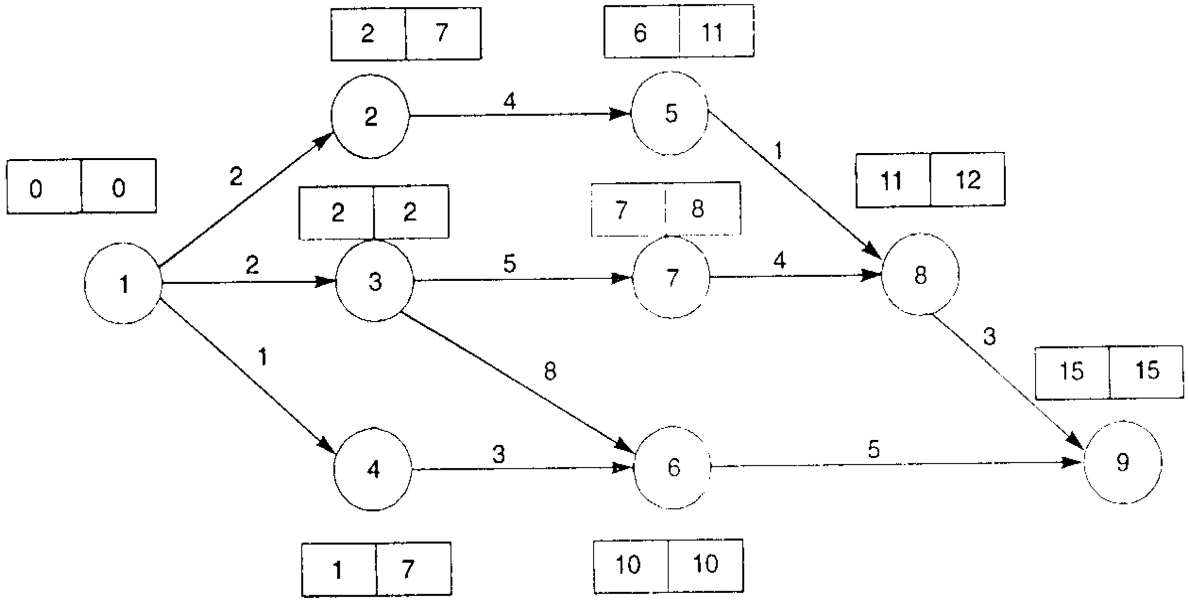


Table: Activity Relationship

Activity	Duration	ES	EF	LS	LF	TF
1 -2	2	0	2	5	7	5
1 -3	2	0	2	0	2	0
1 -4	1	0	1	6	7	6

Activity	Duration	ES	EF	LS	LF	TF
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	5	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 7 with one crane
- Finish 2 — 5 at 7 + 4 =11 with the same crane
- Finish 5 — 8 at 11 + 1 = 12 with the same crane
- Finish 8 — 9 at 12+ 3=15 with the same crane

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 6:

Considering a small maintenance project, as given below, plan it with the help of CPM.

Table: Activity Relationship

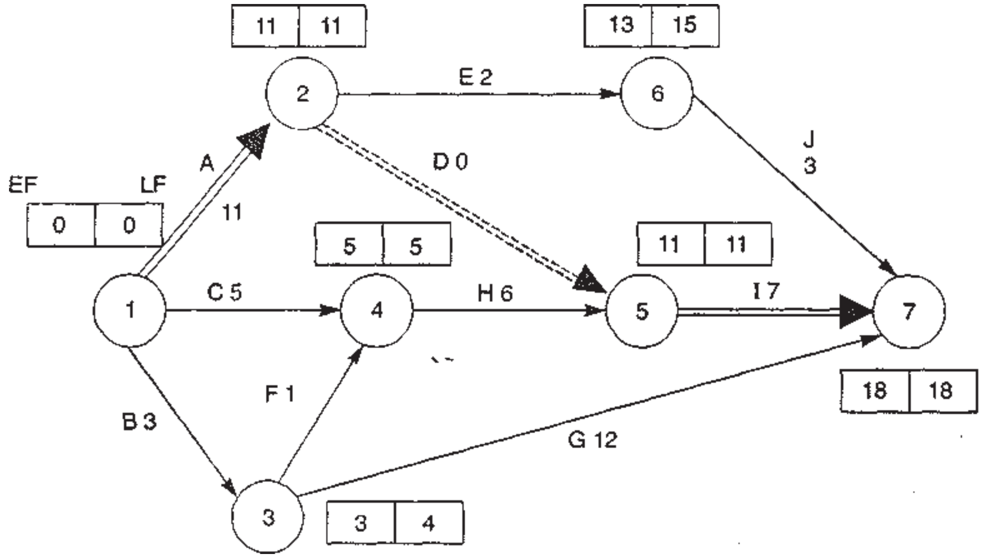
Activity	Duration	Predecessor
A	11	Nil
B	3	Nil
C	5	Nil
D	0	A
E	2	A
F	1	B
G	12	B
H	6	C,F
I	7	D, H
J	3	E

Compute the following for each job:

Early start time (ES), late start time (LS), early finish time (EF), late finish time (LF), Total Float (TF), Free float (FF), minimum total duration of the project, if all the jobs have been scheduled to start as early as possible and the work has been in schedule up to the end of week 5. There is strike on week 6 causing a delay of 1 week. Draw a CPM diagram for the jobs remaining to be done when work resumes on week 7.

Solution:

Network representing the given project:



The ES, EF, LS, LF, TS, FS have been computed as discuss earlier and entered in the below.

Table: Activity Relationship

Activity	Duration	ES	EF	LS	LF	TS	Slack at Head	FS
A	11	0	11	0	11	0	0	-
B	3	0	3	1	4	1	1	-
C	5	0	5	0	5	0	0	-
D	0	11	11	11	11	0	0	-
E	2	11	13	13	15	2	2	-
F	1	3	4	4	5	1	0	1
G	12	3	15	6	18	3	0	3
H	6	5	11	5	11	0	0	-
I	7	11	18	11	18	0	0	-
J	3	13	16	15	18	2	0	2

FS for ending activities will be taken as 0 (zero).

The minimum duration of the project is 18 weeks.

Figure shown is a squared CPM network, which depicts the jobs yet to be done on week 7.

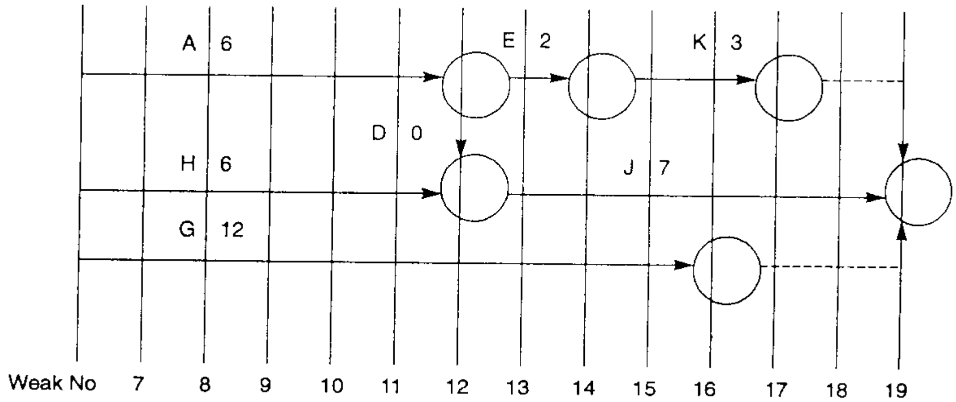
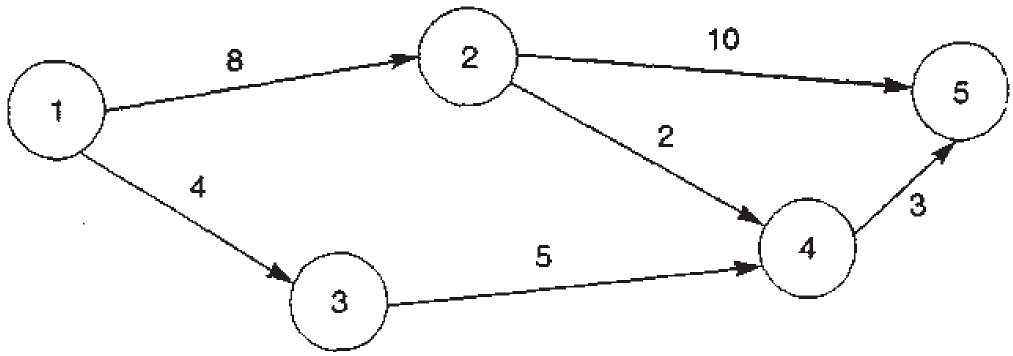


Illustration 7:

For given network find Total Float (TF), Free Float (FF) and Independent Float (IF)



Solution:

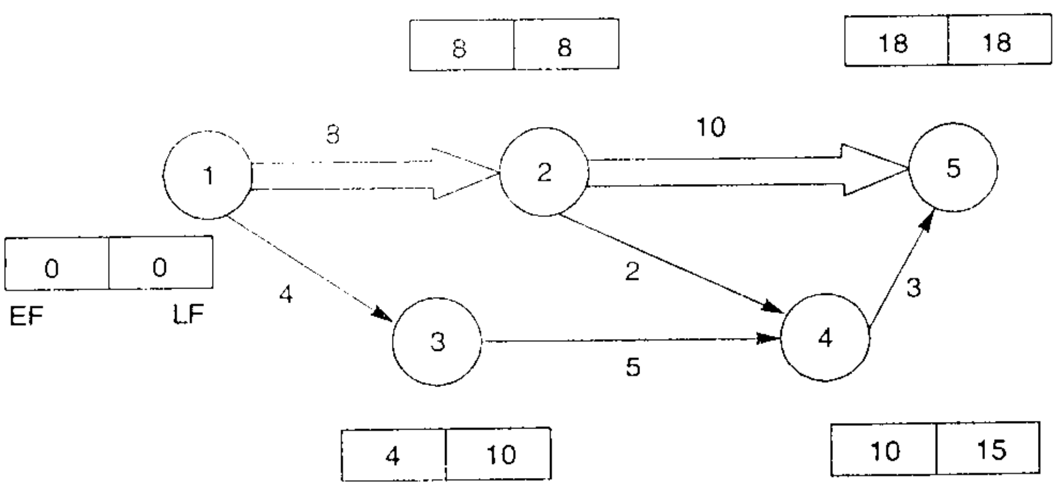


Table: Activity Relationship

Activity	**T**	**ES**	**EF (1+2)**	**LS (5-1)**	**LF**	**TF (4-2) (5-3)**	**Slack at head event**	**FF (6-7)**	**Slack at tail event**	**IF (8-9)**
	1	2	*3*	*4*	*5*	6	*7*	*8*	9	*10*
1 -2	8	0	8	0	8	0	0	0	0	0
1 -3	4	0	4	6	10	6	6	0	0	0
2-4	2	8	10	13	15	5	5	0	0	0
2-5	10	8	18	8	18	0	0	0	0	0
3-4	5	4	9	10	15	6	5	1	6	-5 (taken
										as 0)
4-5	3	10	13	15	18	5	0	5	5	0

Total Float = 0 on the Critical Path, which is 1 - 2 - 5

Ilustration 8:

Draw PERT Network

- Find expected time and variance for each activity
- Probability of completing project in 32 days.
- Total project duration

Table: Activity Relationship

Activity	**Estimated Time**		
	T_O	T_M	T_P
1 -2	6	9	18
1 -3	5	8	17
2-4	4	7	22
Activity	**Estimated Time**		
3-4	4	7	16
4-5	4	10	22
2-5	4	7	10
3-5	2	5	8

Solution:

Table: Activity Relationship

Activity Direction (Expected Time)	ES	EF	LS	LF	Float	Variance
1-2 (6 + 4x9 + 18)/6 =10	0	10	0	10	0	$((18-6)/6)^2$ =4
1-3 (5 + 8x4 + 17) /6 = 9	0	9	16	25	16	$((17-5)/6)^2$=4
2-4 (4 + 4x7 + 22) /6 = 9	10	19	10	19	0	$((22 - 4)/6)^2$ = 9
3-4 (4 + 4x7+16)/6 = 8	9	17	11	19	2	$((16-4)/6)^2$ =4
4-5 (4 + 4x10 + 22)/6 =11	19	30	19	30	0	$((22-4)/6)^2$ =9
2-5 (4 + 4x7+10)/6 =7	10	17	23	30	13	$((10-4)/6)^2$ =1
3-5 (2 + 4x5 + 8) /6 =5	9	14	25	30	16	$((8 - 2)/6)^2$ = 1

Critical Path =1-2-4-5

Variance along critical path = $\Sigma\sigma^2 = \sigma^2_{1-2} + \sigma^2_{2-4} + \sigma^2_{4-5}$

$$= \sigma = 22^{1/2} = 4.69$$

$$Z = (T_S - T_E)/\sigma = (32\text{-}30)/4.69 = 0.42$$

From Normal Distribution Table: P = 65.54%

Illustration 9:

Consider a project for which the time estimates are given in the table below. Calculate Activity variance.

Table: Activity Relationship

Activity	Estimated Time (days)		
	Most Optimistic To	Most Likely Time T_m	Most Pessimistic T_p
1-2	2	5	8
1-3	1	4	7
2-3	0	0	0
2-4	2	4	6
2-6	5	7	12
3-4	3	5	10
4-5	4	6	10
4-6	2	5	8
5-6	2	4	6

Solution:

First calculating the estimated average expected time and variance of each activity.

Table: Activity Relationship

Activity	Estimated Time (days)			Expected Time Te = $(T_0+4T_m+T_p)/6$	Variance $\{(T_p - T_0)/6\}^2$
	T_0	T_m	T_p		
1-2	2	5	8	5	1
1-3	1	4	7	4	1
2-3	0	0	0	0	0
2-4	2	4	6	4	16/36
2-6	5	7	12	7.5	49/36
3-4	3	5	10	5.5	49/36
3-5	3	6	9	6	1
4-5	4	6	10	6.33	1
4-6	2	5	8	5	1
5-6	2	4	6	4	16/36

Difference between CPM and PERT

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 is associated with uncertainty in the time estimates for activity while in CPM these estimates are treated as fairly deterministic. CPM is also extended to cost-time trade-off decisions. As the project completion time is squeezed, the time for the lowest project cost is the optional decision for project planning PERT is considered event oriented while CPM is mainly activity oriented.

Sl. No.	PERT	CPM
1.	Time estimate is probabilistic with uncertainty in time duration Three time estimates	Time estimate is deterministic with known time durations. Single time estimate
2.	Event oriented	Activity oriented
3.	Focused on time	Focused on time-cost trade off
4.	More suitable for new projects	More suited for repetitive projects
5.	Most costly to maintain	Easy to maintain
6.	Suitable for complex projects where uncertain timing is like research programmes	Suitable where problems of resource allocation exist like construction projects
7.	Dummy activity required for proper sequencing	Use of dummy activity not necessary

Benefits of PERT and CPM

- PERT and CPM force the planners to think of the various activities in the project, their time estimates and sequencing. It develops a very good understanding of the project and its requirements.
- Sequencing of activities, information of the earliest and latest time helps to work out the slack time, if available, at any event.
- Helps in resource planning, both in terms of quality and time when required.
- Helps in planning of manpower requirements and the requirements of expertise. In case of some disturbance in the project execution, the project manager could use the manpower more effectively.
- Highlights the resource constraints and helps in timely project execution, within budget provisions.
- Useful at many stages of project management.
- Gives.critical path and slack time at various events. In cases of emergencies or change of situations,they help in crashing the project activities time and thereby controlling the project time.
- It is mathematically simple. Computers could do the work of analysis much faster with accuracy.
- Helps in trade-off between project completion time and project cost.
- Provides project documentation which is easily understandable by all at different levels.
- Very useful in monitoring the project cost.
- The project manager gets answers for the following questions:
  - i. When is the completion date?
  - ii. On what schedule can it be completed?
  - iii. What is the budget of the project?
  - iv. What are the critical activities?
  - v. Which are the dependent and independent activities?
  - vi Which activities have positive slack?
  - vii. How the project could be finished early at the least cost?

Crashing of Network (Time Cost Relationship)

In CPM/PERT network techniques, time is related to cost and the object is to develop an optimum time-cost relationship. The ultimate object of the network techniques is not only to bring improvement in planning, scheduling and control of project but also to assess the reduce the target time so that the time saved can be utilised for additional production or otherwise. Furthermore, every organisation wants to accomplish the desired objective at minimum cost also. Sometimes, it may be desirable to extend the project duration if there is considerable saving in costs. Thus, time-cost relationship is of great significance in project management.

Having drawn the network identifying the critical path is the first step cost analysis. Critical path represent the longest activity in chain. Therefore, any attempt either at reducing the overall time of project or reducing cost of operation or both requires conditional in project time which is possible by allocating additional resource along critical path. For example, if we are prepared to employ a person on overtime work it could be prepared and completed earlier but at some additional cost. Similarly, by increasing workforce we may again reduce the time of a particular activity. By doing so, we have diverted manpower from some other activity, which, in turn, might increase the activity time of latter. In case it is possible that additional resources can be diverted from non-critical path activities and consequently the increase in duration of such activities is less than the slack, such diversion will not increase the cost of the project, otherwise it increases the cost. So, time reduction is possible by the following techniques:

- Controlling activities along the critical path.
- Increase in resources like manpower. (Possible to shift from non-critical path activities.)
- Overtime operation.
- Subcontracting or external resources in the form of men and material.
- Combination of the above.

Only reducing the duration of the critical activities in the project network can bring down the overall project duration. To reduce the scheduled time, non-critical activities can be considered as potential pools of resources for diverting to critical activities.

Crashing on non-critical path, subject to the condition, the crashing is limited without upsetting critical path. This cycle is again repeated by un-crashing and crashing till the desired result is obtained. For bigger projects, trial and error method is not feasible. Linear programming and use of computers are found very popular and useful in such cases.

Total Project Costs: The total project cost is the sum of direct costs and indirect costs. The direct cost represents the expenditure, which can be directly allocated to different activities in a project, like labour, material, etc. Indirect cost consists of overheads, depreciation, insurance, supervisory cost, etc. The longer the project takes to complete, the higher are the indirect costs. Figure shows the indirect cost curve, direct cost curve and the corresponding total cost curve.

From the total cost curve of figure it is-clear that the minimum total cost is obtained at some duration known as the optimum duration. The corresponding cost is known as minimum cost. If the duration of the project is increased, total cost will increase, while if the project duration is decreased to the crash value, project cost will be highest.

The duration of the project can be shortened by systematic analysis of critical path activities,« crashing costs and corresponding costs effect of indirect costs. For this, time costs relationship should be critically examined. Figure 2.7.15 shows a generalised curve between direct cost and project duration (time).

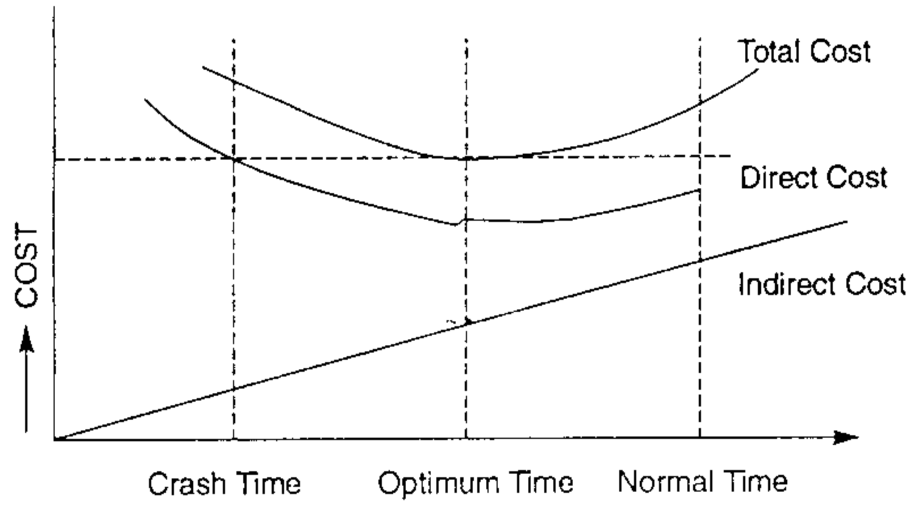


Fig. 2.7.15 Time Cost Relationship

The project has the highest cost corresponding to the crash duration and has normal cost corresponding to the normal duration. Thus, we have two types of times defined below:

(i) *Normal Time*: A normal time is the standard time associated with normal the resource of the organisation to perform the activity.

(ii) *Crash Time*: Crash time is the minimum possible time in which an activity can be completed by employing extra resources. Crash time is that time, beyond which the activity cannot be shortened by any amount of increase in resources.

(iii) *Normal Costs*: The expenditure incurred on normal resources for completing any activity in normal time is known as normal costs.

(iv) *Crash Costs*: The total expenditure incurred on normal and additional resource for crashing the time is known as crashed costs.

The cost slope formula can be represented as

$$\text{The slope} = \frac{\text{Crashed Cost} - \text{Normal Costs}}{\text{Normal Time} - \text{Cash Time}}$$

Cost slope represents the extra cost of shortening the duration of the activity by one time unit. For reducing the activity duration the management may agree for extra expenditure but to keep this expenditure minimum we must concentrate on those activities for which cost slope is minimum.

It can be observed that shortening the project duration leads to an increase in direct costs but decrease in overhead (indirect) costs and the strategy will be justified only when it results in net saving. The normal tendency of every manufacturer is to produce at minimum cost and to have most efficient use of human resources. But, in emergencies or sudden rush of orders, if production is to be increased by increasing rate of production then naturally additional expenditure is to be introduced (e.g., working overtime or in two shifts) which will result in extra expenditure. Manufacturer will be tempted to crash the time only when the profit earned from additional production is more than the extra expenditure on crashing.

[The Concept of "Project Crashing" is detailed in the final Course S N No 11 of Paper 15. Hence not in intermediate Course]

Resource Allocation

Every project consists of a number of activities. There may be activities, which are to be performed simultaneously and may require common resource. Requirements of resource to execute these simultaneous activities may exceed the available resources. However, at some other period of the execution of the same project, there may be very few activities, which may require these resources. Hence, the requirement of a particular type of resource may not be uniform during the project duration (labour, capital, equipment).

Every management wants to allocate the limited resources equipments to various activities in such a manner that there is best possible use of resources at disposal. PERT and CPM techniques provide valuable guidelines for most systematic and economic allocation of resources. The presence of slack or float for some of the activities enables the management to delay that activity for some time and use the resource to some more urgent activities on critical path. The resource allocation procedure consists of two main activities, namely resource smoothing and resource levelling.

There are many activities in a project requiring varying levels of resource. In the resource levelling process, the activities are so rescheduled that the maximum of peak resource requirement does not exceed the limit of available resource. The available resources should, however, not be less than the maximum number of quantity required for any activity of the project. Rescheduling of the available floats are first used. By doing so, the resources requirement for these activities is decreased. Thus, in the source levelling process, the project duration initially planned might be increased.

Resource Smoothing

The time scaled version of various activities and their resource requirement with corresponding floats, if any, is used for resource smoothing. The periods of maximum demand for resource are located and the activities, according to their float values, are shifted for balancing the resource needs and availability. Thus, intelligent utilisation of floats can smoothen demand of resource to a great extent.

Steps in Resource Allocation

(a) Resource requirements for each activity are listed for each item of resource, i.e., men, machine, material, etc.

(b) The category-wise availability of different resource, both with respect to quantity and time, is also listed,

(c) The allocation resource to activities lying on the critical path is given to priority but for non-critical activity some compromise can be made. When several jobs compete for the same resource preference is given to one with least slacks. R/S is buster eleborated in final Cours . Hence problem on a allocation is not discussed in CMA intermidia course since out of the ambit this loued

Line of Balance (LOB) Technique

When the work is of repetitive nature, LOB helps in planning the resource utilisation without creating clashes so that targetted output can be successfully achieved. This technique can be effectively used in the construction work of mass housing, high rise building, tunnels, etc. Here standardisation of design is possible by balancing the manpower with other resources to optimise the overall cost. In this case, the productivity of men and machine is also maximised. The areas of weaknesses can be identified to focus proper attention for further improvement.

The basic requirement of the line of balancing is to create work stations for the total work requirements so that monitoring at these stations be made possible to find out surpluses or deficiencies. This will help to balance the complete project by balancing each station or stage with the use of LOB. The following two things can be achieved.

(i) Work can be completed as per the plan.

(ii) At each station, time of completion of work will depend upon its requirement.

Buffers can be used between the stations to meet out the uncertainty requirements for which scheduling will be required.

The line of balance technique is based on the underlying assumption that the rate of production for an activity is uniform. In other words, the production rate of an activity is linear where line is blotted on one axis, usually horizontal, and units or staging an activity on the vertical axis. The production rate of an activity is the slope of the production line and is expressed in terms of units per time.

Scheduling with LOB

The following steps will be required to prepare LOB schedule:

(i) Preparation of logic diagram.

(ii) Calculation of man-power requirements for each activity.

(iii) Calculation of output target to meet out project dead line.

(iv) Completion of LOB schedule.

(v) Some extra time or buffer time be allowed at each station to meet out exegencies.

(vi) Examination of schedule with alternatives in mind.

LOB scheduling can be performed more efficiently when the concept of line-of-balance is combined with network technology. Usually, a network diagram for one of the many units to be produced is prepared and incorporated into LOB schedule.

The LOB method manipulates worker-hour estimates, and the optimum size of crews to generate the LOB diagram. Worker-hour estimates and optimum crew size are usually obtained through direct interaction with a schedular, the site manager, or related sub-contractors who are knowledgeable enough to reflect the actual conditions of the project and its constituent activities. Once the number of crews and expected rate of output have been computed for each activity, the LOB diagram can be plotted. The number of units to be produced is plotted against time. Two oblique and parallel lines, whose slope is equal to the actual rate of output will denote the start and finish lines respectively of each activity in all units from the first to the last.

CHRISS is a computerised system to schedule high rise building construction and is developed using the LOB technology assisted by expert system.

COST-BENEFIT ANALYSIS (CBA)

CBA provides the information to make a sound and balanced business decision about the cost and benefits, or values, of various economic choices (for an investment). It is a methodology for management to use when decisions need to be made among the competing alternatives. It enables the agency to quantify the activities of the existing and alternative processes on monetary and non-monetary basis. When the agency conducts a CBA, it defines its objectives and alternatives in terms of costs and benefits. It also defines important assumptions, factors, and judgments to build the cost and benefits used in comparing alternatives. The final product is a consistent document that enables the agency to understand what costs and what benefits are associated with the various alternatives.

It is important to identify and estimate costs and benefits using a common comprehensive structure (WBS) so that alternatives can be consistently compared and reflect accurate results/ conclusions. Solid advance planning and definition are essential in completing a timely and useful CBA in an exhaustive manner. Also, many activities will go through several iterations as various aspects of project are better defined. It can also be used as the basis to justify decisions, as a baseline to measure progress against stated goals, and as a guide to understand the impact of proposed changes.

The underlying foundation for analysing the costs and benefits of proposed solutions includes the following sequence:

1. Define the project, objectives, alternatives, assumptions, ground rules, and the elements to be cost.
2. Research the cost elements, analyse them, collect the appropriate data, decide on an estimating methodology, and then cost them all.
3. Identify the principal functional and technical cost drivers and their sensitivity to changes in assumptions.
4. Analyse risk items and perform sensitivity analysis, including collecting total lifecycle costs and benefits.
5. Analyse the relative merit of alternatives.
6. Present the results.

Keep the approach flexible and tailorable so that the effort and results are consistent with the size and complexity of alternatives being evaluated—the lifecycle phase, and the level and type of review being supported.

It is always helpful to know, in general, how the final product and its content should look. This knowledge will help the agency to organise the work as it progresses. The amount of detail and information included in a CBA depends on the size and complexity of the individual project. For very small projects, a short white paper or a few slides will suffice to cover the relevant information. Time and money spent on an analysis should be worth it. It should be a tool to help organise the information so that economical decisions could be made.

CBA might include the following:

- Detailed cost estimates for individual alternatives, including the basis for estimating each work breakdown structure element
- A WBS outline and a dictionary that defines what is in each cost element
- Detailed schedules that can later be used to manage the project
- Specific references and guidance documents supporting the project
- Data sources and references to support the estimating methodology
- A glossary that defines abbreviations and terms used in the analysis

The document should accurately support agency recommendations irrespective of its structure.

Steps in Cost-Benefit Analysis

The general steps for performing a CBA are listed below. Using this approach as a framework for developing a CBA will help the agency evaluate its status quo / alternative (as-is/to-be) processes, define objectives more thoroughly and address the alternative consistently. Although the general outline should always be followed, the amount of details used during each step will vary depending on the size and complexity of the individual project.

1. **Define the Project:** This step is the most critical. It forms the foundation for the rest of the effort. It includes identifying the problem to be solved, the objectives of the mission or function, and the alternatives that will satisfy the customer's needs while staying within the environmental factors, such as assumptions and constraints. It also includes defining the work breakdown structure deliverables to be costed and the assumptions and ground rules for the status quo and alternative models. The WBS becomes the outline for the rest of the work to be done. The WBS will be updated on a regular basis as the analysis progresses.

2. **Research the Cost Elements.** This step includes researching the cost elements that make up the WBS, collecting appropriate cost-driver data, analysing and validating the data, deciding on an estimating methodology, and then costing all the elements. The need is to develop future profiles of the current system and the projected profiles of alternative proposed systems.

   The process of identifying, development, acquisition, operating costs and benefits is necessary even if formulas and cost elements are not well defined using techniques, such as parametric method, analogy method, bottoms-up engineering method, etc. The total cost of product, taking into account its size, complexity and extent of work, covers all differentiating costs for all elements used for research, design, development, integration, test, acquisition, deployment, management, operation and disposal of modified process or systems.

Techniques for estimating costs include the following:

- **Parametric method:** Collect all relevant historical data and derive cost estimating relationships that relate costs as dependent variable to one or more independent variables that reflects physical or performance characteristics of the system or process. The statistics, assumptions along with the database are used as supporting data for each WBS element's cost estimate.
- **Analogy method:** This method uses comparisons with the completed projects or catalog prices whose costs or benefits are known.
- **Bottoms-up engineering method:** This involves decomposing the project into discrete activities and elements, such as labour material, etc. and quantifying them.
- **Actual cost method:** This method uses experience from prototypes, engineering, and testing to analyse cost and schedule variances and estimates of project completion.

3. **Identify Cost Drivers.** Once the basic estimating is done, there is a need to identify the principal functional, technical, and schedule cost drivers and their potential sensitivity to changes in assumptions or project decisions in the preparation for the next step.

4. **Analyse Risk and Sensitivity.** Once the costs are calculated for each lifecycle phase, they are then aggregated to show the total lifecycle costs and benefits. Based on this information, the agency will identify the cost-risk items and perform sensitivity analysis to determine whether changes might alter the original recommendations or simply assess what happens if some sensitive cost element exceeds the current estimate. The sensitivity analysis tests the impact of risk and uncertainty to determine which conditions might change the ranking of alternatives.

Some of the techniques of the analysis are:

- **Contingency analysis:** This analysis identifies how alternatives might be affected by changing the criteria of evaluation or ground rules.
- **Risk and uncertainty analysis:** Both these are statistical techniques. Risk analysis is generally defined as the consequences of uncontrollable random events from a known probability distribution. For uncertainty analysis probability distribution is unknown.
- **Sensitivity analysis:** This uses some of the same statistical techniques as risk and uncertainty analysis to analyse how sensitive it is to change the ranking of alternatives based on major cost drivers.
- **Parametric analysis:** This technique uses cost estimating results by using statistical techniques like curve fitting techniques to develop relationships and validate them.

5. Analyse Alternatives. Next, analyse the relative merit of alternatives against each other, including their sensitivity to specified risks and potential changes. The results should also compare the net benefits over time, return on investment (ROI), and show the break-even point for your investment.

Some common procedures involve

- Present Value (PV) Analysis
- Return on Investment
- Break-even Analysis

6. Present the Results. The final step is to put together the presentation materials to support your analysis and recommendations. Depending on the size and complexity of the project, this could be as simple as a white paper or briefing or it could be more formalised.

2.8 WAITING LINES & SIMULATION

SIMULATION

In general terms, simulation involves developing a model of some real phenomenon and then performing experiments on the model evolved. It is a descriptive, and not optimizing technique. To simulate is to initiate. In simulation, a given system is copied and the constants associated with it are manipulated in that artificial environment to examine the behavior of the system.

Process of Simulation

Broadly there are four phases of the simulation process :

(i) Definition of the problem and statement of objectives

(ii) Construction of an appropriate model

(iii) Experimentations with the model constructed

(iv) Evaluations of the results of simulations.

The first step in problem solving of any situation is to identify and clearly define the problem and list the objective(s) that the solution is intended to achieve. This is true of simulation as well. A clear statement not only facilitates the development of an appropriate model but also provides a basis for evaluation of the simulation results. In general, simulation aims to determine how the system under consideration would behave under certain conditions. Naturally, the more specific the analyst is about what he is looking for, the greater the chances that the simulation model will be designed to accomplish that. Thus, the scope and the level of detail of the simulation should be decided upon carefully.

The next step in simulation is the development of a suitable model. During the course of a simulation, the model mimics the important elements of what is being simulated. A simulation model may be a physical or mathematical model, a mental conception, or a combination. Many simulations involve physical models. Examples include a scaled down model of an aeroplane or ship constructed out of wood or other material. Since physical models are relatively expensive to build, mathematical models are often preferred. In such a model, mathematical symbols or equations are used to represent the relationships in the system.

Collection of data is a significant aspect of model development, and the quantum and type of data needed are directly governed by the scope and extent of the detail of the simulation. The data are needed both for model development and evaluation. Obviously, the model for simulation must be so designed that it would enable evaluation of the key decision alternatives. An ancillary step here is of designing experiments. The experiments help answer the 'what if. . . ' types of questions in simulation studies. By going through this process, the analyst is able to learn about the system behaviour.

Once the simulation model is developed, the next step is to run it. If the model is deterministic, with all its parameters known and constant, then only a single run would suffice. On the other hand, if the simulation is stochastic in nature, with the parameters subject to random variation, then a number of runs would be needed to get a clear picture of the model performance. The probabilistic simulation is akin to the random sampling where each run represents one observation. Thus, statistical theory can be used to determine the optimal sample sizes. Evidently, the greater the variability inherent in the simulation results, the larger would be the simulation runs needed to obtain a reasonable degree of confidence that the results are truly indicative of the system behaviour.

The last step in the process of simulation is to analyse and interpret the results of the runs. The interpretation of results is, in a large measure, dependent on the extent to which the simulation model portrays the reality. Obviously, closer the approximation of the real system by the simulation model, lesser will be the need for adjusting the results and also lesser will be the risk inherent in applying the results.

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 the objective of predicting the system's behaviour. 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 distributions 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. Information relating to 200 days' sales is,

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

Assuming that this is an adequate representation of the distribution of demand for the cake, we can derive the probability distribution of demand by expressing each of the frequencies in terms of proportions. This is done by dividing each one of the values by 200—the total frequency. The resultant distribution follows:

Demand (No. of cakes)	:	5	6	7	8	9	10	11	12
Probability	:	0.02	0.05	0.08	0.25	0.31	0.19	0.06	0.04

Thus, there is 0.02 or 2 per cent chance that 5 cakes would be demanded on a day, a 0.05 or 5 per cent chance that the demand would be for 6 cakes . . . and so on. This distribution would serve as the model of the situation under consideration.

The second thing required for simulation is a mechanism to simulate the model-something to capture the random nature of the given system. Thus, we should have available a procedure that would help us to select, at random, values for the variables which can be used to approximate the state of the system. Such a mechanism can be any random number generator consisting of a device or a procedure by which random numbers can be determined and/or selected.

There are various ways in which random numbers (or apparently random, but not truly so) may be generated. These could be: result of some device like coin or die; published tables of random numbers, midsquare method, or some other sophisticated method. It may be mentioned here that the 'random' numbers generated by some methods may not be really random in nature. In fact such numbers are called pseudo-random numbers. There are some tests with which numbers may be tested for their randomness but we shall not consider them here and consider only briefly how the numbers may be obtained and used.

One way to generate random numbers is to fix up a spinning arrow on a common clock. When the arrow is spun, the number on which it stops would be taken to be random number for that trial. Naturally, any number of spinnings of the arrow would result in an equal number of random numbers. In a similar way, random numbers can be generated using spinning of a roulette wheel, tossing dice . . . and like that. Although simple, these are very slow methods and cannot meet the practical requirements where a large number of random numbers may be needed.

A more fast and convenient method is to make use of the published tables of random numbers, like the one published by the Rand Corporation (of USA): A Million Random Digits. A random number table is a very efficient way to generate random data in most situations. The numbers in this table are in random arrangements. The underlying theory is that each number has an equal opportunity of being selected.

Still on a more sophisticated level, computers are used for generating the random numbers. With computers, it is typically easier to generate random numbers by an arithmetic process as needed rather than to read the numbers from a stored table. An early, probably the earliest, method proposed for use on digital computers to generate random numbers is the midsquare. To illustrate this method, suppose that we wish to generate four-digit integers and the last number generated was 8,937. To obtain the next number, in the sequence, we square the last one and use the middle four digits of the product. In this case the product is 79869969 so that the next pseudo-number is 8,699. The next few numbers in the sequence are 6726, 2390, 7121 and so on. Thus, using this method, having drawn up a suitable computer programme, a four-digit number may be fed into the computer and a list of pseudo-random numbers obtained.

Of all the random number generators, we shall make use of random number tables for demonstrating the simulation process. To consider how the table can be used for generating data relating to our bakery problem, we proceed as follows:

Step 1 - An assignment has to be worked out so that the intervals of random numbers will correspond to the probability distribution. Here, since the probabilities have been calculated to two decimal places, which add up to 1.00, we need 100 numbers of two digits to represent each point of probability. Thus we take random numbers 00 through 99 to represent them. Now, as the probability of 5 cakes is equal to 0.02, we assign two random numbers 00-01 to this demand level; the probability of 6 cakes being equal to 0.05, the next five numbers, 02-06 would be assigned to this level. In a similar manner, each of the demand levels would be assigned appropriate intervals as given here. It may be mentioned that cumulative probabilities shown are calculated to ease the determination of the random number intervals. The cumulative probabilities column allows the assigned numbers to correspond to the same probability range for each event.

Demand (No. of cakes)	Probability	Cumulative Probability	Random Number Interval
5	0.02	0.02	00 - 01
6	0.05	0.07	02 - 06
7	0.08	0.15	07 - 14
8	0.25	0.40	15 - 39
9	0.31	0.71	40 - 70
10	0.19	0.90	71 - 89
11	0.06	0.96	90 - 95
12	0.04	1.00	96 - 99

Instead, if probabilities are calculated to three decimal places, then 3-digit random numbers would be required . . . and so on.

Step 2 - Once the random number intervals are determined, we select a tracking pattern for drawing random numbers from the random number table. We may start with any column and row of the table and read the values in any set manner—horizontally, vertically, or diagonally. Using the pattern,-we draw the random numbers and match them with the assigned events. We may decide, for example. The random numbers, according to this pattern are 61, 74, 24, 03, 59, 16, 84, 92, 52, 07 and so on. We draw as many random numbers as the number of days' demand is required to be simulated.

The first of the list of the numbers, 61, lies in the interval 40-70 corresponding to the demand level of 9 units. Thus, the simulated demand for the first day is 9 cakes. In a similar manner, we can obtain the demand for each of the days. For the 10-day period, we have the following demand:

Day	1	2	3	4	5	6	7	8	9	10
Random Number	61	74	24	03	59	16	84	92	52	07
Demand (cakes)	9	10	8	6	9	8	10	11	9	7

Having considered the method of generating data with random numbers, we now proceed to illustrate the simulation of an inventory and a queuing system. They follow in turn.

Simulation of Queuing System

The characteristics of the situation described were based on the assumptions, among others, that the arrivals are Poisson distributed while the service times follow an exponential distribution. Although such assumptions are often appropriate for the real life queuing systems, they are not invariably so. Thus, where such assumptions fail to apply, formal mathematical analysis can be extremely difficult and even impossible. Simulation provides the answer in such cases.

We shall illustrate the use of simulation in the study of queues through the following example:

Illustration 1:

In a large workshop undertaking servicing jobs, the mechanics obtain their tools and requirements from a central store. The manager, perturbed about the waiting time of mechanics, is in the process of determining whether more attendants be hired for the store for raising the level of service. The idle time cost for the mechanics and the wages required to be paid to the attendants being known, he wishes to ascertain how many attendants may be employed to minimise the total cost involved. For helping the manager solve his problem using simulation, we proceed as follows. The following data on the times between successive arrivals and the service times for the mechanics have been obtained from the past 200 observations made on the system presently in operation.

Distribution of inter-arrival time:

Time (Minutes)	Frequency	Probability
0	12	0.06
3	18	0.09
6	50	0.25
9	74	0.37
12	32	0.16
15	14	0.07
Total	**200**	

Distribution of service time :

Time (Minutes)	Frequency	Probability
4	8	0.04
6	20	0.10
8	36	0.18
10	88	0.44
12	48	0.24
Total	**200**	

Random Number are:

Inter Arrival : 58, 47, 23, 69, 35, 55, 69, 90, 86, 74, 39, 15, 90, 98, 39, 14, 52, 56, 21, 23, 00, 87, 20, 40, 73.

Services : 87, 39, 28, 97, 69, 87, 52, 52, 15, 85, 41, 82, 98, 99, 23, 77, 42, 60, 22, 91, 68, 36, 22, 92, 34.

Solution:

As usual, in the first step we assign random numbers to each observed arrival time interval based on the likelihood of the occurrence of each time interval as shown in Table 2.8.1. For instance, the probability of arrival within 0 minutes of the last arrival (implying simultaneous arrivals) is 0.06. Therefore, we assign the two-digit random numbers 00 through 05 to the event of 0 minutes between the arrivals. To facilitate this process, as before, cumulative probabilities have been determined as given in the third column of the table.

Table 2.8.1: Random Number Coding: Inter-arrival Times

Time (minutes)	Probability	Cumulative Probability	Random Number Interval
0	0.06	0.06	00 - 05
3	0.09	0.15	06 - 14
6	0.25	0.40	15 - 39
9	0.37	0.77	40 - 76
12	0.16	0.93	77 - 92
15	0.07	1.00	93 - 99

The same procedure is followed for the service time distribution. **Table 2.8.2** depicts the cumulative probabilities and the random number coding for each of the observed service times. The table shows, for instance, that the probability of service time of 4 minutes is 0.04. Thus the random numbers 00-03 are assigned to the event that the service time is 4 minutes. If a random number in the range of 00-03 is drawn from the random number table, the event that 'the service time is 4 minutes' is assumed to have occurred.

Table 2.8.2: Random Number Coding: Service Times

Time (minutes)	Probability	Cumulative Probability	Random Number Interval
4	0.04	0.04	00-03
6	0.10	0.14	04-13
8	0.18	0.32	14-31
10	0.44	0.76	32-75
12	0.24	1.00	76-99

Now we are ready to simulate the operation. To determine the arrival times of the successive mechanics, we start with the fifth major column of the table of random numbers, and for the service times, we begin with the fourth major column, and read vertically down in each case. Supposing that a total of 25 observations are decided to be made, we draw 25 random numbers for each, the inter-arrival times and the service times. These numbers are given in columns 2 and 5, respectively of **Table 2.8.3**. The times corresponding to the random numbers, as determined from the **Tables 2.8.1 and 2.8.2**, are contained in columns 3 and 5, respectively.

Now, we start with the first mechanic and observe that the random number for the arrival is 58. This lies in the interval 40-76 and therefore corresponds to the time period of 9 minutes. Assuming that the workshop starts at 8.00 a.m., the first arrival at the store would be at 8.09 a.m. Further, the random number for service being 87, which lies in the interval 76-99 in the **Table 2.8.2**, a service time of 12 minutes is suggested. Thus the service to him begins at 8.09 a.m. and ends at 8.21 a.m. Obviously, there would be no waiting time for the mechanic. The second of the arrivals' random number is 47 which also indicates an inter-arrival time of 9 minutes. Thus, he would come to the store at 8.18 a.m.—9 minutes after the first arrival. Since the store would be free at 8.21 a.m. from the first mechanic, the service to the second would start at that time. Thus, the waiting time for him would be 3 minutes. Corresponding to the random number 39 for service time for this mechanic, the time needed is 10 minutes. This means that the service to this mechanic would go from 8.21 to 8.31 a.m.

Notice that when the first mechanic is being serviced between 8.09 and 8.21 a.m., then the second mechanic would have to wait. Thus, the queue length over this interval would be taken to be 1.

Table 2.8.3: Simulation Worksheet

S. No.	Arrival		O'clock	Service		Waiting Time (mts)	Service		Queue Length
	R. No.	Time		R. No.	Time		Begins	Ends	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1	58	9	8.09 am	87	12	00	8.09 am	8.21 am	1
2	47	9	8.18	39	10	03	8.21	8.31	1
3	23	6	8.24	28	8	07	8.31	8.39	2
4	69	9	8.33	97	12	06	8.39	8.51	2
5	35	6	8.39	69	10	12	8.51	9.01	2
6	55	9	8.48	87	12	13	9.01	9.13	2
7	69	9	8.57	52	10	16	9.13	9.23	2
8	90	12	9.09	52	10	14	9.23	9.33	2
9	86	12	9.21	15	8	12	9.33	9.41	2
10	74	9	9.30	85	12	11	9.41	9.53	2
11	39	6	9.36	41	10	17	9.53	10.03	2
12	15	6	9.42	82	12	21	10.03	10.15	3
13	90	12	9.54	98	12	21	10.15	10.27	4
14	98	15	10.09	99	12	18	10.27	10.39	4
15	39	6	10.15	23	8	24	10.39	10.47	4
16	14	3	10.18	77	12	29	10.47	10.59	5
17	52	9	10.27	42	10	32	10.59	11.09	6
18	56	9	10.36	60	10	33	11.09	11.19	6
19	21	6	10.42	22	8	37	11.19	11.27	6
20	23	6	10.48	91	12	39	11.27	11.39	5
21	00	0	10.48	68	10	51	11.39	11.49	4
22	87	12	11.00	36	10	49	11.49	11.59	3
23	20	6	11.06	22	8	53	11.59	12.07 pm	2
24	40	9	11.15	92	12	52	12.07 pm	12.19	1
25	73	9	11.24	34	10	55	12.19	12.29	0
				Total		625 mts			73

In the same way we proceed further and determine the arrival and waiting times for the mechanics, as contained in the columns 4 and 7 of the **Table 2.8.3**. Queue length for each interval of the service times is obtained by considering the number of mechanics reaching upto the upper limit of that interval after the one being currently serviced.

From the column showing the pattern of the mechanics' waiting time, and the last column containing the queue length, we can obtain the average waiting time and the average queue length by dividing the total of each one by the number of observations, 25. We get, the average waiting time = 625/25 = 25 minutes, and the average queue length = 73/25 = 2.92 mechanics.

Using this information, the manager can determine the total cost. For examining other alternatives, he can do so by estimating the new service time patterns based on additional attendants. He would have to simulate each new alternative to determine the outcome based on the new service patterns and choose the best one.

Applications of Simulation

In spite of its limitations, simulation is a very potent, flexible, and, therefore, a commonly employed quantitative tool for solving decision problems. It has been applied successfully to a broad spectrum of problems. To count a few, its use extends to areas like police dispatching and beat design; location of emergency vehicles like ambulances; making inventory policy decisions; evaluation of operating alternatives at airports; in financial planning—both portfolio selection and capital budgeting, scheduling the production processes; large scale military battles as well as individual weapons systems for aiding in the designing of both the weapon systems and of the strategic and tactical operations. Simulation is of paramount importance where the experimentation with the real situation is risky. The use of computer simulation for studying the likely behaviour of the nuclear reactors during accidents is a case in point. Obviously, testing actual reactors or even scaled down reactor models under emergency conditions would involve excessive risks.

Thus, its application in situations which are too complex to permit mathematical solution, its simplicity and use in varied fields, its power in enabling the decision-maker to conduct experiments that help in understanding the system's behaviour while avoiding the risks associated with conducting tests on the model's real-life counterpart, and also availability of extensive computer software packages, are the main factors which account for the popularity of simulation technique.

Illustration 2:

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 'Pressurex'. 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 A_1	Assembly A_2
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 A_1 and the last two digits for processing time on assembly A_2.

4134	8343	3602	7505	7428
7476	1183	9445	0089	3424
4943	1915	5415	0880	9309

Solution:

In the first stage, we assign random number intervals to the processing times on each of the assemblies. This is shown in **Table 2.8.4.**

Table 2.8.4: Random Number Coding for Process Times

Time (mts.)	Assembly A_1			Assembly A_2		
	Prob.	Cum. Prob.	RN Interval	Prob.	Cum. Prob.	RN Interval
10	0.10	0.10	00 - 09	0.20	0.20	00 - 19
11	0.15	0.25	10 - 24	0.40	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	0.95	80 - 94
14	0.10	1.00	90 - 99	0.05	1.00	95 - 99

The simulation worksheet given in **Table 2.8.5** shows the simulated data on the process times. Thus, the random numbers for the first unit are 41 and 34, respectively, for the assemblies A_1 and A_2. From the **Table 2.8.4** we observe that the times corresponding to these are 12 and 11 minutes respectively. Thus the total time required for the unit is 23 minutes. In the same way, the time for the other 14 units are determined and shown in the last column of the table. The expected completion time for a unit works out to be 23.27 minutes.

Table 2.8.5: Simulation Worksheet

Unit	Assembly A_1		Assembly A_2		Total Time
	R. Number	Time	R. Number	Time	(mts.)
1	41	12	34	11	23
2	74	13	76	12	25
3	49	12	43	11	23
4	83	13	43	11	24
5	11	11	83	13	24
6	19	11	15	10	21
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

Expected Time = 349/ 15

= 23.27

Illustration 3:

A company manufactures around 150 mopeds. The daily production varies from 146 to 154 depending upon the availability of raw materials and other working conditions.

Production per Day	Probability
146	0.04
147	0.09
148	0.12
149	0.14
150	0.11
151	0.10
152	0.20
153	0.12
154	0.08

The finished mopeds are transported in a specially arranged lorry accommodating only 150 mopeds. Using following random numbers 80, 81, 76, 75, 64, 43, 18, 26, 10, 12, 65, 68, 69, 61, 57, simulate the process to find out:

(i) what will be the average number of mopeds waiting in the factory?

(ii) what will be the average number of empty spaces on the lorry?

Solution:

As a first step, we allocate random numbers 00-99 in proportion to the probabilities associated with the production of scooters per day, as shown in **Table 2.8.6.**

Table 2.8.6: Allocation of Random Numbers

Production per Day	Probability	Cumulative Probability	Random Number Interval
146	0.04	0.04	00 - 03
147	0.09	0.13	04 - 12
148	0.12	0.25	13 - 24
149	0.14	0.39	25 - 38
150	0.11	0.50	39 - 49
151	0.10	0.60	50 - 59
152	0.20	0.80	60 - 79
153	0.12	0.92	80 - 91
154	0.08	1.00	92 - 99

Based on the given random numbers, we may simulate the production per day as shown in **Table 2.8.7**. Along with, the number of scooters waiting or number of empty spaces in the lorry for each day are indicated.

Table 2.8.7: Simulation Worksheet

S. No.	Random Number	Production	No. of Scooters Waiting for Space	No. of Empty Spaces in Lorry
1	80	153	3	0
2	81	153	3	0
3	76	152	2	0
4	75	152	2	0
5	64	152	2	0
6	43	150	0	0
7	18	148	0	2
8	26	149	0	1
9	10	147	0	3
10	12	147	0	3
11	65	152	2	0
12	68	152	2	0
13	69	152	2	0
14	61	152	2	0
15	57	151	1	0
		Total	21	9

Average number or scooters waiting for space in the lorry = Total no. of scooters waiting for Space/Total number of days

= 21/15 = 1.4

(ii) Average number of empty spaces in the lorry = 9/15 = 0.6

Illustration 4:

A company manufactures 30 units per day. The sale of these items depends upon demand which has the following distribution:

Sales (Units)	Probability
27	0.10
28	0.15
29	0.20
30	0.35
31	0.15
32	0.05

The production cost and sale price of each unit are ₹ 40 and ₹ 50, respectively. Any unsold product is to be disposed off at a loss of ₹ 15 per unit. There is a penalty of ₹ 5 per unit if the demand is not met. Using the following random numbers, estimate the total profit/loss for the company for the next ten days:

10, 99, 65, 99, 95, 01, 79, 11, 16, 20

If the company decides to produce 29 units per day, what is the advantage or disadvantage to the company?

Solution:

As a first step, random numbers 00-99 are allocated to various possible sale values in proportion to the probabilities associated with them. This is shown in **Table 2.8.8**.

Table 2.8.8: Assignment of Random Numbers

Sales (Units)	Probability	Cumulative Probability	Random Number Interval
27	0.10	0.10	00 - 09
28	0.15	0.25	10 - 24
29	0.20	0.45	25 - 44
30	0.35	0.80	45 - 79
31	0.15	0.95	80 - 94
32	0.05	1.00	95 - 99

Now, we simulate the demand for the next ten days using the given random numbers, as shown in **Table 2.8.9**.

From the given information, we have,

Profit per unit sold = ₹50 - ₹ 40 = ₹10

Loss per unit unsold = ₹15

Penalty for refusing demand = ₹5 per unit

Using these inputs, the profit/loss for the ten days is calculated as given in the table, first when production is 30 units per day and then when it is 29 units.

It is evident that the total profit for ten days is ₹2,695 when 30 units are produced. Also, if the company decides to produce 29 units per day, the total profit works out to be the same, as shown calculated in last column of the table.

Table 2.8.9: Simulation Worksheet: Calculation of Profit/Loss

Day	Random Number	Estimated Sales (units)	Profit/Loss per Day with Production	
			30 units	29 units
1	10	28	(28 × 10) (-2 × 15) = ₹ 250	(28 × 10) -(1 × 15) = ₹ 265
2	99	32	(30 × 10) (-2 × 5) = ₹ 290	(29 × 10) - (3 × 5) = ₹ 275
3	65	30	(30 × 10) = ₹ 300	(29 × 10) -(1 × 5) = ₹ 285
4	99	32	(30 × 10) (-2 × 5) = ₹ 290	(29 × 10) -(3 × 5) = ₹ 275
5	95	32	(30 × 10) (-2 × 5) = ₹ 290	(29 × 10) -(3 × 5) = ₹ 275
6	01	27	(27 × 10) (-3 × 15) = ₹ 225	(27 × 10) -(2 × 15) = ₹ 240
7	79	30	(30 × 10) = ₹300	(29 × 10) -(1 × 5) = ₹ 285
8	11	28	(28 × 10) (-2 × 15) = ₹ 250	(28 × 10) -(1 × 15) = ₹ 265
9	16	28	(28 × 10) (-2 × 15) = ₹250	(28 × 10) -(1 × 15) = ₹ 265
10	20	28	(28 × 10) (-2 × 15) = ₹ 250	(28 × 10) -(1 × 15) = ₹ 265
Total Profit			**₹ 2,695**	**₹ 2,695**

Illustration 5:

Dr. Strong is a dentist who schedules all her patients for 30-minutes appointments. Some of the patients take more or less than 30 minutes depending on the type of dental work to be done. The following summary shows the various categories of work, their probabilities and the time actually needed to complete the work.

Category	Time Required	Probability of Category
Filling	45 Minutes	0.40
Crown	60 Minutes	0.15
Cleaning	15 Minutes	0.15
Extraction	45 Minutes	0.10
Check-up	15 Minutes	0.20

Simulate the dentist's clinic for four hours and determine average waiting time for the patients as well as the idleness of the doctor. Assume that all the patients show up at the clinic at exactly their scheduled arrival time starting at 8 a.m. Use the following random numbers for handling the above problem: 40, 82, 11, 34, 25, 66, 17, 79.

Solution:

As a first step, we determine random number intervals. This is done below:

Category	Time Required	Prob.	Cum. Prob.	Random Number Interval
Filling	45 m	0.40	0.40	00 - 39
Crown	60 m	0.15	0.55	40 - 54
Cleaning	15 m	0.15	0.70	55 - 69
Extraction	45 m	0.10	0.80	70 - 79
Check-up	15 m	0.20	1.00	80 - 99

The simulation is shown in **Table 2.8.10**. Each of the patients is assumed to require service in accordance with the random number associated with him/her. For example, the first patient with random number 40 is assumed to need 'crown', as the number falls in the group 40-54.

Table 2.8.10: Simulation Worksheet: Dentist's Clinic

Patient	Arrival Time	Random Number	Service Time Needed	Service		Waiting Time (Minutes)	Idle Time (Minutes)
				Begins	Ends		
1	8.00 AM	40	60	8.00 AM	9.00 AM	0	0
2	8.30 AM	82	15	9.00 AM	9.15 AM	30	0
3	9.00 AM	11	45	9.15 AM	10.00 AM	15	0
4	9.30 AM	34	45	10.00 AM	10.45 AM	30	0
5	10.00 AM	25	45	10.45 AM	11.30 AM	45	0
6	10.30 AM	66	15	11.30 AM	11.45 AM	60	0
7	11.00 AM	17	45	11.45 AM	12.30 PM	45	0
8	11.30 AM	79	45	12.30 PM	1.15 PM	60	0
			Total			285	0

From the table, we get

Doctor's idle time = nil

Average waiting time of patients = 285/8= 35.6 minutes

Some more examples of queuing situations are given in **Table 2.8.11**.

Table 2.8.11: Queuing Examples

Situation		Arriving Customers	Service Facility
(a)	Passage of customers through a supermarket checkout	Shoppers	Checkout counters
(b)	Flow of automobile traffic through a road network	Automobiles	Road network
(c)	Transfer of electronic messages	Electronic messages	Transmission lines
(d)	Banking transactions	Bank patrons	Bank tellers
(e)	Flow of computer programmes through a computer system	Computer programmes	Central processing unit
(f)	Sale of theatre tickets	Theatre-goers	Ticket booking windows
(g)	Arrival of trucks to carry fruits and vegetables from a central market	Trucks	Loading crews and facilities
(h)	Registration of unemployed at employment exchange	Unemployed personnel	Registration assistants
(i)	Occurrences of fires	Fires	Firemen and equipment
(j)	Flow of ships to the seashore	Ships	Harbour and docking facilities
(k)	Calls at police control room	Service calls	Policemen

The waiting lines develop because the service to a customer may not be rendered immediately as the customer reaches the service facility. Thus, lack of adequate service facility would cause waiting lines of customers to be formed. The only way that the service demand can be met with ease is to increase the service capacity (and raising the efficiency of the existing capacity if possible) to a higher level. The capacity might be built to such high level as can always meet the peak demand with no queues. But adding to capacity may be a costly affair and uneconomic after a stage because then it shall remain idle to varying degrees when there are no or few customers. A manager, therefore, has to decide on an appropriate level of service which is neither too low nor too high. Inefficient or poor service would cause excessive waiting which has a cost in terms of customer frustration, loss of goodwill in the long run, direct cost of idle employees (where, for example, the employees have to wait near the store to obtain the supplies of materials, parts or tools needed for their work), or loss associated with poor employee morale resulting from being idle. On the other hand, too high a service level would result in very high set up cost and idle time for the service station(s). Thus, the goal of queuing modelling is the achievement of an economic balance between the cost of providing service and the cost associated with the wait required for that service.

General Structure of Queuing System

The general structure of a queuing system is depicted in Figure 2.8.1

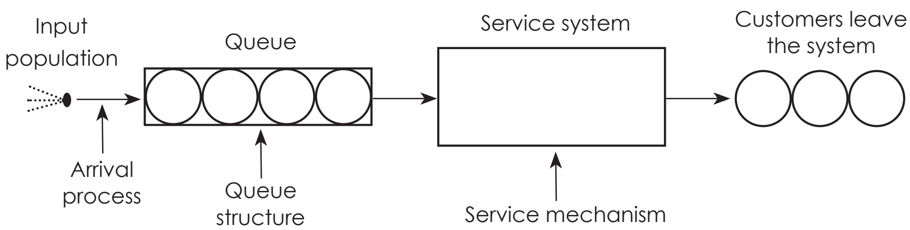


Fig. 2.8.1: General Structure of the Queuing System

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 bases 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 were 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 are Poisson distributed.

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 2.8.2(a)** illustrates such a model.

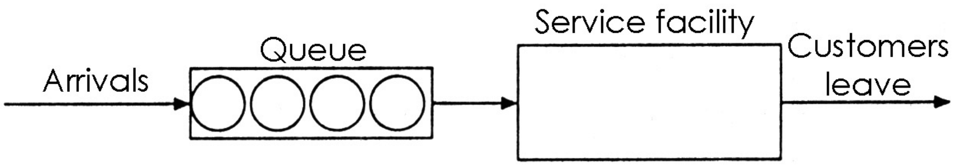


Fig. 2.8.2(a): Single Server, Single Queue Model

(ii) Multiple, parallel facilities with single queue:

That is, 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 2.8.2(b).**

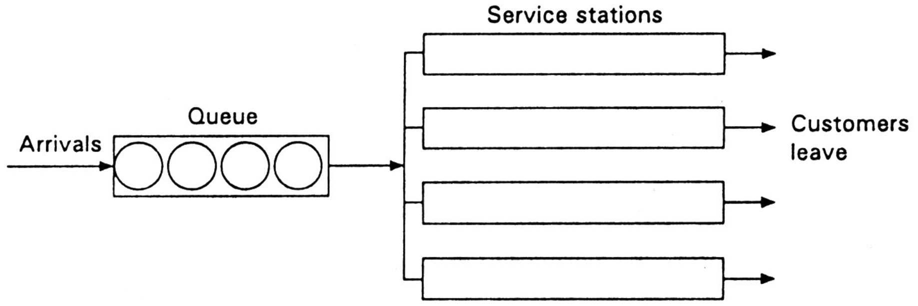


Fig. 2.8.2(b): Multiple, Parallel Servers, Single Queue Model

(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 provide an example of this type of model. **Figure 2.8.2(c)** portrays such a model.

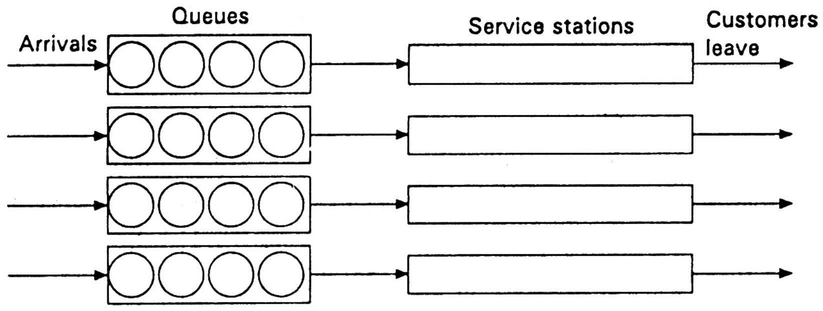


Fig. 2.8.2(c): Multiple, Parallel Servers, Multiple Queues Model

(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 2.8.2(d)** shows such a situation.

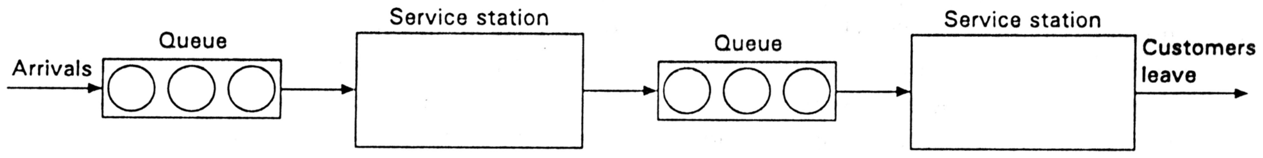


Fig. 2.8.2(d): Multiple Servers in Series

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, we have to consider 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 the last are served first. For example, assume that letters to be typed, or order forms to be processed accumulate in a pile, 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).

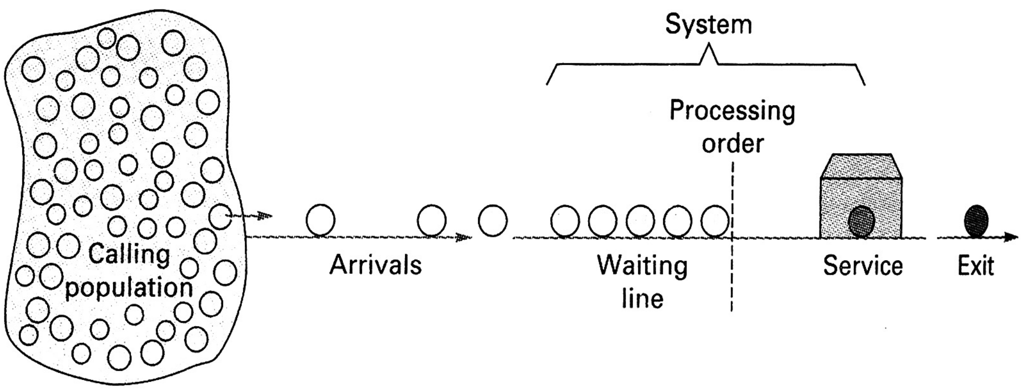


Fig 2.8.3: A simple queuing system

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 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 gas stations.

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 2.8.4 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.

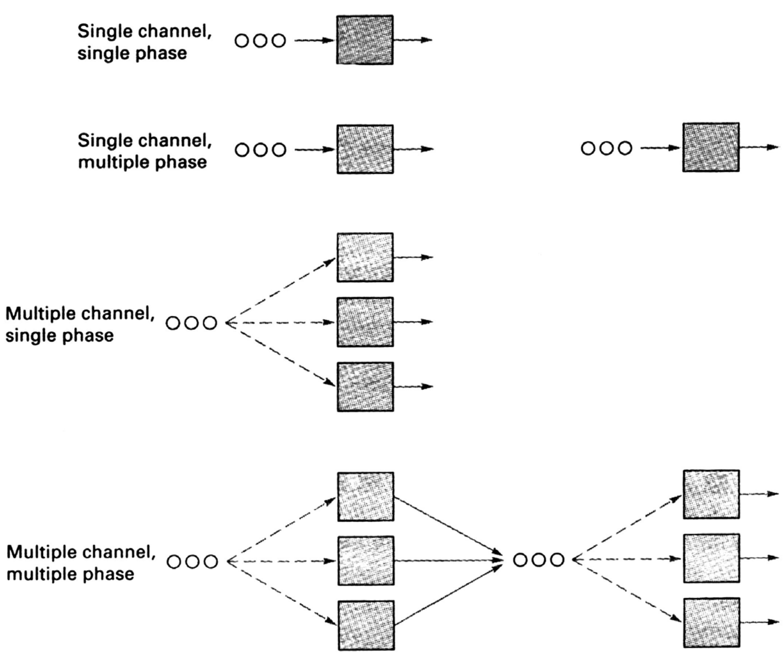


Fig. 2.8.4: Four common variations of queuing systems

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.

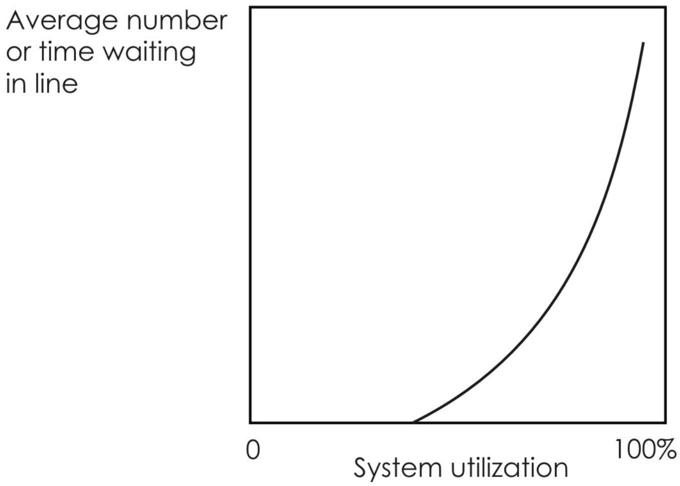


Fig. 2.8.5: The average number waiting in line and the average time customers wait in line increase exponentially as the system utilization increases

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 2.8.12** provides a list of the symbols used for the infinite-source models.

Table 2.8.12 Infinite-source symbols

Symbol	Represents
λ	Customer arrival rate
μ	Service rate per server
L_q	The average number of customers waiting for service
L_s	The average number of customers in the system (waiting and/or being served)
r	The average number of customers being served
p	The system utilization
W_q	The average time customers wait in line
W_s	The average time customer's spend in the system (waiting in line and service time)
$1/\mu$	Service time
P_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).

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).

$$p = \frac{\lambda}{M\mu}$$

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,

$L_s = \lambda W_s$, and $L_q = \lambda W_q$

The implications of this are important to 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 2.8.6: Basic Relationships

	Line	**+**	**Service**	**=**	**System**
Customers ⟶	000	→	○	→	
Average number waiting:	L_q	+		=	L_s
Average time waiting:		+		=	W_s

The average number of customers

Waiting in line for service: L_q [Model dependent. Obtain using a table or formula.]

In the system (line plus being served): $L_s = L_q + r$

The average time customers are

Waiting in line: $W_q = \frac{L_q}{\lambda}$

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 8:

Customers arrive at a bakery at an average rate of 16 per hour on weekday mornings. The arrival distribution 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: λ = 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 μ = 20 customers per hour.

b. $r = \frac{\lambda}{\mu} = \frac{16}{20} = 0.80$ customer.

Table 2.8.13: Formulas for basic single-server model

Performance Measure	Equation
Average number in line	$L_q = \frac{\lambda^2}{\mu(\mu-\lambda)}$
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

$L_s = L_q + r = 3.2 + .80 = 4.0$ customers

$W_q = \frac{L_q}{\lambda} = \frac{3.2}{16} = 0.20$ hour, or 0.20 hour x 60 minutes/hour = 12 minutes

W_s = Waiting in line plus service

$Wa = \frac{1}{\lambda} = 0.20 + \frac{1}{20} = 0.25$ hour, or 15 minutes

d. System utilization is $\rho = \frac{\lambda}{M\mu}$.

For $M = 1, \rho = \frac{16}{1(20)} = 0.80$

For $M = 2, \rho = \frac{16}{2(20)} = 0.40$

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 9:

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:

$\lambda = 15$ customers per hour

$$\mu = \frac{1}{\text{Service time}} = \frac{1\,\text{customer}}{3\,\text{minutes}} \times 60 \text{ minutes per hour}$$

= 20 customers per hour

a. $\rho = \dfrac{\lambda}{M\mu} = \dfrac{15}{1(20)} = 0.75$

b. Percentage idel time = 1– 0.75 = 0.25, or 25 percent

c. $Lq = \dfrac{\lambda}{M(M-\lambda)} = \dfrac{225}{20(20+5)} = \dfrac{225}{(20 \times 5)} = \dfrac{225}{100} = 0.25$

d. $w_S = \dfrac{L_q}{\lambda} + \dfrac{1}{\mu} = \dfrac{2.25}{15} + \dfrac{1}{20}$ = 0.20 hours, or 12 minutes

e. $P_0 = 1 - \dfrac{\lambda}{\mu} = 1 - \dfrac{15}{20} = 0.25$ and $P_4 = P_0\left(\dfrac{\lambda}{\mu}\right)^4 = 0.25\left(\dfrac{15}{20}\right)^4 = 0.079$

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 8:

Wanda's Car Wash & Cry is an automatic, five-minute operation with a single bay. One 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:

$\lambda = 8$ cars per hour

$\mu = 1$ per 5 minutes, or 12 per hour

$$L_q = \frac{\lambda^2}{2\mu(\mu-\lambda)} = \frac{8^2}{2(12)(12-8)} = 0.667 \text{ car}$$

$$w_S = \frac{La}{\lambda} + \frac{1}{\mu} = \frac{0.667}{8} + \frac{1}{12} = 0.167 \text{ hours, or 10 minutes}$$

Multiple Servers, M/M/S

A multiple-server system exists whenever there are two or more servers working independently to provide service to customer arrivals. Use of the model involves the following assumptions:

1. A Poisson arrival rate and exponential service time.
2. Servers all work at the same average rate.
3. Customers from a single waiting line (in order to maintain first-come, first-served processing).

Formulas for the multiple-server model are listed in Table 2.8.18. Obviously, the multiple-server formulas are more complex than the single-server formulas, especially the formulas for L_q and P_0.

Note: The other models of this Multiple Services M/M/S are not discussed in the intermediate level.

For knowledge and information only:

MODELS

The queuing models can be categorised as being deterministic or probabilistic. If each customer arrives at known intervals and the service time is known with certainty, the queuing model shall be deterministic in nature. -The vast majority of the queuing models are, however, based on the assumption that one or more elements of the queuing system can be expressed only in probabilistic terms. Hence, nearly all of the queuing models are of probabilistic type.

1. Deterministic Queuing Model

Let us first consider the case where the customers arrive in the queuing system at regular intervals and the service time for each customer is known and constant.

Suppose that customers come to a bank's teller counter every 5 minutes. Thus the interval between the arrival of any two successive customers is exactly 5 minutes. Suppose further that the banker takes exactly 5 minutes to serve a customer. Here the arrival and the service rates are each equal to 12 customers per hour. In this situation there shall never be a queue and the banker shall always be busy with work.

Now, suppose that the banker can serve 15 customers per hour. The consequence of this higher service rate would be that the banker would be busy $4/5^{th}$ of the time and idle in 1/5th of his time. He shall take 4 minutes to serve a customer and wait for 1 minute for the next customer to come. There would be, as before, no queue.

If, on the other hand, the banker can serve only 10 customers per hour, then the result would be that he would be always busy and the queue length will increase continuously without limit with the passage of time. It is easy to visualize that when the service rate is less than the arrival rate, the service facility cannot cope with all the arrivals and eventually the system leads to an explosive situation. The problem in such situations can be resolved by providing additional service station(s). Symbolically, let the arrival rate be λ customers per unit time and the service rate is μ customers per unit time.

Then,

if $\lambda > \mu$ the waiting line shall be formed which will increase indefinitely; the service facility would always be busy; and the service system will eventually fail; and

if $\lambda \leq \mu$ there shall be no waiting time; the proportion of time the service facility would be idle is $1 - \lambda/\mu$.

The ratio $\lambda/\mu = \rho$ is called the average utilization, or the traffic intensity, or the clearing ratio., For our present model,

if $\rho > 1$, the system would ultimately fail, and

if $\rho \leq 1$, the system works and p is the proportion of time it is busy

We can easily visualize that the condition of uniform arrival and uniform service rates has a very limited practicability. Such conditions may exist when we are dealing, for example, with movements of items for processing in highly automated plants. However, generally, and more particularly when human beings are involved, the arrivals and servicing time are variable and uncertain. Thus, variable arrival rates and servicing times are the more realistic assumptions. The probabilistic queuing models, as mentioned previously, are based on these assumptions.

2. Probabilistic Queuing Models

Of the numerous queuing models available, we shall consider the following models:

(a) Poisson-exponential, single server model-infinite population;

(b) Poisson-exponential, single server model-finite population; and

(c) Poisson-exponential, multiple server model-infinite population.

In each of these, the words 'Poisson-exponential' indicate that the customer arrivals follow, Poisson distribution

while the service times are distributed exponentially. To recapitulate, if the arrivals are independent, with the average arrival rate equal to λ per period of time, then, according to the Poisson probability distribution, the probability that n customers will arrive in the system during a given interval T, is given by the following:

$$P\ (\text{n customers during period T}) = e^{-m}\frac{m^n}{n!}$$

where $m = \lambda T$, and $e = 2.7183$

Illustration 9:

Assume that at a bank teller window the customers arrive in their cars at the average rate of twenty per hour according to a Poisson distribution. Assume also that the bank teller spends an average of two minutes per customer to complete a service, and the service time is exponentially distributed. Customers, who arrive from an infinite population, are served on a first-come-first-served basis, and there is no limit to possible queue length.

(i) What is the expected waiting time in the system per customer?

(ii) What is the mean number of customers waiting in the system?

(iii) What is the probability of zero customers in the system?

(iv) What value is the utilization factor?

Solution:

Here, arrival rate $\lambda = 20$ customers/hour,

service rate $\mu = 30$ customers/hour.

Thus, $p = \lambda/\mu = 20/30 = 2/3$.

(i) Expected waiting time in the system per customer,

$$W_s = \frac{1}{\lambda - \mu} = \frac{1}{30 - 20} = \frac{1}{10} \text{ hour or 6 minutes}$$

(ii) Mean number of customers waiting in the system,

$$L_q = \frac{\rho^2}{1-\rho} = \frac{(2/3)^2}{1-2/3} = \frac{4}{3}$$

(iii) Probability of zero customers in the system,

P(0) = 1 – ρ = 1 – 2/3 = 1/3

(iv) Utilization factor, ρ = 2/3.

Illustration 10:

A warehouse has only one loading dock manned by a three-person crew. Trucks arrive at the loading dock at an average rate of 4 trucks per hour and the arrival rate is Poisson distributed. The loading of a truck takes 10 minutes on an average and can be assumed to be exponentially distributed. The operating cost of a truck is ₹ 20 per hour and the members of the loading crew are paid @ ₹ 6 each per hour. Would you advise the truck owner to add another crew of three persons?

Solution:

According to the given information,

λ= 4 trucks/hour

μ = 6 trucks/hour.

We have,

Total hourly cost = Loading Crew Cost + Cost of Waiting time

At present

Loading crew cost = No. of loaders x Hourly wage rate

= 3 x 6 = ₹ 1 8 per hour

Cost of waiting time = Expected waiting time per truck (W_s) x Expected arrivals per hour (λ) x Hourly waiting cost

$= \frac{1}{6-4}$ x 4 x 20 = ₹ 40 per hour

Alternatively, cost of waiting time = Expected number of trucks in the system (Ls) x Hourly waiting cost

$= \frac{4}{6-4}$ x 20 = ₹ 40 per hour

∴ Total cost = ₹ 18 + ₹ 40 = ₹58 per hour

With proposed crew addition

Loading crew cost = 6 x 6 = ₹ 36 per hour

Cost of waiting time = $\frac{4}{12-4}$ x 20 = ₹ 10 per hour

∴ Total cost = ₹ 36 + ₹ 10 = ₹ 46 per hour

Conclusion: It is advisable to add a crew of three loaders.

Illustration 11:

A factory operates for 8 hours everyday and has 240 working days in the year. It buys a large number of small machines which can be serviced by its maintenance engineer at a cost of ₹ 4 per hour for the labour and spare parts. The machines can, alternatively, be serviced by the supplier at an annual contract price of ₹ 20,000 including the labour and spare parts needed. The supplier undertakes to send a repairman as soon as a call is made but in no case more than one repairman is sent. The service times of the maintenance engineer and the supplier's repairman are both exponentially distributed with respective means of 1.7 and 1.5 days. The machine breakdowns occur randomly and follow Poisson distribution, with an average of 2 in 5 days. Each hour that a machine is out of order, it costs the company ₹ 8. Which servicing alternative would you advise it to opt for?

Solution:

We shall calculate the total cost involved for each of the alternatives for taking the decision. Total Annual Cost = Cost of idle machinery time + Cost of labour and spare parts

Cost of Idle Machinery Time = Expected no. of machines in the system x No. of working hours per year x Hourly idle time cost

Alternative 1: Maintenance by company engineer

We have, from the given information,

λ = 2/5 machines per day

μ = 1/1.7 machines per day

Expected number of machines in the system,

$$L_s = \frac{\lambda}{(\mu - \lambda)} = \frac{2/5}{\frac{1}{1.7} - \frac{2}{5}} = \frac{17}{8} \text{ letters}$$

Cost of Idle Machinery Time = $\frac{17}{8}$ x 1920 x 8 = ₹32,640

Cost of Labour and Spare Parts = No. of machines in the system x No. of working hours per year × Hourly cost

= $\frac{17}{8}$ × 1920x4 = ₹16,320

∴ Total cost = 32,640 + 16,320 = ₹48,960 p.a.

Alternative 2: Maintenance by supplier

We have,

λ = 2/5 machines per day

μ = 1/1.5 machines per day

Expected number of machines in the system,

$$L_s = \frac{\lambda}{(\mu - \lambda)} = \frac{2/5}{\frac{1}{1.5} - \frac{2}{5}} = \frac{3}{2} \text{ machines}$$

Cost of Idle Machine Time = 3/2 × 1920 x 8 = ₹23,040

Cost of Labour and Spare Parts = ₹20,000

∴ Total cost = 23,040 + 20,000 = ₹43,040 p.a.

Clearly, then, the maintenance of the machines by the supplier is the better alternative.

Illustration 12:

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:

(a) Average queue length.
(b) Average length of non-empty queues.
(c) Average number of workers in system including the worker being attended.
(d) Mean waiting time of an arrival,
(e) Average waiting time of an arrival who waits, and
(f) The type of policy to be established. In other words, determine whether to go in for the additional number of tool store-room attendant which will minimize the combined cost of attendant's idle time and the cost of workers' waiting time. Assume the charges of a skilled worker ₹4 per hour and that of tool store-room attendant ₹0.75 per hour.

Solution:

Here,

$\lambda = \frac{1}{60}$ per second = 1 per minute

$\mu = \frac{1}{40}$ per second = 1.5 per minute

(a) Average queue length:

$$= L_q = \frac{\lambda}{\mu} \times \frac{\lambda}{\mu - \lambda} = \frac{1}{1.5} \times \frac{1}{1.5-1} = \frac{1}{0.75} = \frac{4}{3} \text{ workers}$$

(b) Average length of non-empty queues:

$$L_n = \frac{\mu}{\mu - \lambda} = \frac{1.5}{1.5-1} = 3 \text{ workers}$$

(c) Average number of workers in the system:

$$L_s = \frac{\lambda}{\mu - \lambda} = \frac{1}{1.5-1} = 2 \text{ workers}$$

(d) Mean waiting time of an arrival

$$W_q = \frac{\lambda}{\mu} \times \left(\frac{1}{\mu - \lambda}\right) = \frac{1}{1.5} \times \left(\frac{1}{1.5-1}\right) = \frac{4}{3} \text{ minutes}$$

(e) Average waiting time of an arrival who waits

$$W_n = \frac{1}{\mu - \lambda} = \frac{1}{1.5-1} = 2 \text{ minutes}$$

(f) Probability that the tool room attendant remains idle:

$$P_O = 1 - \frac{\lambda}{\mu} = 1 - \frac{1}{1.5} = \frac{1}{3}$$

Idle time cost of an attendant:

$\frac{1}{3}$ x 8 x 0.75 = ₹ 2 per day

Waiting time cost of workers:
= W_q x No. of workers arriving / day x Cost of workers
= $(\frac{4}{3} \times \frac{1}{60})$ x (8 x 60) x ₹4 = ₹42.67 / day
As the waiting time cost is much higher than the idle time cost. It is justified to employ an additional tool room attendant.

Scheduling

Scheduling pertains to establishing the time of the use of specific resources within an organisation. It relates to the use of equipment, machines, facilities and human activities. Scheduling is necessary in every organisation regardless of the nature of its activities. For example, in manufacturing organisations, production must be scheduled, which means developing schedules for workers, machines, equipments, maintenance etc. In service organisations such as hospitals-admission, surgery, nursing assignments and support services such as cleaning, maintenance, security, meal preparation etc., must be scheduled. In educational institutions, classrooms, instruction and students must be scheduled.

Scheduling, means organising a production line to produce products in time efficiently with least use of time and maximum utilisation of resources (especially men and machines).

Objectives of Scheduling

(i) To prevent unbalanced use of time among departments and work centres or to evenly load all machines in the production line.

(ii) To utilise machines and labour in such a way that the output is produced within the established lead time so as to (a) deliver the products/services in time and (b) complete production in the shortest cycle time possible at minimum total cost of production.

(iii) To reduce idle time of labour and machines, which might be caused due to waiting for materials, waiting for movement, waiting for inspection and waiting for want of work.

(iv) To fix up delivery dates for various manufacturing activities and for the finished products.

(v) To increase the efficiency of production or productivity.

Managerial Considerations in Scheduling

Scheduling in production and operations management helps to allocate scarce resources. For example, machine time is a scarce resource that is allocated to different jobs, labour (or employee) time is allocated to different activities and facilities are scheduled for a given activity at a particular time period. In all these scheduling tasks, different criteria may be used in deciding which of several schedules is best. Those criteria may relate to the amount of time the machine or equipment might idle, the importance of a certain order or a certain customer, or the level at which the resource is utilised. In general there are six criteria that may be used in evaluating different possible schedules. They are:

(i) Providing the product or service when the customer wants it.

(ii) Minimising the length of time taken to produce that product or service (referred to as flow time)

(iii) Minimising the level of work-in-progress (WIP) inventories

(iv) Minimising the amount of idle time of equipment or machine.

(v) Minimising the amount of idle time of employees and

(vi) Minimising costs

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.

Information Needed for Scheduling Process

Before starting scheduling process it is necessary to collect sufficient information about jobs, activities, employees, equipment, machines or facilities that are to be scheduled. Depending on the scheduling situation, various types of data must be collected.

They are:

(i) Jobs : (a) Due dates, (b) Routings with standard set up and processing times, (c) material requirements, (d) Flexibility of due dates, (e) Importance of completing the job by due date.

(ii) Activities : (a) Expected duration, (b) Precedence relationships, (c) Desired time of completion.

(iii) Employees : (a) Availability, (b) job capabilities, (c) Efficiency at various jobs, (d) Wage rates.

(iv) Equipment/Machine : (a) Machine or work centre capacities, (b) Machine or work centre capabilities, (c) Cost of operation, (d) Availability

(v) Facilities : (a) Capacities, (b) Possible uses, (c) Cost of Use, (d) Availability.

Scheduling Techniques for Job Shop

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 methods used for 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 First in First Out (FIFO). Otherwise, if the orders are received from single customer at different point of time in a week/month, then the production manager pile up all 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 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 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.

Sequencing rules for single facility: When we have a single facility, and the orders are in queue, then they are processed depending on the rules mentioned below:

(a) First in first served or first in first out (FIFS/FIFO): Here the jobs are processed as they come in. This is commonly observed queue discipline.

(b) Shortest processing time (SPT): The jobs having shortest processing time are processed first. This is just to avoid formation of queue. For example, when you go for Xeroxing a document, and other person comes for Xeroxing a book, then document is Xeroxed and then the book is taken for Xeroxing.

(c) Minimum due date (MDD): Here jobs are processed in ascending order of their available time before delivery date. By doing so, we can keep up the delivery promises. To meet the delivery promises, if necessary, overtime, sub contracting etc., may be used.

(d) Last come first served or last in first out (LCFS/LIFO): This generally happens in case of inventory stocking and using. When material piles up, the material at the top i.e., material last arrived is used first.

(e) Static slack for remaining operations (SSRO): Static slack is given by: (Due date - Remaining processing time/number of remaining operations). Here jobs are processed in ascending order of the operations.

(f) Dynamic slack for remaining operations (DSRO): Dynamic slack is given by: (Due date - expected time of remaining operations / number of remaining operations). Here the jobs are done in ascending order of the ratio dynamic slack.

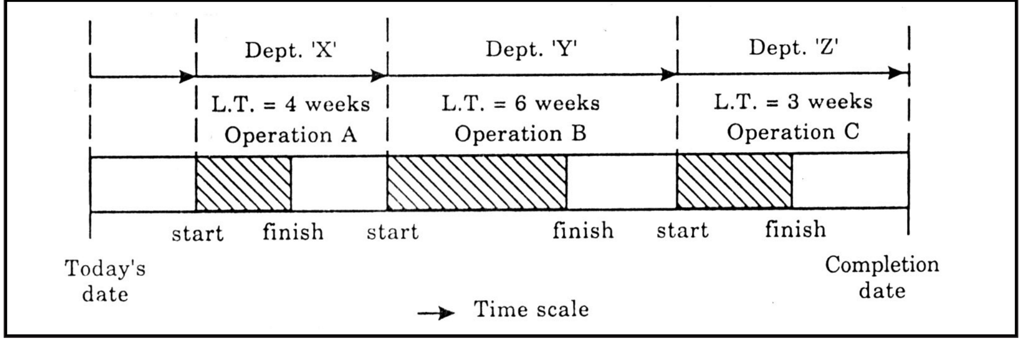
The type of scheduling technique used in job shop depends on the volume of orders, the nature of operations and the job complexity. Two types of scheduling'techniques used are:

1. Forward scheduling   2. Backward scheduling

A combination of forward and backward scheduling may often be used in practice.

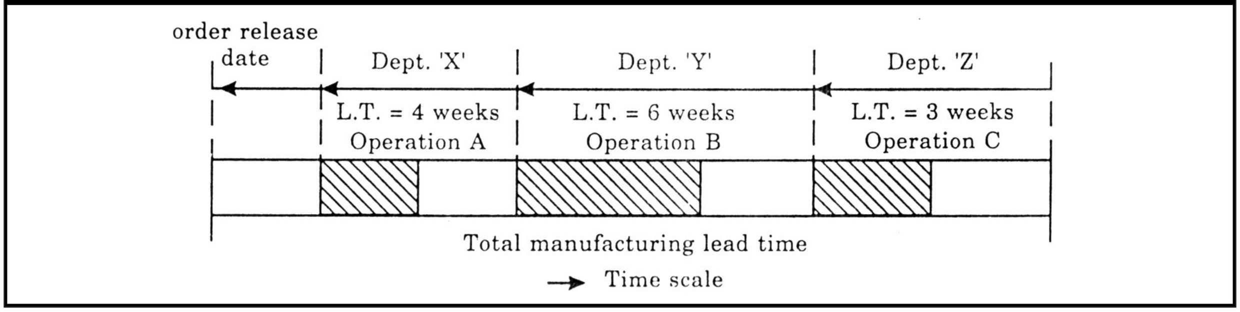
Forward scheduling : In this approach, each task is scheduled to occur at the earliest time that the necessary material will be on hand and capacity will be available. It assumes that procurement of material and operations start as soon as the customers' requirements are known. The customers place their orders on a "needed-as-soon-as possible" basis. The earliest completion date, assuming that everything goes as planned, could be quoted to the potential customer. Some buffer time may be added to determine a date that is more likely to be achievable, if it is acceptable to the customer. Forward scheduling is used in many companies such as steel mills and machine tool manufacturers where jobs are manufactured to customer orders and delivery is requested on "as early as possible." basis. Forward scheduling is well suited where the supplier is usually not able to meet the schedules. This type of scheduling is simple to use, gets jobs done in shorter lead times but accumulates high work in process inventories. **Exhibit 2.8.1** illustrates forward scheduling.

Exhibit 2.8.1 : Example of Forward Scheduling



Backward scheduling : This scheduling technique is often used in assembly-type industries and in job shops that commit in advance to specific delivery dates. After determining the required schedule dates for major sub-assemblies, the schedule uses these required dates for each component and works backward to determine the proper release date for each component manufacturing order. The job's start date is determined by "setting back" from the finish date the processing time for the job. By assigning jobs as late as possible, backward scheduling minimizes inventories since each job is not completed until it is due but not earlier. Backward scheduling is also known as reverse scheduling. (See Exhibit 2.8.2)

Exhibit 2.8.2 : An Example of Backward Scheduling



Stages in Scheduling

Scheduling is performed in two stages, viz. 1. Loading, 2. Dispatching

Loading : Loading or shop loading is the process of determining which work centre receives which job. It involves assigning a job or task to a particular work centre to be performed during a scheduling period (such as a week). Loading of work centres depends on the available capacity (or determined by load schedules) and the expected availability of the material for the job. The jobs are assigned to machines on work centres taking into consideration the priority sequencing and machine or work centre utilization.

Dispatching : Dispatching is sequencing and selecting the jobs waiting at a work centre (i.e., determining which job to be done next) when capacity becomes available. It is the actual authorizing or assigning the work to be done. The dispatch list is a means of priority control. It lists all jobs available to a work centre and ranks them by a relative priority. When priorities have been assigned to specific jobs, scheduling gets implemented through the dispatch list.

Finite Loading and Infinite Loading : Loading procedures are categorized as either finite loading or infinite loading. In finite loading, jobs are assigned to work centres by comparing the required hours for each operation with the available hours in each work centre for the scheduling period. In infinite loading, jobs are assigned to work centres without regard to capacity (as if the capacity were infinite).

(a) **Finite loading** : Finite loading systems start with a specified capacity for each work centres and a list of jobs to be processed at the work centre (sequencing). The work centre's capacity is allotted to the jobs by simulating job starting times and completion times. The finite loading system combines, loading, sequencing and detailed scheduling. It creates a detailed schedule for each job and each work centre based on the capacity of the work centre.

Exhibit 2.8.3 : Finite Loading

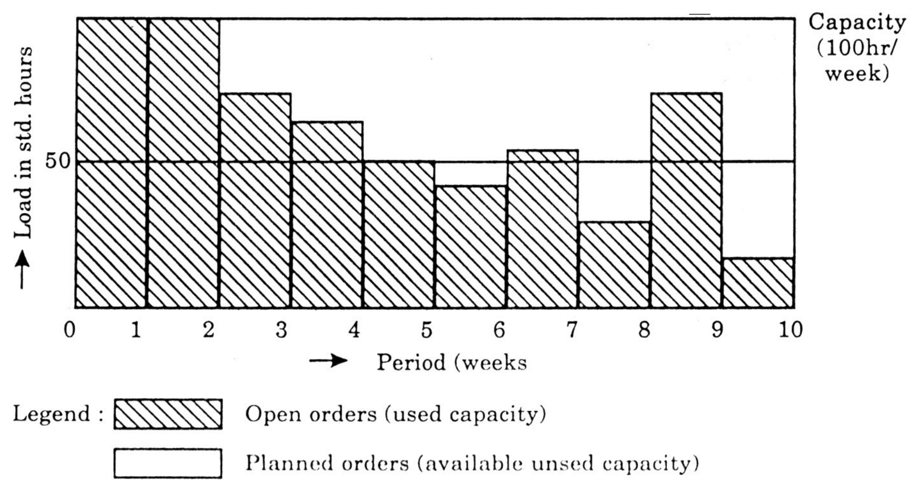
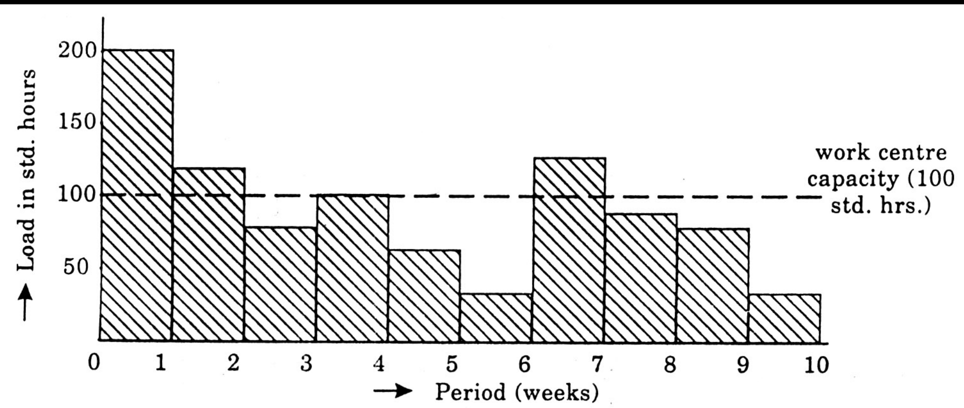


Exhibit 2.8.3 shows a finite capacity load profile for a work centre having a capacity of 100 labour hours per week.

(b) **Infinite loading** : The process of loading work centres with all the jobs when they are required without regard to the actual capacity available at the work centre is called infinite loading. Infinite loading indicates the actual released order demand (load) on the work centre so as to facilitate decision about using overtime, sub-contracting or using alternative routings, delaying selected orders.

Exhibit 2.8.4 : Infinite Loading



Load Charts and Machine Loading Charts

(a) **Load chart or load schedule** : A load schedule or load chart is a device for comparing the actual load (labour hours and machine hours) required to produce the products as per the MRS against the available capacity (labour hours and machine hours) in each week.

Exhibit 2.8.5 : Load Schedule

Week No.	1	2	3	4	5	6
Load (Std. hours)	100	100	80	60	50	70

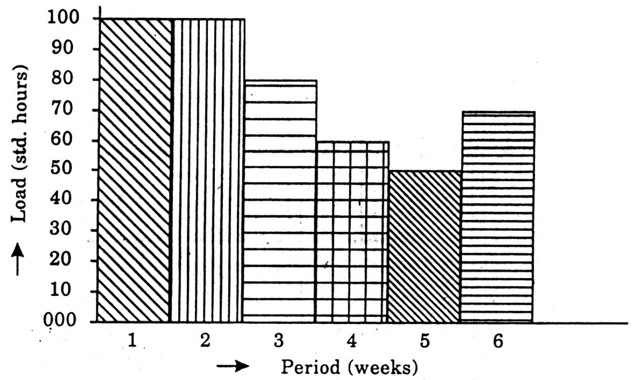


Exhibit 2.8.5 illustrates the load schedule or chart shown graphically for a particular work centre having a weekly capacity of 100 standard hours and the weekly load for six weeks period. The load against each time period (i.e., week) is as shown

(b) **Machine loading chart (Gantt load chart)** : Gantt Charts are used to display graphically the work loads on each machine or in each work centre. There are two types of Gantt charts (i) Gantt load chart (ii) Gantt scheduling chart or program chart.

Exhibit 2.8.6(a) : Gantt Load Chart Drawn for a Particular Week of a Particular Month

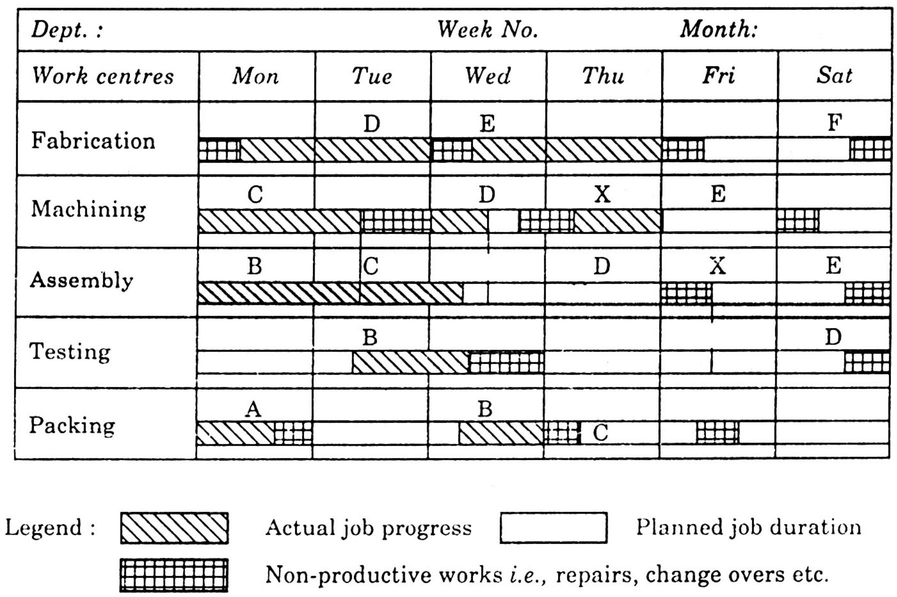


Exhibit 2.8.6(a) illustrates a Gantt load chart drawn for a particular week of a particular month. Gantt charts are simple to devise and easy to understand. The Gantt load chart offers the advantage of ease and clarity in communicating important shop information.

Exhibit 2.8.6(b) : Gantt Scheduling Chart

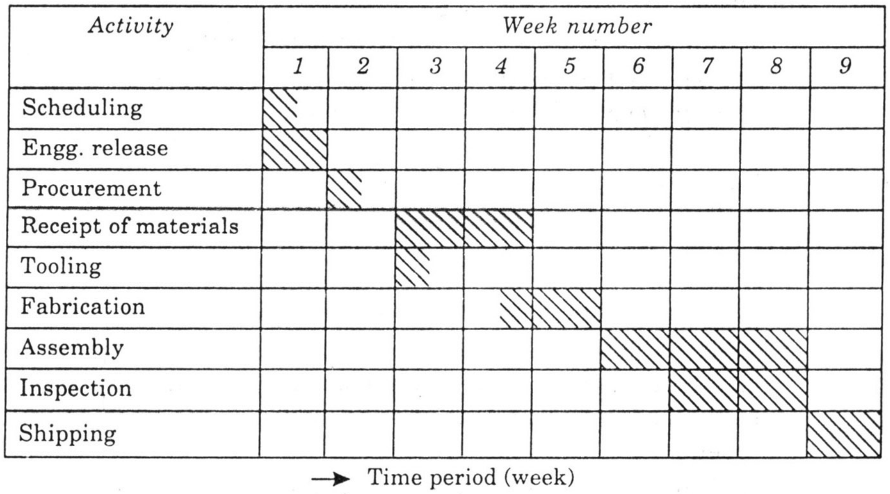


Exhibit 2.8.6 (b) illustrates a Gantt scheduling chart.

Priority Sequencing

When several jobs compete for the capacity of a machine or a work centre, the question of sequencing the jobs arises. This question is answered by determining the priority for all the jobs waiting in the que by applying priority sequencing rules.

The priority indicates the sequence in which the jobs will be processed on the machine or in the work centre. When the machine or work centre becomes free, the job with the highest priority is assigned. Choice of the right sequencing rule based on one criterion becomes quite difficult as no single rule is ideal for all situations. Some of the criteria used are:

(a) Set up costs or change over costs.

(b) Work-in-progress inventory cost.

(c) Idle time.

(d) Number or percent of jobs late.

(e) Average job lateness.

(f) Average flow time.

(g) Average number of jobs in the system.

(h) Average time to complete a job etc.

Single-Criterion Priority Sequencing Rules

Some single-criterion priority sequencing rules are:

1. First come first served (FCFS)
2. Shortest processing time (SPT) or shortest - operation time (SOT) or minimum processing time (MINPRT).
3. Longest processing time (LPT) or longest - operation time (LOT)
4. Least slack job (LS) first or minimum slack (MIN SLACK) job first.

5. Earliest due date (EDD) job first
6. Truncated shortest processing job first (TSPT)
7. Preferred customer order (PCO) first
8. Random selection (RS)
9. COVERT (Cost over time)
10. Least change-over cost.

The rules of sequencing are explained in detail in the following paragraph.

1. First come-first served (FCFS) rule : Jobs are scheduled for work in the same sequence as they arrive at the facility or work centre. This juie is commonly applied in service centres such as bank,super bazaars and barber shops.
2. Shortest process time job (SPT) first : The job which has the shortest processing/ operation time on the machine or at the work centre is given the highest priority to be loaded as the next job for processing. This rule minimizes the in-process-inventory, however at the expense of keeping the jobs having longer processing time for a longer time in the work centre, thereby increasing the job through-put time (i.e., manufacturing cycle time).
3. Longest processing time (LPT) job first: The job with the longest processing/operation time is scheduled as the first job to be loaded on the machine among the jobs waiting in queue.
4. Least slack (LS) job first: In this rule highest priority is given to the job which has the least slack. Slack is the difference between available time and the duration of processing the job. Slack = Available time - Processing time.
5. Earliest due date (EDD) job first : This rule sequences the jobs waiting in the queue at the work centre or machine according to their due dates and the jobs are processed according to their due dates i.e., job having earliest due date is given highest priority while loading the job on the machine (or work centre). This rule does not ensure that all jobs will be completed on time i.e., within their due dates.
6. Truncated shortest processing time (TSPT) job first : This rule sequences the jobs according to SPT rule, except that the jobs that have been waiting for a time period longer than a specified truncation time are given higher priority than other jobs.
7. Preferred customer order (PCO) rule : Jobs belonging to a preferred customer are given a higher priority than other jobs.
8. Random-selection : This rule is not used normally. It may be used when no other consideration is important.
9. COVERT (cost over time) rule : This rule uses the ratio of expected delay cost (C) to the processing time (T). The job with the largest ratio is given the highest priority.

$$\text{Cost over time ratio} = \frac{\text{Expected delay cost (C)}}{\text{Processing time (T)}}$$

10. Least change-over cost : The sequencing of jobs is done by analyzing the total cost of making all of the machine change over between jobs.

Scheduling Product Focused Systems

In product focused systems there are only a few standardized product designs, the products are usually produced on produce to stock and sell basis finished goods inventories are held and the production rates of individual products exceed their demand rates.

Some of the scheduling implications are:

1. Little pre production planning concerning route sheets, job instructions, process plans and product design etc.
2. Schedules can be based on economic production runs (E.B.Q.) for products without firm delivery schedules to customers.
3. The major scheduling concerns are timing of production line change-overs and length of production runs.

The most common scheduling decisions are:

(a) How long should the production run be for each product model and when should machine change - over be scheduled?

(b) If products are to be produced to a specific delivery schedule stipulated by the customer at any point of time (during a review period) how many cumulative units should have passed each upstream process step if future deliveries are to be on schedule? The techniques used in resolving scheduling related problems in product-focused production systems are: 1. Batch scheduling, 2. Scheduling and controlling production for delivery schedules.

Batch Scheduling

Batch production falls between job shop production and continuous production. In batch production system, the output is inventoriable and can be produced in substantial volume, eventhough the volume may not justify continuous production. In these situations it is necessary to determine the lot size for a batch to be produced at one time in addition to scheduling the batch on the facilities. Examples of such production are production of pharmaceutical products, paints etc., The decision to be taken by operations managers are: (i) the lot size and (ii)Othe scheduling decision regarding when to begin the processing of the batch.

A key trade-off in the determination of the lot size for an item is between set-up costs and inventory carrying costs. Another important consideration is the requirement to produce a feasible schedule that meets the demand for all items. For example, if set-up costs are low as compared to inventory carrying costs, it may be advantageous to go for small lot sizes but it may not be possible to produce the required quantities of all items within the specified time period if these small lot sizes are employed. This will happen if much of the time is consumed for machine set-ups, thereby reducing the available production time. To overcome this problem, larger lot sizes may have to be employed which will result in higher inventory carrying cost. Hence it is necessary to compute economic lot sizes while maintaining feasibility in scheduling batches of sucn lot sizes for the items to be produced.

Economic Batch Quantity (EBQ) or Economic Run Length (ERL)

Two types of costs associated with lot manufacture are

(a) Set-up costs i.e.,, costs/unit which decrease with batch size.

(b) Inventory carrying cost which increases with batch size.

Set-up cost includes:

(i) Cost of releasing work orders shop orders, stores requisitions tool requisitions etc.

(ii) Cost of first off inspection, cost of rejections till machine set up is ready for production run

(iii) Machine set up cost for mounting accessories, tools, jigs and fixtures on the machine

(iv) Cost of dismantling the setup after the production run

Inventory carrying costs include:

(i) Cost of working capital tied up in average inventory

(ii) Cost of handling and storing materials (i.e., parts produced)

(iii) Insurance charges and taxes

(iv) Cost of spoilage and obsolescence etc.

Case 1 : Instantaneous supply with no simultaneous consumption:

Let A = Annual demand for an item in units

S = set-up cost per set-up

I = Inventory carrying cost per unit per year as a percentage of inventory value

C = Cost per unit of the item produced

Q = Economic: batch quantity or economic run length.

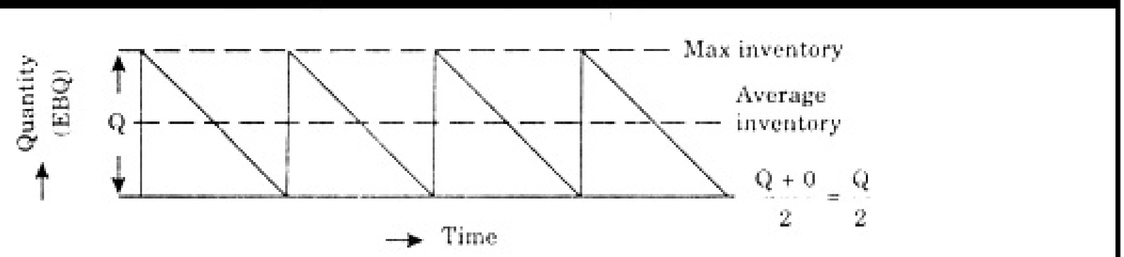
The Solution :

No. of batches per year = A/Q

Set-up cost per year = A/Q x S

Average inventory held = Q/2

Exhibit 2.8.7



Inventory carrying cost per year = $\frac{Q}{2} \times C \times I$

Total cost per year = Set up cost per year + Inventory carrying cost per year

i.e., T.C. $= \frac{A}{Q} \times S + \frac{Q}{2} CI$

For minimizing the total cost,

$$\frac{d.T.C.}{dQ} = -\left(\frac{AS}{Q^2}\right) + \left(\frac{CI}{2}\right)$$

For TC to be minimum, $\frac{d.T.C.}{dQ} = 0$

Or, $-\left(\frac{AS}{Q^2}\right) + \left(\frac{CI}{2}\right) = 0$

Or, $\frac{CI}{2} = \frac{AS}{Q^2}$ or, $Q^2 = \frac{2AS}{CI}$

Or, $Q = \sqrt{\frac{2AS}{CI}}$

i.e., Economic Batch Qty. (EBQ) or Economic Run Length (ERL) = $\sqrt{\frac{2 \times \text{Annual demand} \times \text{Set-up cost}}{\text{Unit cost} \times \text{Inventory carrying cost (\%)}}}$

If inventory carrying cost is expressed as carrying cost per unit per year for an item instead of as a percentaage of the value of its inventory, then,

Carrying cost per unit per year C_c = CI (Rupees) (i.e., unit cost x carrying cost as %age)

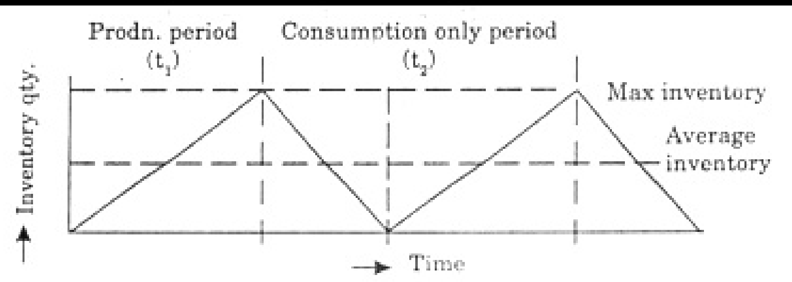
The EBQ formula can be rewritten as EBQ $= \sqrt{\dfrac{2AS}{C_c}}$

i.e., Economic Batch Quantity $= \sqrt{\dfrac{2 \times \text{Annual demand} \times \text{Set-up cost}}{\text{Unit cost} \times \text{Inventory carrying cost per unit per year (₹)}}}$

Case 2 : Non-instantaneous supply with simultaneous consumption

Exhibit 2.8.8 illustrates the EBQ model showing the inventory level and consumption pattern when production and consumption takes place simultaneously.

Exhibit 2.8.8



Considering the case where production and consumption of an item takes place simultaneously

Let A = Annual demand for an item

d = demand or consumption rate (unit/time period (say weekly)

p = production rate (units/time period (say weekly)]

S = set up cost per set up

C = cost per unit of item produced

I = Inventory carrying cost per year per unit as a %ge of value of inventory

Q_1 = Economic batch quantity (Non-instantaneous supply)

Determination of EBQ

No. of set-ups $= \dfrac{A}{Q_1}$

Set-up cost per year $= \dfrac{A}{Q_1} \times S$

Average inventory = Maximum inventory built up/2

To calculate the inventory built up let us assume that the production period is t_1 (weeks) and consumption only period is t_2 (say weeks).

Quantity produced in time t_1 = Q, (at a rate of 'p' per week)

$$Q_1 = p \times t_1 \quad \text{or} \quad t_1 = \frac{Q_1}{p}$$

Consumption during period t_1 (at the rate of 'd' per week) $= dt_1$

$$= d \times \frac{Q_1}{p} \quad \text{or, } Q_1 \times \frac{d}{p}$$

(Max. inventory built up during period t_1) = Qty. produced - Qty. consumed

$$= Q_1 - Q_1 \times \frac{d}{p} \quad = Q_1\left(1 - \frac{d}{p}\right)$$

Average inventory $= \frac{Q_1}{2}\left(1 - \frac{d}{p}\right)$

Inventory carrying cost per year $= \frac{Q_1}{2}\left(1 - \frac{d}{p}\right)CI$

Total cost (TC) per year = Set-up cost per year + Inventory carrying cost per year

$$TC = \frac{A}{Q_1}S + \frac{Q_1}{2}\left(1 - \frac{d}{p}\right)CI$$

For the total cost (TC) to be minimum, $\frac{d\,T.C.}{dQ_1} = 0$

i.e., $$-\frac{A}{Q_1^2}S + \frac{\left(1 - \frac{d}{p}\right)CI}{2} = 0 \quad \text{or,} \quad \frac{A}{Q_1^2}S = \frac{\left(1 - \frac{d}{p}\right)CI}{2}$$

or, $$Q_1^2 = \frac{2AS}{\left(1 - \frac{d}{p}\right)CI}$$

or, $$Q_1 = \sqrt{\frac{2AS}{\left(1 - \frac{d}{p}\right)CI}}$$

or $$Q_1 = \sqrt{\frac{2AS}{CI\left(1 - \frac{d}{p}\right)}}$$

Complexities of EBQ Scheduling

1. Because of differing requirements, set-up costs and inventory carrying costs for each job, inventories resulting from EBQ lots may not last through a complete cycle. Because of stock-outs, special orders of smaller size may then be needed resulting in capacity dilution.

2. Competition for machine and/or worker time may cause scheduling interference especially when operating near capacity limits. Lots may be split in order to maintain scheduled commitments leading to reduced capacity due to increased set up time..:
3. Limited capacity of a bottleneck machine or process through which all or most of the jobs must be sequenced, may exert pressure towards smaller lot sizes and causing splits ups.
4. Where parts or products are produced in regular cycles, individual lot-sizes are determined to fit in with the cycles rather than from the balance of setup and inventory carrying costs for each item.
5. The assumption of constant demand may not be met either as a result of seasonal usage or sales or because demand is dependent on production schedules of other parts, sub-assemblies or products.
6. The production lot size may not be equal to transit-lot-size, thereby making EBQ formulation invalid.

   Most of the above reasons for deviating from EBQ formula lead to smaller lot sizes and to reductions in effective capacity.

   The EBQ formula is used in practice as a guide for determining the length of production runs for a single inventory item. As a comprehensive batch scheduling technique it is not entirely satisfactory because of the following facts.

   (a) Inventory items share common production capacity.

   (b) 'Length of production run' decisions must be made simultaneously for all inventory items to be produced in each time period.

   (c) The EBQ decision should be based on most current information about demand rates and production rates and not on estimates of annual demand.

These deficiencies of the EBQ formula in planning the length of production runs have led to the development of the 'RUN-OUT' method for planning production schedules in capacity-constrained production operation when batches of product varieties are produced on common assembly lines.

Scheduling and Controlling Production for Delivery Schedules - Line of Balance (LOB) Method

It is quite common that production systems often produce products as per the commitment to a delivery schedule promised to the customers. These delivery schedules can be a part of a purchase order.

In order to ensure that the actual product deliveries match with the planned delivery schedules, a system must be devised to schedule and control all the processing steps of the production system.

Quite often, the firm may be in schedule in terms of deliveries, but may default soon on deliveries because the production pipe line may run out of products sooner or later. When this happens, it may be too late to take corrective action, because the deliveries get affected until the pipe line can again be refilled with products.

Line-of-Balance technique has been used successfully to schedule and control upstream processing steps in a variety of production systems producing goods and services.

LOB Technique

The Line of Balance technique is used in production scheduling and control to determine, at a review date, not only how many (quantity) of an item should have been completed by that date, but also how many should have passed through the previous (upstream) operation stages (processing steps) by that time so as to ensure the completion of the required delivery schedule.

LOB is a charting and computational technique for monitoring and controlling products and services that are made to meet specific delivery schedules. The concept of LOB is similar to the time phased order point system (TPOP) .and MRP system (Material Requirements Planning). Starting from the delivery schedule (date) for the final product and the quantity, the product structure tree is drawn on a horizontal scale, off-setting lead time on a time scale, reflecting the, previous processing steps or stages of production. The processing steps or production stages may include purchased parts, machined parts, sub-assemblies and major assembly operations to support delivery schedule for the finished product. The LOB chart shows the quantity of parts, components, sub assemblies, major assemblies and end products produced at every stage and at any given review date. It indicates the quantity of goods or services that should have been completed at every production stage or processing step and at any given time, so as to meet the delivery date for the end product.

The LOB technique shows the desired progress as well as the actual progress achieved on the LOB chart. The LOB technique can be best explained with an example as below:

Illustration 13:

XYZ Company has received customer orders to deliver a product for which the operations program and the delivery schedules are given below :

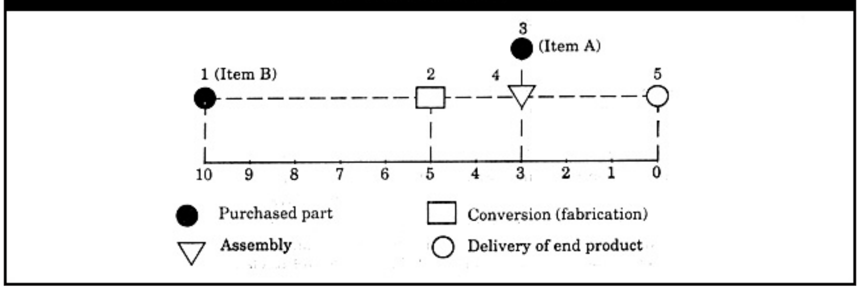
Delivery Schedule

Develop a LOB chart and determine the quantities that should have passed through the upstream processing step/stages during the review point at the end of 2nd week.

Table 2.8.14

Week No.	Qty. of end product to be delivered
1	5
2	10
3	10
4	10
5	15

Exhibit 2.8.9 : Operations Programme



Solution :

Method : The five stages required to be followed in LOB technique are

1. Preparation of operation programme or assembly chart,
2. Preparation of cumulative completion / delivery schedule or objective chart.
3. Construction of LOB chart
4. Construction of program progress chart
5. Analysis of progress and corrective action.

These stages are illustrated below:

Stage 1 : Preparation of operation programme or assembly chart:

The operation programme or assembly chart shows the 'lead time' for each operation stage/processing step. The 'lead time' is the length of time prior to the completion of the final operation/processing step by which intermediate operations must be completed.

Exhibit 2.8.10 illustrates an operation programme chart or assembly chart:

The delivery date for the finished product (end item) is zero and the time scale indicating 'lead time' runs from right to left. The operation programme chart indicates that purchased part A must be combined with item B in operation stage/processing step 4 three days before completion of end item.

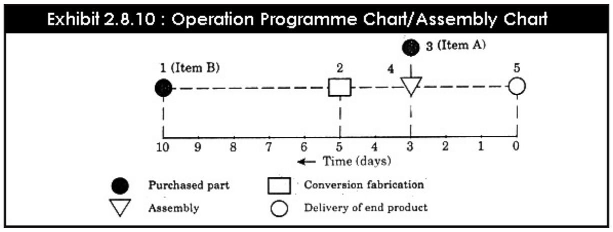


Exhibit 2.8.10 : Operation Programme Chart/Assembly Chart

Item B, prior to combination has undergone a conversion operation which has to be completed five days before the completion of end item. The purchased part for item B must be available 10 days prior to the delivery date for end item which means the longest lead time is 10 days.

Stage 2 : Preparation of completion schedule (cumulative) or objective chart.
The quantities of end item to be completed week by week and cumulatively are indicated in the cumulative completion schedule and shown in **Table 2.8.15** below:

Table 2.8.15: Cumulative Completion Schedule

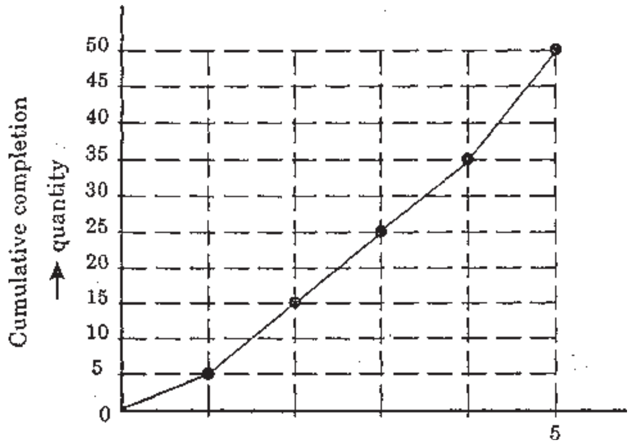
Week No.	Qty. of end item to be completed	Cumulative quantity to be completed
1	5 nos.	5 nos.
2	10 nos.	15 nos.
3	10 nos.	25 nos.
4	10 nos.	35 nos.
5	15 nos.	50 nos.

The cumulative completion schedule is shown graphically in the objective chart in **Exhibit 2.8.11** below:

Stage 3 : Construction of line of balance chart:

The line of balance shows the quantity of item that should have been completed at each operation stage/processing step in a particular week at which progress will be reviewed so as to meet the delivery schedule for the finished product and to meet the completion schedule quantities cumulatively.

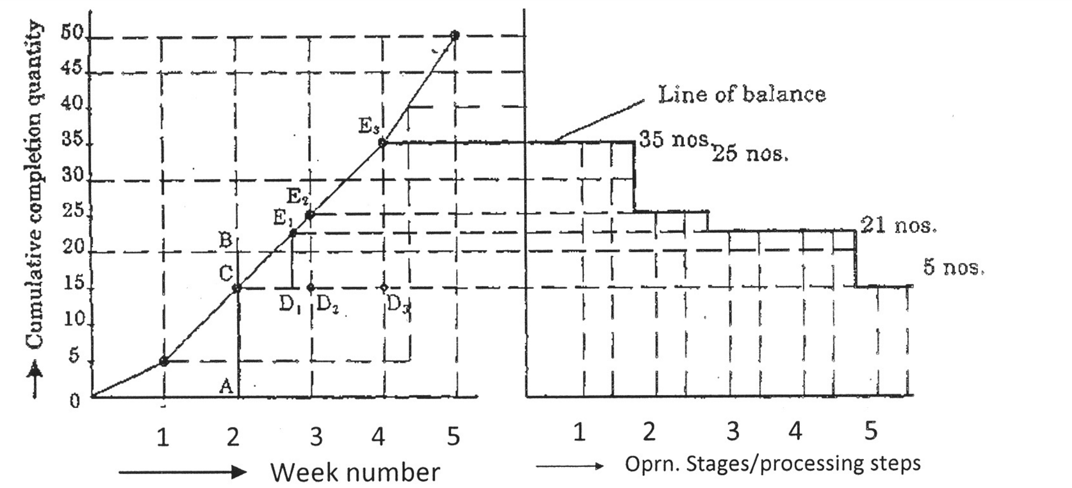
Exhibit 2.8.11 : Cumulative Completion Schedule Graph or Objective Chart



The line of balance chart can be constructed graphically as illustrated below: The following step are required to construct the line of balance chart graphically.

Step (a) : Draw the cumulative completion schedule graph as shown in **Exhibit 2.8.12(a)**

Exhibit 2.8.12(a) : Cumulative Completions Schedule **Exhibit 2.8.12(b) : Line of Balancing Schedule**



Step (b): Draw a vertical line AB on the-cumulative completion schedule graph at the week at which the review is to take place (say 2nd week in this example)

Step (c) : Draw the line of balance schedule on the right hand side of the cumulative completion schedule graph [ref. **Exhibit 2.8.12(b)**]. Show by means of vertical bars, the 5 operation stages on the LOB schedule and indicate the quantities of the item that should have been passed through the operation stages/ processing steps 1 to 5, by means of height of the vertical bars for each operation stage/processing step. In this example, it is done as below: Let line A B cut the cumulative completion schedule graph at point 'C. From 'C' draw a horizontal line upto the vertical bar at operation stage/processing step 5. The height of the vertical bar indicates the quantity of the item that should have been completed at operation stage No.5 (i.e., completion of end product). In this example this quantity of end product that should have been completed by the end of week number two is 15 nos. :

Step (d): For each of the other operation stages/processing step (i.e., operation stages 1 to 4) find out how many should have been completed at the end of week No.2. This will be the total of not only the requirements for the completed end item by the two-week review date but also the quantity to be completed in the lead time for that operation. This is determined graphically as follows:

Draw a horizontal, line C, D, from the line AB, such that length C, D, indicates the lead time (i.e., 3 days) for operation stages 4 & 3. From D, draw a vertical line to cut the cumulative completion, schedule graph at E_1. Draw a horizontal line from E, extending it upto the vertical bars drawn at operation stage No.4 and 3 (note both operations 4 & 3 have the same lead time of 3 days). The height of the vertical bars at operation stages 4 & 3 indicate the quantities of the item that should have passed through these two stages. In this example it is 21 nos. (Analytically calculated as 15 + (3/5) x 10 - 15 + 6 - 21 Nos.)

Similarly, for operation stages no.2, draw a horizontal line CD_2 such that the length CD_2 indicates a lead time of 5 days (or one week assuming 5 days working per week). Draw a vertical line D_2 E_2 to cut the cumulative completion graph at E_2. Draw a horizontal line from E_2 upto the vertical bar drawn at operation stage 2 on the line of balance schedule. The height of this vertical bar indicates the quantity of the item that should have been completed at operation stage 2 at the 2nd review week, (in this case quantity is 25 nos.)

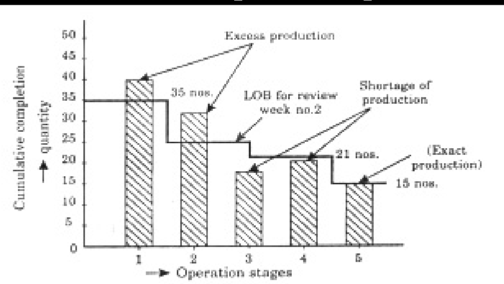
For operation stage No.1, draw a horizontal; line CD_3 such that the length CD_3 indicates the lead time for operation stage No. 1 (in this Example it is 10 days or 2 weeks). Draw a vertical line D_3E_3 to cut the cumulative completion graph at E_3. Draw a horizontal line from E upto the vertical bar dream at operation stage No.1 on the LOB schedule/The height of the vertical bar indicates the quantity of the item that should have been completed at operation stage no.1 (in this case the quantity is 35 i.e., 35 nos. of purchased part B should have been received by the end of 2nd review week).

Step (e): Draw the line of balance (a stair case step like line) by joining the tops of the vertical bars for each operation stage.

Stage 4 : Construction of program progress chart:
The program progress chart for the review week (week No.2 in this example) is shown in **Exhibit 2.8.10.** In this graph, the actual numbers of items produced at each operation stage against the quantities that should have been produced as indicated by line by balance are shown on the LOB chart. This chart indicates clearly the excess or shortage quantities of the item at the operation stages which is illustrated in the Exhibit 2.8.9. The actual quantities are shown by hatched vertical bars.

Stage 5 : Analysis of progress and corrective action.

Exhibit 2.8.13 : Programme Progress Chart



By referring to the programme process chart which is prepared every week the difference between the desired production (as indicated by line of balance) for the. review week (week no. 2 in this example) can be compared with the actual production achieved at the end of the review week (shown by height of hatched vertical bars for each operation stage). The excess production or short fall in production can be found out and appropriate corrective action such as expediting delivery of bought-out item (item B) or production of in-house made items or reducing the production to bring it in line with the line of balance.

Benefits of LOB Technique

1. LOB is a simple planning and control technique which like network analysis formalizes and enforces planning discipline and enables control to be exercised at each stage of the production line.
2. LOB prevents any feeling of false security which might be engendered if the delivery of an item is on schedule but unappreciated shortfalls at early stages are building up trouble.
3. LOB enables identification of short falls or even excessive production or purchasing levels, so that corrective action can; be taken in good time.
4. LOB achieves its greatest benefits when products or services are produced to specific delivery schedules production involves1 many processing steps and production lead times are long.

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.

Sfep 2 : Estimate the task time (amount of time it takes a worker 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 were being produced.)

Sfep 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

$$\left.\begin{array}{r}\text{Ideal or theoretical}\\ \text{minimum no. of workers}\\ \text{required in the assy.}\\ \text{line/production line}\end{array}\right\} = \frac{\begin{pmatrix}\text{Total operation}\\ \text{or task time}\end{pmatrix} \times \begin{pmatrix}\text{Output units}\\ \text{required per period}\end{pmatrix}}{\text{Available time per period per worker}}$$

$$N = \sum t \times \left(\frac{1}{CT}\right) = \frac{\sum t}{CT}$$

Balancing Efficiency : An efficient line balancing will minimize the amount of idle time. The balance efficiency can be calculated as:

(i) $$E_{ffB} = \frac{\text{Output of task time}}{\text{Input by workstation times}} = \frac{\sum t}{CT \times N}$$

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

(ii) $$E_{ffB} = \frac{\text{Theoretical minimum number fo workers}}{\text{Actual number of workers}}$$

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 (one hour) 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 :

$$N_t = \frac{\text{Sum of all task time } (\sum t)}{\text{Cycle time (CT)}}$$

$$\text{Cycle time} = \frac{\text{Available time}}{\text{Output required}}$$

(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

$$\text{Utilisation or Balance efficiency} = \frac{\text{Minimum no. of workstations}}{\text{Actual no. of workstations}} \times 100 = \frac{\sum t}{CT \times N}$$

Line Balancing Procedure

Steps :

1. Calculate the cycle time and determine the theoretical minimum number of workstations

$$N_t = \frac{\sum t}{CT} = \frac{\text{Sum of all task time}}{\text{Cycle time}}$$

$$\text{Cycle time (CT)} = \frac{\text{Available time}}{\text{Output required}}$$

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 14:

Table shows the time remaining (number of days until due date) and the work remaining (number of day's 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 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 B E C A D

(3) (6) (7) (8) (9)

(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 work remaining)

Job	Slack	(Days)
A	8-7	= 1
B	3-4	= (-1)
C	7-5	= 2
D	9-2	= 7
E	6-6	= 0

Sequence : B E A C D

-1 0 1 2 7

(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.

Sequence :

D	B	C	E	A
2	4	5	6	7

(e) LPT (Longest Processing time job first) also referred to as LOT (Longest operation time job first) rule.

Sequence :

A	E	C	B	D
7	6	5	4	2

Illustration 15:

The following jobs have to be shipped a week from now (weak has 5 working days)

Job	A	B	C	D	E	F
Number of day's 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 clue date is 5 days for all jobs

Job	Slack	(days)
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 :

C	D	E	B	F	A
-2	-1	0	1	2	3

(b) Calculation of Critical ratio :

$$\text{Critical ratio} = \frac{\text{Due Date-Date Now}}{\text{Lead Time Remaining}} = \frac{DD-DN}{LTR} = \frac{\text{Available time}}{\text{Operation time}}$$

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

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.

Sequencing

Sequencing problems arise when we are concerned with situations where there is a choice as to the order in which a number of tasks can be performed. In such cases, the effectiveness is a function of the order or sequence in which the tasks are performed. A sequencing problem could involve jobs in a manufacturing plant, aircraft waiting for landing and clearance, maintenance scheduling in a factory, programmes to be run on a computer center, customers in a bank, and so forth.

The sequencing problems to get solved, since most of the tasks are performed, the aircraft do land and the customers transact business. However, most of these problems are solved casually or automatically without an explicit recognition that a problem even existed, much less than that a solution was obtained. Sometimes an ordering is determined by chance. more often the tasks are performed in the order in which they arise. A common basis evolved out of a sense of fair play is the first come first served' basis of solution of sequencing problems. This basis may be appropriate for customers in a hank, but it may not necessarily be applied to inanimate jobs on a factory floor.

We shall consider the sequencing problems in respect of the jobs to be performed in a factory and study the method of their solution. Such sequencing problems can he broadly divided in two groups. In the first one, there are n jobs to be done, each of which requires processing of some or all of the k different machines. We can determine the effectiveness of each of the sequences that are technologically feasible (that is to say, those satisfying the restrictions on the order in which each job must be processed through the machines) and choose a sequence which optimizes the effectiveness. To illustrate, the timings of processing of each of the n jobs on each of the k machines, in a certain given order, may be given and the time for performing the jobs may be the measure of effectiveness. We shall select that sequence(s) for which the total time taken in processing all the jobs on the machines would be the minimum.

The second type of sequencing problems deal with the situations where we have a system with a certain number of machines and a list of jobs to be done. and every time that a machine completes a job on which it is engaged, we have to decide on the next job to be starred.

Our concern in the present chapter is with the first type of problems.

The following is a typical sequencing problem. A company has to complete ten jobs in one week. The jobs must be processed on three different machines M_1, M_2 and M_3. They are all processed first on machine M_1. then on M_2, and finally on M_3. The production hours, including processing, set-up and movement time, required for each job on each machine are given in following table:

	Production	**Time (in hrs)**	
Job			
1	2	5	4
2	6	8	2
3	7	6	4
4	3	7	2
5	5	4	4
6	2	1	8
7	6	3	2
8	5	5	5
9	4	3	3
10	2	8	1

The objective is to determine the sequence of jobs which will allow all jobs to he performed so that the time, from the beginning of the first job till the completion of the last job, is the minimum. Of course, there may be more than one such sequence in a given ease. The answer to the sequencing problem would also indicate to the management information like which of the machine(s) would, if at all, be idle and for how long, whether the work on all the jobs can be done in the given week without overtime, and if not, which jobs will need overtime work.

In particular, we shall consider the following types of sequencing problems,

- Processing n jobs on two machines
- Processing n jobs on three machines
- Processing n jobs on k machines
- Processing 2 jobs on k machines

The Assumptions

There are some general assumptions made to solve the sequencing problems. These are given here:

(a) The processing times on various machines are independent of the order in which different jobs are processed on them.

(b) The time taken by different jobs in going from one machine to another is negligible.

(c) A job once started on a machine would be performed to the point of completion uninterrupted.

(d) A machine cannot process more Than one job at a given point of time.

(e) A job would start on a machine as soon as the job and the machine on which it is to be processed are both free.

Solving the Sequencing Problems

Sequencing problems can be solved using the Gantt Chart and by applying an algorithm. First, we shall consider the Gantt Charts which are used for handling relatively simpler problems involving two machines.

Gantt charts We shall illustrate the use of the Gantt Charts with the help of the following examples.

Example: Suppose that there are two jobs J_1 and J_2, each requiring work on two machines M_1 and M_2, in this order, with the required processing limes given as follows:-

Processing Time (Hours)

Job	Machine	
	M_1	M_2
J_1	4	10
J_2	8	7

What order of performance of the jobs will involve the least time?

For processing the two jobs, two orders are possible J_1-J_2 and $J_2 – J_1$. Both the alternatives are evaluated in **Figure 2.8.7**. The first part of the figure depicts the job sequence J_1--J_2. According to this sequence, the two jobs can be completed in 21 hours. The other sequence J_2-J_1, is shown in the second part wherein it is clear that the two jobs would take 25 hours to finish.

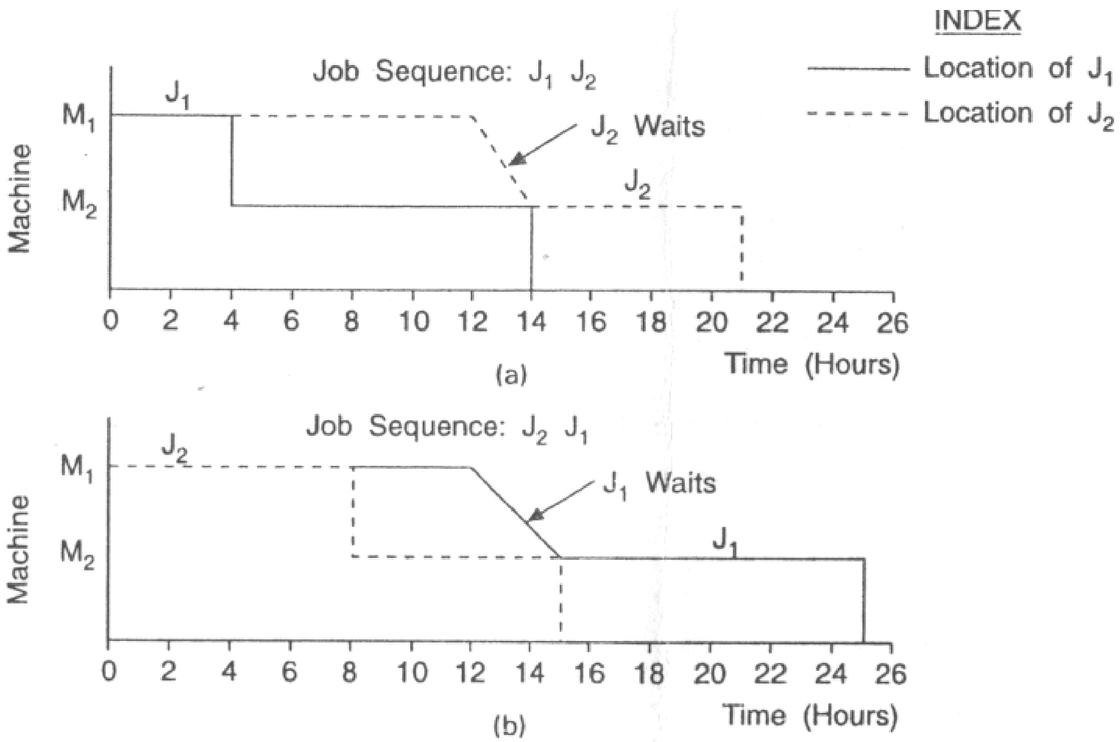


Fig. 2.8.7 Gantt Chart

Clearly then, the job sequence J_1-J_2 is optimal, since the total elapsed time, T, is the lower of the two.

Illustration 16:

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 2.8.16: Calculation of Total Elapsed Time (T)

<u>Job</u>	<u>Machine A</u>		<u>Machine B</u>	
	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.

Maintenance Crew Scheduling

The method of solving sequencing problems relating to the scheduling of jobs in a factory can be extended to scheduling the factory maintenance crews in such a way as to minimise their idle time. Suppose that a company has a set of different machines in its plant that need preventive maintenance. The team is divided into two groups A and B. First, crew A takes the machine and replaces the parts according to the needs. Then crew B resets the machine and puts it back into operation. If the service times of both the groups on the different machines are known, we can determine the sequence in which the maintenance jobs be done so that the idle time of the crews is the least.

The rules, like for sequencing problems given earlier, when the service tunes are given in the columnar form, are as follows:

(a) Choose the smallest of all values that appear in the two columns.

(b) If the value is in the first column, then that machine in respect of which the value. is, shall be serviced by crew A in the beginning.

(c) If it is in the second column, then that machine will be serviced by crew A in the end.

(d) If there is a tie in the same column, either of the machines involved is selected and assigned the first, or the last, place accordingly as the tie is in the first or the second column.

(e) After making the assignment, cross out the machine involved.

(f) Continue in the manner of the steps (a) to (c) until all assignments are made.

The resulting sequence shall ensure minimisation of the idle time of maintenance crew.

Illustration 17:

The maintenance crew of a company is divided in two groups, C_1 and C_2, which cares for the maintenance of the machines. Crew C_1 is responsible for replacement of parts which are worn out while crew C_2 oils and resets the machines hack for operation. The times required by crews C_1 and C_2 on different machines which need working on them are given as follows:

Machine	Maintenance Time (Hrs.)	
	Crew C_1	Crew C_2
M_1	8	5
M_2	6	3
M_3	10	7
M_4	11	12
M_5	10	8
M_6	14	6
M_7	4	7

In what order should the machines be handled by crews C_1 and C_2 so that the total time taken is minimised?

Solution:

In accordance with the rules given earlier, the order in which machines should be handled is as follows:

M_7 M_4 M_5 M_3 M_6 M_1 M_2

The total elapsed time is obtained in **Table 2.8.17**.

Table 2.8.17: Determination of Table Elapsed Time

Machine	Crew C_1		Crew C_2	
	Start	Finish	Start	Finish
M_7	0	4	4	11
M_4	4	15	15	27
M_5	15	25	27	35
M_3	25	35	35	42
M_6	35	49	49	55
M_1	49	57	57	62
M_2	57	63	63	66

The total time required by the maintenance crew to handle the seven machines is 66 hours. The working *and the* idle hours *of the crews* C_1 and C_2 *are shown in* **Figure 2.8.8**.

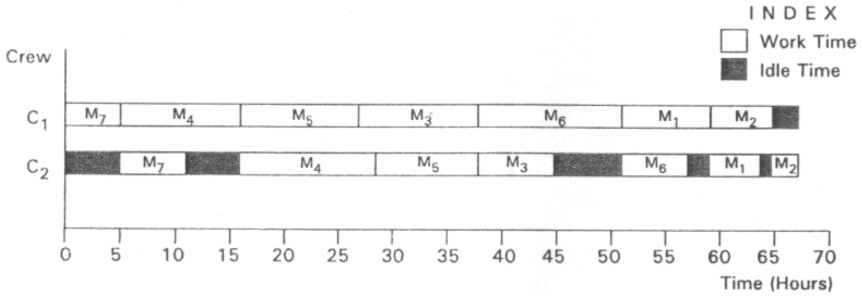


Fig. 2.8.8: Gantt Chart Showing Working of Crew

Illustration 18:

A company plans to fill six positions. Since the positions are known to vary considerably with respect to skill and responsibility, different types of aptitude tests and interviews are required for each. While the aptitude tests are conducted by people from the clerical positions, the lob interviews are held by the personnel from the management cadre. The job interviews immediately follow the aptitude test. The time required (in minutes) by each of the positions is given here,

Position	P_1	P_2	P_3	P_4	P_5	P_6
Aptitude Test	140	180	150	200	170	100
Job Interview	70	120	110	80	100	90

If it is desired to minimise the waiting time of the management personnel, in what order the position filling be handled?

Solution:

From the given information, the optimal sequence can he determined using the algorithm. This would be P_2, P_3. P_5, P_6. P_4 and P_1. The total elapsed time *T is* equal to 1010 minutes, *as* shown calculated in **Table 2.8.18**, while the idle time for the management personnel would be: 180 + 30 + 60 + 110 + 60 = 440 minutes.

Table 2.8.18: Calculation of Total Elapsed Time T

Position	Aptitude Test		Job Interview	
	Start	Finish	Start	Finish
P_2	0	180	180	300
P_3	180	330	330	440
P_5	330	500	500	600
P_6	500	600	600	690
P_4	600	800	800	880
P_1	800	940	940	1010

Illustration 19:

A firm works 40 hours *a week* and has *a* capacity *of* overtime work to *the extern of* 20 hours in a week. It has received seven orders to be processed on three machines A, B, and C, in the order A, B, C to be delivered in a week's time from now. The process times (in hours) are recorded in the given table:-

Job	:	1	2	3	4	5	6	7
Machine A	:	7	8	6	6	7	8	5
Machine B	:	2	2	1	3	3	2	4
Machine C	:	6	5	4	4	2	1	5

The manager, who, in fairness, insists on performing the jobs in the sequence in which they are received, is refusing to accept an eighth order, which requires 7, 2, and 5 hours respectively on A, B and C machines, because, according to him, the eight jobs would require a total of 61 hours for processing, which exceeds the firm's capacity. Advise him.

Solution:

The processing of 8 jobs according to the manager's plan will indeed take 6t hours. It needs to be examined, however, if this plan is optimal.

To obtain the optimal sequence, first the timings of the processing of all the eight jobs would be tabulated as given in **Table 2.8.19**.

Table 2.8.19: Processing Time (Hours)

Job	Machine *A*	Machine *B*	Machine C
1	7	2	6
2	8	2	5
3	6	1	4
4	6	3	4
5	7	3	2
6	8	2	1
7	5	4	5
8	7	2	5

From the table,

Min A_j = 5, Max B_i = 4, and Min C_i = 1

Since Min A_i > Max B_i, the first of the conditions laid previously is satisfied. We proceed now to make the consolidation table, as shown in **Table 2.8.20**.

Table 2.8.20: Consolidation Table

Job	$G_i = A_i + B_i$	$H_i = B_i + C_i$
1	9	8
2	10	7
3	7	5
4	9	7
5	10	5
6	10	3
7	9	9
8	9	7

According to this, several optimal sequences are possible, of which one is as follows :

7, 1, 8, 4, 2, 5, 3, 6.

The total elapsed time T can be obtained as shown in the **Table 2.8.21**. It equals 57 hours. Thus, the jobs can be processed within the given capacity level.

Table 2.8.21: Determination of Total Elapsed Time, T

Job	Machine *A*		Machine *B*		Machine *C*	
	Start	Finish	Start	Finish	Start	Finish
7	0	5	5	9	9	14
1	5	12	12	14	14	20
8	12	19	19	21	21	26
4	19	25	25	28	28	32
2	25	33	33	35	35	40
5	33	40	40	43	43	45
3	40	46	46	47	47	51
6	46	54	54	56	56	57

2.9 HUMAN RESOURCE PLANNING & OPTIMIZATION

Objective

- To understand the concept and nature of human resource planning;
- To understand the process involved in human resource planning;
- To make the forecast of human resource needs and their availability in the organisation in the future.
- To understand the time dimension of human resource plans;
- To identify the barriers to effective human resource planning; and
- To adopt measures to overcome these;

Concept of Human Resource Planning

In order to understand the concept and features of HRP, let us consider the following statement:

"Although human resource planning means different things to different people, general agreement exists on its ultimate objectives—the most effective use of scarce talent in the interests of the labour and the organisation."

This statement reflects that there is lack of agreement on the contents of HRP. This happens because there is lack of complete unanimity over various terms in management including HRM as this is yet to achieve the status of science where various terms have universal meaning. Therefore, in order to conceptualise HRP, let us go through some definitions.

On the basis of the review of various definitions of HRP, Geisler has emphasized that a suitable definition of HRP should include four aspects – forecasting manpower needs, developing appropriate policies and programmes for meeting those needs, implementing policies and programmes. Based on these aspects, he has defined HRP as follows :

"Human Resource Planning (HRP) is the process – including forecasting, developing, implementing, and controlling – by which a firm ensures that it has the right number of people and right kind of people doing things for which they are economically most suitable'.

This definition of HRP serves the purpose adequately and most of the definitions are based on this. For example, Decenzo and Robbins have defined HRP as follows:

"Specifically, human resource planning is the process by which an organisation ensures the right place, at the right time, capable of effectively completing those tasks that will help the organization achieve its overall objectives,"

Similarly, Leap and Crino have defined HRP as follows:

"Human resource planning includes the estimation of how many qualified people are necessary to carry out the assigned activities, how many people will be available, and what, if anything, must be done to ensure that personnel supply equals personnel demand at the appropriate point in the future"

Based on the above Definitions, following Features of HRP may be Identified

1. HRP is a process which includes various aspects through which an organization tries to ensure that right people, at right place, and at right time are available.
2. It involves determination of future needs of manpower in the light of organizational planning and structure. Therefore, it depends heavily on these factors. Determination of manpower needs in advance facilitates management to take up necessary actions.
3. It also takes into account the manpower availablility at a future period in the organization. Therefore it indicates what actions can be taken to make existing manpower suitable for future managerial positions and the gap between needed and available manpower can be fulfilled.

Importance of Human Resource Planning

HRP is of primacy nature and therefore, it precedes all other HRM functions. Without HRP, no other functions can be undertaken in any meaningful way. HRP translates the organizational objectives and plans into the number and kind of personnel needed to achieve those objectives. Without a clear-cut planning estimation of the organisation's human resource need is reduced to mere guesswork. In particular, HRP contributes in the following ways in managing human resources in an organization.

1. **Defining future personnel need:** Planning defines future personnel need and this becomes the basis of recruiting and developing personnel. In its absence, there is likelihood of mismatch between personnel needed and personnel available. Lack of systematic HRP has resulted into large scale overstaffing in many public sector organizations . For example, in Steel Authority of India Limited, there are170,000 employees and McKinsey & Company, consultancy firm engaged by SAIL to devise its revival strategy, has suggested pruning of this level to bring it to 100,000.Similar problem exists in many other organisations. This type of problem exists in many private-sector organisations and they have gone for voluntary retirement scheme offering huge compensation. This has happened because of lack of systematic HRP.Lack of systematic HRP has created another type of problem. Many public-sector enterprises have remained top-less for a considerable period of time, prominent ones being Gas Authority of India (27 months), National Hydroelectric Power Corporation (18 months), State Farms Corporation (17 months), and so on. This is all because of faulty or no HRP. Occurrence of such phenomena can be avoided by proper HRP.

2. **Coping with Changes:** In the Indian and international business scenes, fast changes are taking place. In the Indian context, such changes have been brought by liberalisation of economy. At the international level, there is growing global competition because of the freedom in international trade initiated by World Trade Organisation . Every organisation is trying to compete on the basis of technology and managerial talents which have resulted into global talent war. In this war, only those companies will survive which adopt a formal, meticulous HRP. Change in technology has attached more premium to knowledge and skills resulting into surplus manpower in some areas and shortage in other areas. HRP helps in creating a balance in such a situation as through this, manpower needs and availability can be identified much in advance.

3. **Providing Base for Developing Talents:** Jobs are becoming more and more knowledge-oriented. This has resulted into changed profile of manpower. For example, in Larsen and Toubro, MBAs, engineers, and technicians constitute about 70 per cent of its total employee strength of 20,000. Because of increasing emphasis on knowledge, there is shortage of certain category of personnel and there are frequent movements of personnel from one organisation to another. The replacement cost of such personnel is estimated to be 1.5 times of the expenses incurred on these personnel. Therefore, an organisation must be ready to face such an eventuality by taking proper HRP.

4. **Increasing Investment in Human Resources:** The cost of acquiring, developing and retaining personnel is increasing much faster than the average rate of inflation. Cost of acquiring MBAs from reputed institutes is increasing by more than 20-25 percent per annum. This increasing cost can be taken care of by proper HRP which provides the way for effective utilization of such talents. In fact, such a high cost has forced many companies to have a relook at their HRM functions and particularly HRP and to align these with new situations.

5. **Forcing Top Management to involve in HRM.** Systematic HRP forces top management of an organization to participate actively in total HRM functions, an area that has been neglected by most of the companies until recently. As we shall see shortly, if there is active involvement of top management in the preparation of human resource plans, it is expected to appreciate the real value of human resources in achieving organizational effectiveness.

Responsibility for Human Resource Planning

Formulation of human resource plan is a shared task between top management, line managers and HR department. Top management is involved in HRP process because ultimately, it approves various plans of the organization as a whole. Two types of plans are more seriously discussed at the level of Board of Directors of a company: one is financial plan including investment decisions and another is human resource plan particularly involving higher level managers. Thus top management shares the responsibility of approving human resource plans and creating climate for undertaking systematic HRP.

The second group of personnel involved in HRP process is the functional managers under whom people work. Though these managers do not prepare overall human resource plans, ultimately, they are responsible for the effective utilization of human resources and , therefore, they must know what kind of personnel they need. HR department undertakes coordinative functions and various procedural activities which ultimately results into HR plan. In this context, Pareek has observed as follows:

"It is the top managements responsibility to project share vision and short-term goals. The projected vision and plans are then translated into human resource requirements for their respective departments by the line managers. Detailed analysis of required competencies in terms of levels and numbers are developed by personnel department."

The responsibilities of HR department in regard to HRP process have been described by Geisler as follows:

1. To assist, counsel, and pressurise the operating management to plan and establish objectives;
2. To collect and summarise data in total organisational terms and to ensure consistency with long-term objectives and other elements of the total business plan;
3. To monitor and measure performance against the plan and keep the top management informed about it; and
4. To provide research necessary for effective manpower and organisational planning.

Human Resource Planning Process

HRP is a process and it proceeds through various interrelated activities. For example. National Industrial Conference Board, USA, has viewed that manpower planning could be seen as a series of activities consisting of the followings:

1. Forecasting future manpower requirements, either in terms of mathematical projections of trends in the economy and developments in the industry, or of judgemental estimates based upon specific future plans of the company;
2. Inventorying present manpower resources and analysing the degree to which these resources are employed optimally;
3. Anticipating manpower problems by projecting present resources into the future and comparing them with the forecast of the requirements, to determine their adequacy, both quantitatively and qualitatively; and
4. Planning the necessary programmes of recruitment, selection, training, deployment, utilisation, transfer, promotion, development, motivation and compensation so that future manpower requirements will be met.

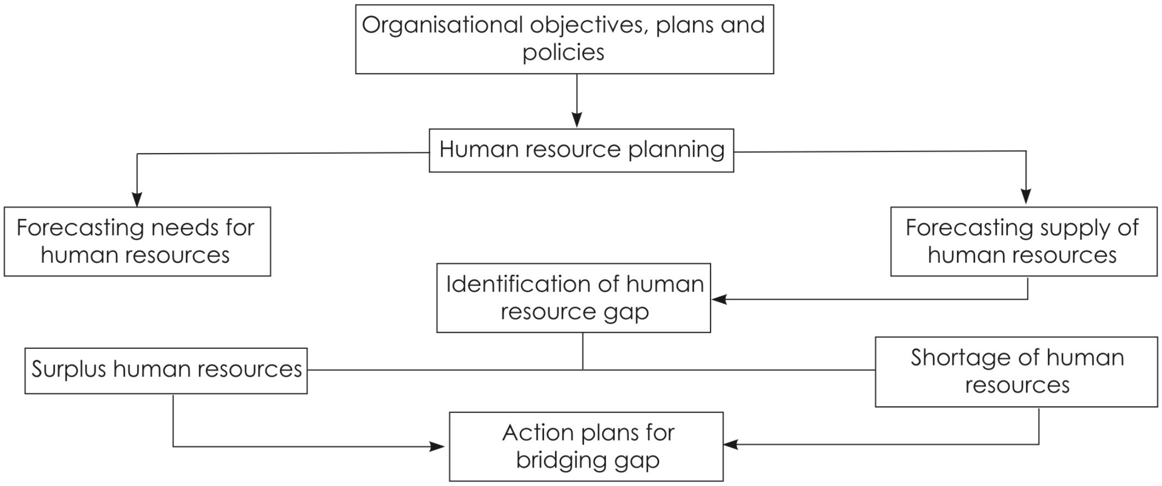


Fig. 2.9.1: Human Resource Planning Process

Let us discuss various steps of HRP in brief to understand their interrelationships which will be followed by the detailed discussion of various ingredients of HRP.

1. **Organisational Objectives, Plans and Policies:** The starting point of any activity in an organization is its objectives which generate various plans and policies which provide direction for future course of action. Out of this direction, various subsystems of the organization devise their own plans and programmes. Thus, each subsystem's plans and programmes are linked to organizational plans and policies. To the extent this linkage is not proper, subsystem's contribution to the achievement of organizational objectives is adversely affected. This is true with HRP too. While going through the process of HRP, therefore, organizational policies with regard to effective utilization of human resources should be identified and incorporated in planning process. Specifically, following questions are important in this regard:

    - Are vacancies to be filled by promotions from within or by hiring from outside?
    - How do the training and development objectives interface with the HRP objectives?
    - What union constraints are encountered in HRP and what policies are needed to handle these constraints?
    - How to downsize the organization to make it more competitive?
    - To what extent production and operations be automated and what can be done about those displaced?
    - How to ensure continuous availability of adaptive and flexible workforce?

2. **Human Resource Planning:**Taking direction from organisational objectives and plans and the above policy considerations, human resource plan is prepared. The planning process consists of two major activities: forecasting needs of human resources and forecasting supply of human resources. Both these types of forecasting aim at finding out the additional requirement of personnel both in terms of quantity and quality at a future date.

3. **Identification of Human Resource Gap:** Forecasting needs for human resources and forecasting supply of human resources, both taken together, help to identify gap between human resources needed and their availability. This gap may be in two forms either there may be surplus human resources or there may be shortage of human resources.

4. **Action Plans:**Various action plans are devised to bridge the human resource gap. If there is surplus of human resources either because of improper HRP in the past or because of change in organisational plan, such as divestment of business or closing down some businesses because of various reasons, action plans may be devised to prune their size through layoff, voluntary retirement etc. If there is shortage of human resources, action plans may be devised to recruit additional personnel.

    Thus, the major ingredients of HRP process are forecasting needs for human resources, forecasting supply of human resources, and identification of human resource gap. This is the last the aspect of HRP process, then it becomes the base for developing various action plans.

Forecasting needs for Human Resources

The first essential ingredient of HRP is the forecasting needs for human resources in an organisation over a period of time. In one way, we can say that it depends on the scale of operations of the organisation over that period of time. To some extent it is true. However, total human resource needs do not have complete linear relationship with volume of operation. This happens because there are factors which affect this relationship such as change in machine-man relation, change in productivity, etc. For example look at the figures of sales and number of employees in Reliance Industries over a period of time as given in Table 2.9.1

Table 2.9.1: Sales and number of employees in Reliance Industries

	Years ended March 31				
	1999	**1997**	**1995**	**1992**	**1985**
Sales (₹ in crore)	14,533	8,730	7,019	2,953	733
Employees (Number)	16,640	16,778	12,560	11,940	9,066

The Table shows that volume of operation has increased at faster rate than the number of employees. Therefore, in making forecast for human resource requirements, all those factors which have impact on the relationship between volume of operation nad number of employees must be taken into consideration. Though this makes HRP exercise quite cumbersome, this provides clear answer to the critical question 'how many persons will be required in future?' While volume of operation of the organization is available from its plan documents. HR department has to make a forecast for the requirement of human resources based on those documents. Forecasting of human resource requirements serves the following purposes:

1. To quantify the jobs necessary for producing a given number of goods or offering a given amount of service;
2. To determine what staff-mix is desirable in the future;
3. To assess appropriate staffing levels in different parts of the organization so as to avoid unnecessary cost;
4. To prevent shortage of people where and when they are needed most; and
5. To monitor compliance with legal requirements with regard to reservation of jobs.

Techniques for forecasting Human Resource needs

In business and economics,various forecasting techniques, ranging from subjective judgemental methods to sophisticated multi-variate analysis and models, are used for different purposes. These techniques have their own contributions and limitations.However,in the case of forecasting human resources needs in an organisation, there is less emphasis on highly quantitative techniques because of emphasis on qualitative aspect of forecasting. Usually, a combination of the following techniques is used:

1. Managerial judgement method
2. Delphi technique
3. Work-study technique
4. Ratio-trend analysis
5. Statistical and mathematical model

Managerial Judgement Method: This is the most commonly practiced and conventional method of forecasting human resource needs. In this method managers prepare the forecast of human resource needs of various categories for their own departments based on their past experiences. This method can be applied in two alternative ways: top-down approach or bottom-up approach. In top-down approach, top management prepares human resource plan for the organisation as a whole with the assistance of HR department. This plan is circulated among various departments with an advice to make necessary amendments wherever required with justifications. After receiving the document from various departments, human resource needs of various departments are finalised usually in a committee meeting of departmental heads. In the bottom-up approach, top management provides broad guidelines for the organisation's plans which are sent to all departmental heads with an advice to prepare their own plan for human resource needs. These plans are reviewed and consolidated by HR department and it prepares a comprehensive human resource need plan for the approval by the appropriate authority. This method is very simple in preparation of forecast of human resource needs. However, if suffers from one basic drawback that most of the forecasts are based on past-practice and, therefore, there is a likelihood that previous figures with some pluses and minuses may be submitted as human resource plan.

Delphi Technique: Named after the ancient Greek oracle at the city of Delphi-where Greeks used to pray for information about the future, Delphi technique is used in group decision making in the present world. In a conventional Delphi technique, a small group designs questionnaire about the problem under study which is sent to various experts related to the field. These experts fill up the questionnaire independently without having any interaction among themselves. The filled-up questionnaires are analysed by the designer, and if there is divergence in opinions of experts, a revised questionnaire is prepared and sent to a larger group of experts. This exercise is repeated until some consensus is reached. Delphi technique is quite useful where the problem cannot be solved by using analytical techniques but its solution requires subjective judgements on a collective basis. For example, what will be the trend of fashion next year, can be known by using Delphi technique.

Delphi technique can be used for forecasting human resource needs in two forms. First, it can be used to know the trends for changing job profile and, consequently, the changing personnel profile across the country or international level. Second, this technique can be used to solicit views of experts in different functional areas of an organisation about the changing profile of personnel in their respective departments in the light of changing environment. Such views are collected and summarised by HR department to arrive at a decision about the types of personnel needed in future. Delphi technique is used primarily to assess long-term needs of human resources.

Work Study Technique: Work study technique is based on the volume of operation and work efficiency of personnel. Volume of operation is derived from the organisational plan documents and increase/decrease in operation can be measured from that. Work efficiency or productivity is measured by time and motion study which specifies standard output per unit of time, say per hour. Thus, the number of operatives required to complete specified volume of operation is:

$$\frac{\text{Planned Output}}{\text{Standard output per hour} \times \text{Standards hours per person}}$$

However, standard output per hour is not always a constant factor generally, it increases over the period of time because of learning which may be through trial and error, learning through observing others, and through communication. Thus, the required personnel may be worked out as given in **Table 2.9.2.**

Table 2.9.2: Forecasting of manpower requirement by work study technique

	At constant productivity	**AC increased productivity (10%)**
Standard output per annum	10,00,000	10,00,000
Standard output per hour	5	5.5
Standard hours per person per annum (300 x 8)	2,400	2,400
Number of persons required	83	75

This exercise can be undertaken for various units of the organisation and aggregate manpower requirement can be calculated. However, this technique just indicated the total number of direct operatives that may be required. For supervisory and other staff, separate exercise is required.

Ratio-Trend Analysis. Under this method, the main emphasis is on the ratios between production/sales level and direct operatives; ratios between direct operatives; and other personnel, say supervisory and managerial personnel. These ratios are worked out for a number of years based on the past records of the organisation and future trends are projected on these ratios. Thus, various ratios and their likely trends become the basis for calculating the human resource needs. While the ratios between production and direct operatives will be worked out on the basis of the work study technique as given in Table 2.9.2, ratios between direct operatives and supervisors can be worked out as given in **Table 2.9.3.**

Table 2.9.3: Forecasting needs for supervisors

Year		No. of operatives	No. of Supervisors	Operative supervisor ratio
Actual	3 years ago	1,000	100	10:1
	2 years ago	1,200	120	10:1
	Last year	1,500	125	12:1
	Next year	1,800	150	12:1
	After 2 years	2,000	154	13:1
	After 3 years	2,200	157	14:1

Such ratios can be worked out for various categories of personnel, such as ratio of supervisors and middle-management personnel, ratio of middle-management personnel and higher-level management for a comprehensive forecast of human resource needs.

Statistical and Mathematical Models. Besides the above techniques, there are certain statistical and mathematical models which may be used for forecasting human resource needs. One such model has been given by Burack and Smith known as Burack-Smith model. Similarly, regression analysis and econometric models which have been formulated to forecast business and economic activities in an economic system may also be used for forecasting human resource needs in an organisation. Let us have a brief look at these.

1. Burack-Smith Model: Burack-Smith model for pesonnel forecasting is based on the selected key variables that affect an organisation's overall human resource needs. The basic equation of this model is:

$$E_n = \frac{(Lagg + G)/x}{Y}$$

Where:

E_n= estimated level of human resource needed in n plan period

Lagg = total business activity of n period in terms of value

G = total growth in business activity in n period based on the current prices

x = average productivity improvement in n period over the current period (if x = 1.08, it means average productivity improvement of 8%)

Y = business activity-personnel ratio of the current year (business activity divided by number of personnel).

The main purpose of this model is to calculate E_n, that is the personnel required in future (n period) and for this purpose, Lagg, G, x, and Y variables have to be measured. How to measure these variables has been indicated in various techniques discussed earlier.

2. **Regression Analysis:** Regression analysis identifies the movement of two or more interrelated series. It is used to measure the changes in a variable (dependent variable) as a result of changes in other variables (independent variables).When regression analysis is used in forecasting human resource needs, the dependent variable is human resource needs and independent variables are business activity, human resource productivity, and business activity-personnel ratio. Equation are established between dependent variables and independent variables to forecast human resource needs at a particular time period.

3. **Econometric Model:** The word econometric is made up of two words: 'econo'and 'metric' refering to the science of economic measurement. An econometric item expresses relationships among different variables, both dependent and independent, and based on those relationships, economic growth of an economic system is predicted. A notable feature of an econometric model is that it treats particular variable which is independent at one level, as dependent at the next level. Thus, the amount of variables goes on increasing and establishing relationships among these variables requires various calculations which may not be possible without the use of computers. For example, in calculating the human resource needs, change in human resource productivity has been taken as an independent variable at one stage. However, when we measure change in productivity, as dependent variable and all those factors affecting productivity as independent variables . This process goes on. In the case of forecasting resource needs, an econometric model helps in understanding the nature of relationships among different variables at different levels.

In practice, often, a combination of different methods of forecasting human resource needs is followed. Even where work-study technique is followed to the human resource needs at the operative level, it is not undertaken every year, as the standards fixed in a year serve the purpose for many years. In order to understand how various methods are applied in practice.

Forecasting of Human Resource Supply

Forecasting of human resource supply is another important ingredient of HRP. After forecasting human resource needs, it is logical to determine how these needs can be met. For a new organisation, all personnel that are needed have to be procured from outside. However, in ongoing organisations, there are existing personnel who may be a source of supply to fill those needs. Considering both these sources, Armstrong has defined forecasting of human resource supply as follows:

"Manpower supply forecasting measures the number of people likely to be available from within and outside an organisation, after making allowances for absenteeism, internal movements and promotions, wastage and changes in work hours, and other conditions of work".

However, in this section, we shall focus our attention on internal source of supply of human resources and outside sources of supply will be taken later as there is a fundamental difference between the two sources. While existing personnel will remain available, with some exceptions, in the organisation during the human resource plan period, in order to get people from outside necessitates a separate process of recruitment and selection. In assessing the availability of human resources from internal sources, an organisation has to consider inflow and outflow of personnel during the plan period, and the type of personnel would be available. These can be undertaken by:

1. Human resource flow model
2. Human resource inventory.

Human Resource Flow Model

An organisation can be considered as a system of flows—both inflows and outflows of various resources. Based on this concept , a flow model of human resources has been developed which is known as Markovain analysis models or simply as Markovian model. This can be applied for organisation as a whole or any of its subsystems. The basic assumption of this model is that, in a system, there are inflows and outflows of personnel during a period, in our case, the HR plan period, In this model, the forecast of human resource supply proceeds as follows:

1. Determination of the period in which HR flows are measured;
2. Establishment of categories, or states as called in the model, to which individual can be assigned;
3. Counting of annual flows of individuals among states for several periods; a state may be absorbing (gains/losses) or non-absorbing in position levels;
4. Estimating the probability of transitions from one state to another based on the past trend; personnel supply is equivalent to non-transition.

The above process can be explained by the example given in Table 2.9.4.

Table 2.9.4: Estimation of personnel supply based on flows

Sources of inflows	No. of persons		Sources of outflows	No. of persons
Transfer in	10 →	No. of supervisors at the beginning of plan period 100	→ Resignations	8
			→ Discharges	2
			→ Retirements	3
Promotion in	8 →		→ Promotions	5
			→ Demotions	1
Total inflows	18 →		→ Total outflows	19
Total supervisors available	99			

Similar exercise can be done for other categories of personnel. The aggregate of all categories of personnel is the total supply of personnel at the end of the plan period (which is the beginning of another plan period). The model is based on the past trends and, therefore, it holds good only when those trends continue in future too.

Human Resource Inventory

Inventory is a term which is normally used to counting of tangible objects, raw materials and finished goods, etc. In the same way, inventory of human resources can also be prepared. However, human resource inventory is not simply counting of heads that are presently available but cataloguing their present and future potentials. Since total human resources of an organization are classified as managerial and non-managerial, skills inventory is related to non- managerial personnel and management inventory is related to managerial personnel. Whatever names are used, an inventory catalogues a person’s skills, qualities, and potentials. The process of preparing human resource inventory involves four steps: determination of personnel whose inventory is to be prepared, cataloguing of factual information of each individual, systematic and detailed appraisal of these individuals and detailed study of those individuals who have potential for development. Since non-managerial personnel differ from managerial personnel types of information are required for preparing their inventories may also differ.

Skills Inventory: Usually, in a skills inventory, following types of information are included:

1. Employee’s personal data
2. Skills—education, Job experience, training, etc.,
3. Special achievements, if any,
4. Salary and job history, and
5. Potentials of the employee.

Management Inventory: A management inventory includes following information:

I. Personal data,
2. Work history,
3. Strengths and weaknesses,
4. Career plan,
5. Promotion potentials,
6. Number and types of employees managed,
7. Total budgets managed, and
8. Any special achievements such as acquisition of degrees, papers presented, conferences attended etc.

The information mentioned above is maintained by human resource information systems. However, there should be periodic review and updation of the information. Human resource inventory provides information about present and future personnel being available in the organization. Through this inventory, the existing and future gaps in personnel and their abilities can be identified. Which becomes the basis for suitable managerial actions.

Identification of Human Resource Gap

Human resource gap is the difference between human resources required at a particular point of time and the human resources being available at that particular time. This gap can be identified on the basis of forecasts for human resource needs and supply. This gap should be measured in respect of various types of personnel because mere aggregate quantitative gap would not serve much purpose. This gap may be of two types: surplus human resources and shortage of human resources. Based on the analysis of this gap, action plans must be developed to overcome this gap. Action plans that are required to deal with surplus human resources include separation of such personnel in various ways over the period of times such as voluntary retirement scheme, lay off, reduced work hours, etc., as the case may be and as permitted by legal requirements. Shortage of human resources can be overcome by making additional recruitment and selection, developing personnel, and motivating and integrating them with the organization.

Time Dimension of Human Resource Planning

Planning is the determination of future course of action. However, the question is what future: near or distant future, immediate or remote future, short-term or long-term future. Determination of degree of futurity is important because in two types of future periods, human resource planning activities and their flexibility differ. HR planning period is linked with the overall organisational planning period which is divided into short-term and long-term. Sometimes, intermediate-term is added in between the two. However, this intermediate-term can be included in the above classification. What will be the duration of short or long-term planning period depends on 'principle of commitment' which implies that long-term planning is not really planning for future decisions, rather, planning the future impact of today's decisions. In other words, a decision is commitment of-resources—both physical and human—and this commitment; differs with the time dimension of a plan. Thus, the problems that emerge in managing human resources differ in two dimensions of HRP periods—short-term and long-term.

Short-Term Human Resource Planning

Short-term HRP is derived out of the long-term HRP and attempts to contribute to the achievement of objectives of long-term HRP. In the short-term which may be a year or so, there is no fundamental change in human resources at organisational operations. Whatever the changes take place, these are the results of the characteristics and events of short-term. For example, there may be change in organisation's human resources due to resignation, death, separation, and promotion. Therefore, the basic problem involved in managing human resources in the short-term is the effective utilisation of existing human resources by matching them with existing organisational jobs. Matching jobs and individuals may be taken up for organisation as a whole or at each individual level.

Matching at Organisation Level

In the short-term, an organisation may have mismatch between its human resources and jobs of two types: either it may have surplus manpower or it may have shortage of manpower. In the case of surplus manpower, matching can be achieved by effecting temporary layoff, reducing work hours, and reducing workload. Each of these may be followed in exclusion of others or may be followed in combination. In the case of shortages, the Matching can be achieved by increasing work-hours, overtime work, and hiring temporary personnel. Normally, these problems arise at the level of operatives and various measures to tackle the problems should be taken in consultation with their representatives because there might be resistance from operatives for such measures.

Matching at Individual Level.

At the individual level, mismatching may be of two types: when an individual has lower capabilities than his job requirements or he has more capabilities than his job requirements. In the first case, matching can be achieved by transferring the individual to a less-demanding job, changing the nature of his job by splitting it, or appointing an assistant to help him. In the second case, matching can be achieved by enlarging the scope of the job, or assigning additional job.

Long -Human Resource Planning

In the long-term, which extends upto five years or beyond though most of the Indian organisations opt for a five-year period, an organisation has flexibility of matching its human resources and jobs by taking actions which have long-term impact. For example, surplus human resources can be pruned by offering voluntary retirement scheme, or these can be utilised by expanding the organisational activities. Similarly, shortages of human resources can be met by additional recruitment and selection of personnel and their development there by increasing the availability of personnel both quantitatively and qualitatively. At the individual levels, gaps between individuals and jobs can be bridged by developing the individuals to match the requirements of their jobs or by promoting them to match their capabilities with the jobs.

Having discussed the human resource planning process and its time dimension, let us see how different companies in India follow human resource planning and the aspects on which they emphasise.

Assessment of HR requirements

ITC Limited

ITC follows a simple process for forecasting its HR needs. Each departmental manager at the Head Office is required to submit a chart of the approved structure of his department to staff department by October 1 every year. At the bottom left hand corner of the chart, he is asked to provide a summary of the sanctioned strength, positions occupied, and the particulars of recruitment required for the next three years. Accuracy is expected for the first year where, forecast must be firm and final. For the remaining two years, allowance is made for changes nearer the time involved. At the right hand corner of the chart, brief particulars of retirements/transfers are provided.

When a change in the structure of the department is expected in a period of three years, an annexure to the chart indicating the change is required. While submitting the chart, each department annexes a brief job description of each position to be filled. To ensure that new recruits are available well in time, each department indicates the time by which the new recruits should join. After receiving the charts from various departments, HR department collates them and recruitment programme is drawn by it and submitted for the approval of the Board of Directors. Recruitment process starts after this approval.

Larsen & Toubro Limited

L&T starts its forecasting human resource needs in the month of November every year.There are eleven plants/units in L&T—prepares &their manpower requirement plans in the in the light of business forecasts supplied by the head office (Mumbai). These plans are reviewed by HR department at the head office and final HR plan is prepared and approved by management committee consisting of senior managers. The HR plan is prepared for one year with a tentative plan for another two years. The budget broadly forms the basis of recruitment of personnel during a year.

Barriers to Effective Human Resource Planning

Effective Human resource planning is a pre-requisite for successful human resource management practices. However, there are certain factors—internal to the organization and external to it—which affect the effectiveness of human resource planning adversely. Some of the more important factors are as follows:

1. Improper linkage between HRP and Corporate Strategy

Human resource management plays crucial role in corporate strategic management and, therefore, it must be linked to strategic management process. In the absence of this linkage, neither HRM nor any of its subsystems will contribute effectively. HRP is the basis of further activities for HRM and, therefore, must be linked to corporate strategic management process at the initial stage. However, many organisations fail to do so. With the result, either they do not have right personnel at right time or face or there is the problem of excessive personnel.

2. Inadequate appreciation of HRP

Another problem that comes in the way of effective HRP is the lack of adequate realisation of HRP. Many organizations which have not realised the importance of human assets in this competitive environment believe that 'people are available when they are needed because of increasing unemployment. So, why they should go for elaborate process of HRP.' So far as unemployment factor is concerned, the argument may appear to be logical. However, the question arises whether these organizations will like to employ those who are unemployable or they need right type of persons. It is not the quantity of persons that matters but it is the quality that matters. So long as the above belief is not changed, either HRP exercise will not be taken or may not be effective.

3. Rigidity in Attitudes

The third factor responsible for ineffective HRP is the rigidity of attitudes on the part of top management as well as HR managers. This is more relevant in the case of those organisations which have renamed their personnel department to human resource department but retained the old culture. In the old culture, human resources have been treated as subordinate factors. For such subordinate factors, elaborate planning is considered as luxury which these organisations would not like to afford.

4. Environmental Uncertainty

The concept of environmental uncertainty involves the lack of prediction about the future behaviour of environment. It depends on complexity and variability of environment. Complexity involves the presence of too many heterogenous factors in the environment and variability involves the rate of change in these factors. High environmental complexity and variability create uncertainty and the exact behaviour of environment may not be predicted. Since planning, including human resource planning, involves commitment whose impact will be felt in some future period, environmental uncertainty makes this commitment, based on future projection unrealistic.For example, in industries where nature of jobs changes too fast or employer turnover rate is very high like information technology sector, HRP turns to be less effective, thus, more meticulous HRP is required for such a situation.

5. Conflict between Long-term and Short-term HRP

Another sources from where ineffectiveness in HRP emerges is the conflict between long-term and short-term HRP. In long-term HRP, the organization has flexibility of matching its human resources and jobs. However, this flexibility is not available in short-term in which jobs have to be matched with existing personnel and some ad hoc arrangement is required. Gradually, this ad hocism becomes deep rooted which affects entire human resource management process. For example, one of the major factors of management problems in public sector enterprises has been the adoption of this ad hoc approach.

6. Inappropriate HR Information System

The effectiveness of HR depends on the timely availability of relevant information regarding the contingent factors which are considered while formulating human resource plans. Such factors are organisational strategy and action plans defining the volume and area of operations, nature of human resource market, employee turnover rate, employee productivity, etc. If the HR information system has not been well developed in an organisation, the projections for the future may at best be in the form of some pluses and minuses. We can easily appreciate the usefulness and validity of such projections. Sometimes, these projections become more frustrating than the non-existence of such projections.

Measures for Making HRP Effective

We have seen that HRP is quite important in the present competitive world' when competition exists not in terms of winning customers but it exists in terms of winning right human resources. Therefore, the question is not whether HR should be formalised or not, the question is how elaborate it should be. Therefore, organisations have to ensure that HRP is made effective. Following measuresinthis context are more relevant:

1. Commitment and involvement of top management in HRP.
2. Proactive, rather than reactive, human resource management approach.
3. Greater participation of line managers at all levels in HRP process.
4. Effective design of HR information system integrated with organisation's management information system.
5. Linking HRP to corporate strategic management process.
6. Enough flexibility in HR plans to take care of changing situations.

Key Concepts for review	
Action plan	Long-term planning
Delphi technique	Markov chain analysis
Econometric model	Planning process
Forecasting	Regression analysis
Human resource flow model	Short-term planning
Human resource gap	Skill inventory
Human resource inventory	Trend analysis
Human resource planning	Work study

There are many situations where the assignment of people or machines and so on, may be called for. Assignment of workers to machines, clerks to various check-out counters, salesmen to different sales areas, service crews to different districts 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 the jobs by different people are different. Obviously, if all persons could do a job in the same time or at the same cost then it would not matter who of them is assigned the job. Thus, in an assignment problem, the question is how should the assignments be made in order that the total cost involved is minimised (or the total value is maximised when pay-offs are given in terms of, say, profits). A typical assignment problem follows:

Assignment Problem: A Variant of The Transportation Problem

The assignment problem can be expressed as a transportation problem also. The various cost (or time) elements are taken as given, and the availability at each of the sources and the requirement at each of the destinations is taken to be 1. Further, as assignments are made on a one-to-one basis, the numbers of origins and destinations should be made exactly equal. The x_{ij} values should equal 0 or 1, so that for a job assigned to a worker x_{ij} would be 1 and other x_{ij} values in that (ith) row and the (jth) column should equal 0.

Thus, an assignment problem is a variation of the transportation problem with two characteristics. First, the pay-off matrix for the problem would be a square matrix, and, second, the optimal solution to the problem would always be such that there would be only one assignment in a given row or column of the pay-off matrix.

There are four methods of solving an assignment problem: (a) complete enumeration method; (b) transportation method; (c) Simplex method; and (d) Hungarian assignment method. We shall discuss these methods now.

(a) Complete Enumeration Method: In this method, all possible assignments are listed out and the assignment involving the minimum cost (or maximum profit if the problem, is of the maximisation type) is selected. It represents the optimal solution. In case there are more than one index assignment patterns involving the same least cost, then they all shall represent optimal solutions—the problem has multiple optima then.

(b) **Simplex Method:** We have seen earlier that an assignment problem can be formulated as a transportation problem which, in turn, is a special type of linear programming problem. Accordingly, an assignment problem can be formulated as a linear programming problem (with integer variables) and solved using a modified simplex method or otherwise.

(c) **Hungarian Assignment Method (HAM):** It may be observed that none of the three working methods discussed earlier to solve an assignment is efficient. A method, designed specially to handle the assignment problems in an efficient way, called the Hungarian Assignment Method, is available, which is based on the concept of opportunity cost. For a typical balanced assignment problem involving a certain number of persons and an equal number of jobs, and with an objective function of the minimisation type, the method is applied as listed in the following steps:

Step 1 Locate the smallest cost element in each row of the 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 In the reduced cost table obtained, consider each column and locate the smallest element in it. Subtract the smallest value from every other 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 Draw the minimum number of horizontal and vertical lines (no the diagonal ones) that are required to cover all the 'zero' elements. If the number of lines drawn is equal to n (the number of rows/columns) the solution is optimal, and proceed to step 6. If the number of lines drawn is smaller than n, go to step 4.

Step 4 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 steps 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 element 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. Now cross the remaining zeros in the column and row in respect of which the assignment is made.

(d) Repeat steps (a) through (c) until all assignments are made.

(e) Determine the total cost with reference to the original cost table.

Example 1: Solve the assignment problem given in using HAM. The information is reproduced in Table 2.9.5.

Table 2.9.5 Time Taken (in minutes) by 4 Workers

Worker	Job			
	A	B	C	D
1	45	40	51	67
2	57	42	63	55
3	49	52	48	64
4	41	45	60	55

The solution to this problem is given here in a step-wise manner.

Step 1 The minimum value of each row is subtracted from all elements in the row. It is shown in the reduced cost table , also called opportunity cost table, given in Table 2.9.6.

Table 2.9.6 Reduced Cost Table 1

Worker	Job			
	A	B	C	D
1	5	0	11	27
2	15	0	21	13
3	1	4	0	16
4	0	4	19	14

Step 2 For each column of this table, the minimum value is subtracted from all the other values.

Obviously, the columns that contain a zero would remain unaffected by this operation. Here only the fourth column values would change. **Table 2.9.7** shows this.

Table 2.9.7 Reduced Cost Table 2

Worker	Job			
	A	**B**	**C**	**D**
1	5	0	11	14
2	15	0	21	0
3	1	4	0	3
4	0	4	19	1

Step 3 Draw the minimum number of lines covering all zeros. As a general rule, we should first cover those rows/columns which contain larger number of zeros. **Table 2.9.7** is required in **Table 2.9.8** and the lines are drawn.

Table 2.9.8 Reduced Cost Table 3

Worker	Job			
	A	**B**	**C**	**D**
1	5	0	11	14
2	15	0	21	0
3	1	4	0	3
4	0	4	19	1

Step 4 Since the number of lines drawn is equal to 4(=n), the optimal solution is obtained. The assignments are made after scanning the rows and columns for unit zeros. Assignments made are shown with squares, as shown in Table 2.9.9.

Table 2.9.9 Assignment of Jobs

Worker	Job			
	A	**B**	**C**	**D**
1	5	$\boxed{0}$	11	14
2	15	~~0~~	21	$\boxed{0}$
3	1	4	$\boxed{0}$	3
4	$\boxed{0}$	4	19	1

Assignments are made in the following order. Rows 1, 3, and 4 contain only one zero each. So assign 1 -B, 3-C, and 4-A. Since worker 1 has been assigned job B, we cross the zero in the second column of the second row. After making these assignments, only worker 2 and job B are left for assignment. The final pattern of assignments is 1-5, 2-D, 3-C, and 4-A, involving a total time of 40 + 55 + 48 + 41 = 184 minutes. This is the optimal solution to the problem—the same as obtained by enumeration and transportation methods.

Illustration 1:

Using the following cost matrix, determine (a) optimal job assignment, and (b) the cost of assignments.

Machinist	Job				
	1	**2**	**3**	**4**	**5**
A	10	3	3	2	8
B	9	7	8	2	7
C	7	5	6	2	4
D	3	5	8	2	4
E	9	10	9	6	10

Solution:

Iteration 1 Obtain row reductions.

Table: Reduced Cost Table 1

Machinist	Job				
	1	**2**	**3**	**4**	**5**
A	8	1	1	0	6
B	7	5	6	0	5
C	5	3	4	0	2
D	1	3	6	0	2
E	3	4	3	0	4

Iteration 2 Obtain column reductions and draw the minimum number of lines to cover all zeros.

Table: Reduced Cost Table 2

Machinist	Job				
	1	2	3	4	5
A	7	0	0	0	4
B	6	4	5	0	3
C	4	2	3	0	0
D	0	2	5	0	0
E	2	3	2	0	2

Since the number of lines covering all zeros is less than the number of columns/rows, we modify the above Table. The least of the uncovered cell values is 2. This value would be subtracted from each of the uncovered values and added to each value lying at the intersection of lines (corresponding to cells A-4, D-4, A-5 and D-5). Accordingly, the new table would appear as shown in below.

Iteration 3

Table Reduced Cost Table 3

Machinist	Job				
	1	2	3	4	5
A	7	$\boxed{0}$	0	2	6
B	4	2	3	$\boxed{0}$	3
C	2	0	1	0	$\boxed{0}$
D	$\boxed{0}$	2	5	2	2
E	0	1	$\boxed{0}$	0	2

The optimal assignments can be made as the least number of lines covering all zeros in Table equals 5. Considering rows and columns, the assignments can be made in the following order:

(i) Select the second row. Assign machinist B to job 4. Cross out zeros at cells C-4 and E-4.

(ii) Consider row 4. Assign machinist D to job 1. Cancel the zero at cell E-1.

(iii) Since there is a single zero in the fifth row, put machinist E to job 3 and cross out the zero at A-3.

(iv) There being only a single zero left in each of the first and third rows, we assign job 2 to machinist A and job 5 to C.

The total cost associated with the optimal machinist-job assignment pattern A-2, B-4, C-5, D-1and E-3 is 3+2+4+3+9=21

Some Special Topics

A. Unbalanced Assignment Problems

The Hungarian method of solving an assignment problem requires that the number of columns should be equal to the number of rows. When they are equal, the problem is a balanced problem, and when not, it is called an unbalanced problem. Thus, where there are 5 workers and 4 machines, or when there are 4 workers and 6 machines, for instance, we have unbalanced situations in which one-to-one match is not possible. In case the machines are in excess, the excess machine(s) would remain idle and so is the case when men are in excess—the number of excess people would not get an assignment.

In such situations, dummy column(s)/row(s), whichever is smaller in number, are inserted with zeros as the cost elements. For example, when the given cost matrix is of the dimension 4 x 5, a dummy row would be included. In each column in respect of this row, a 'zero' would be placed. After this operation of introducing dummy columns/rows, the problem is solved in the usual manner.

B. Constrained Assignment Problems

It happens sometimes that a worker cannot perform a certain job or is not to be assigned a particular job. To cope with this situation, the cost of performing that job by such person is taken to be extremely large (which is written as M). Then the solution to the assignment problem proceeds in the manner discussed earlier. The effect of assigning prohibitive cost to such person-job combinations is that they do not figure in the final solution.

Illustration 2:

You are given the information about the cost of performing different jobs by different persons. The job-person marking x indicate that the individual involved cannot perform the particular job. Using this information, state (i) the optimal assignment of jobs, and (ii) the cost of such assignment.

Person	Job				
	J_1	J_2	J_3	J_4	J_5
P_1	27	18	×	20	21
P_2	31	24	21	12	17
P_3	20	17	20	×	16
P_4	22	28	20	16	27

Solution:

Balancing the problem and assigning a high cost to the pairings P_1-J_3 and given in Table below.

Table Cost Table

Person	Job				
	J_1	J_2	J_3	J_4	J_5
P_1	27	18	M	20	21
P_2	31	24	21	12	17
P_3	20	17	20	M	16
P_4	22	28	20	16	27
P_5(Dummy)	0	0	0	0	0

Now we can derive the reduced cost table as shown Table in next page. Note that the cells with prohibited assignments continue to be shown with the cost element M, since M is defined to be extremely large so that subtraction or addition of a value does not practically affect it. To test optimally, lines are drawn to cover all zeros. Since the number of lines covering all zeros is less than n, we select the lowest uncovered cell, which equals 4. With this value, we can obtain the revised reduced cost table, shown in Table.

Table: Reduced Cost Table 1

Person	Job				
	J_1	J_2	J_3	J_4	J_5
P_1	9	0	M	2	3
P_2	19	12	9	0	5
P_3	4	1	4	M	0
P_4	6	12	4	0	11
P_5(Dummy)	0	0	0	0	0

Table: Reduced Cost Table 2

Person	Job				
	J_1	J_2	J_3	J_4	J_5
P_1	9	$\boxed{0}$	M	6	3
P_2	15	8	5	$\boxed{0}$	1
P_3	4	1	4	M	$\boxed{0}$
P_4	2	8	$\boxed{0}$	0	7
P_5(Dummy)	$\boxed{0}$	0	0	4	0

The number of lines covering zeros is equal to 5(= n), hence the optimal assignment can be made. The assignment is: P_1-J_2, P_2-J_4, P_3-J_5, P_4-J_3, while job J_1 would remain unassigned. This assignment pattern would cost 18 + 12 + 16 + 20 = 66 in the aggregate.

C. Unique Vs Multiple Optimal Solutions

In the process of making assignments, it was stated earlier that we select a row/column with only a single zero to make an assignment. However, a situation may arise wherein the various rows and columns, where assignments are yet to be done, have all multiple zeros. In such cases, we get multiple optimal solutions to the given problem. In any of the problems discussed so far, we have not experienced such a situation. Hence, each one of them has had a unique optimal solution. When a problem has a unique optimal solution, it means that no other solution to the problem exists which yields the same objective function value (cost, time, profit etc.) as the one obtained from the optimal solution derived. On the other hand, in a problem with multiple optimal solutions, there exist more than one solution which all are optimal and equally attractive. Consider the following example.

Illustration 3:

Solve the following assignment problem and obtain the minimum cost at which all the jobs can be performed.

Machinist	Job (Cost in '00 ₹)				
	1	2	3	4	5
A	25	18	32	20	21
B	34	25	21	12	17
C	20	17	20	32	16
D	20	28	20	16	27

Solution:

This problem is unbalanced since number of jobs is 5 while the number of workers is 4. We first balance it by introducing a dummy worker E, as shown Table in below.

Table: Balancing the Assignment Problem

Worker	Job				
	1	2	3	4	5
A	25	18	32	20	21
B	34	25	21	12	17
C	20	17	20	32	16
D	20	28	20	16	27
E	0	0	0	0	0

Obtain reduced cost values by subtracting the minimum value in each row from every cell in the row. This Table is given in below.

Table Reduced Cost Table 1

Worker	Job				
	1	2	3	4	5
A	7	0	14	2	3
B	22	13	9	0	5
C	4	1	4	16	0
D	4	12	4	0	11
E	0	0	0	0	0

Since there is at least one zero in each row and column, we test it for optimality. Accordingly, lines are drawn. All zeros are covered by 4 lines, which is less than 5 (the order of the given matrix). Hence, we proceed to improve the solution. The least uncovered value is 4. Subtracting from every uncovered value and adding it to every value lying at the intersection of lines, we get the revised values as shown in Table.

Table Reduced Cost Table 2

Worker	Job				
	1	2	3	4	5
A	7	$\boxed{0}$	14	6	3
B	18	9	5	$\boxed{0}$	1
C	4	1	4	20	$\boxed{0}$
D	$\boxed{0}$	8	$\cancel{0}$	$\cancel{0}$	7
E	$\cancel{0}$	$\cancel{0}$	$\boxed{0}$	4	$\cancel{0}$

The solution given in above Table is optimal since the number of lines covering zeros matches with the order of the matrix. We can, therefore, proceed to make assignments. To begin with, since each of the columns has multiple zeros, we cannot start making assignments considering columns and have, therefore, to look through rows. The first row has a single zero. Thus, we make assignment A-2 and cross out zero at E-2. Further, the second and the third rows have one zero each. We make assignments B-4 and C-5, and cross out zeros at D-4 and E-5. Now, both the rows left have two zeros each and so have both the columns. This indicates existence of multiple optimal solutions. To obtain the solutions, we select zeros arbitrarily and proceed as discussed below.

(i) Select the zero at D-1, make assignment and cross out zeros at D-3 and E-1 (as both, worker D and job 1, are not available any more). Next, assign worker E to job 3, corresponding to the only zero left. Evidently, selecting the zero at E-3 initially would have the effect of making same assignments,

(ii) Select the zero at D=3, make assignment and cross out zeros at D-1 and E-3. Next, make assignment at the only zero left at E-1. Obviously, selecting the zero at E-1 making assignment in the first place would lead to the same assignments.

To conclude, the problem has two optimal solutions as given below.

Solution 1		**('00 ₹) Cost**	**Solution 2**		**('00 ₹) Cost**
Worker	**Job**		**Worker**	**Job**	
A	2	18	A	2	18
B	4	12	B	4	12
C	5	16	C	5	16
D	1	20	D	3	20
Job left	3		Job left	1	
	Total	66		Total	66

D. Maximisation Case

In some situations, the assignment problem may call for maximisation of profit, revenue, etc. as the objective. For example, we may be faced with the problem of assignment of salesmen in different regions in which they can display different qualities in making sales (reflected in amounts of sales executed by them). Obviously, assignment would be made in such a way that the total expected revenue is maximised. For dealing with a maximisation problem, we first change it into an equivalent minimisation problem. This is achieved by subtracting each of the elements of the given pay-off matrix from a constant (value) K. Thus, we may simply put a negative sign before each of the pay-off values (which is equivalent to subtracting each value from zero). Usually, the largest of all values in the given matrix is located and then each one of the values is subtract from it (the largest value is taken so as to avoid the appearance of negative signs). Then the problem is solved the same way as a minimisation problem is.

Illustration 4:

A company plans to assign 5 salesmen to 5 districts in which it operates. Estimates of sales revenue in thousands of rupees for each salesman in different districts are given the following table. In your opinion, what should be the placement of the salesmen if the objective is to maximise the expected sales revenue?

Expected Sales Data

Salesman	**District**				
	D_1	**D_2**	**D_3**	**D_4**	**D_5**
S_1	40	46	48	36	48
S_2	48	32	36	29	44
S_3	49	35	41	38	45
S_4	30	46	49	44	44
S_5	37	41	48	43	47

Solution:

Since it is a maximisation problem, we would first subtract each of the entries in the table from the largest one, which equals 49 here. The resultant data are given in Table.

Table: Opportunity Loss Matrix

Salesman	District				
	D_1	D_2	D_3	D_4	D_5
S_1	9	3	1	13	1
S_2	1	17	13	20	5
S_3	0	14	8	11	4
S_4	19	3	0	5	5
S_5	12	8	1	6	2

Now we shall proceed as usual.

Step 1

Subtract minimum value in each row from every value in the row. The resulting values are given in Table.

Table: Reduced Cost Table 1

Salesman	District				
	D_1	D_2	D_3	D_4	D_5
S_1	8	2	0	12	0
S_2	0	16	12	19	4
S_3	0	14	8	11	4
S_4	19	3	0	5	5
S_5	11	7	0	5	1

Steps 2, 3

Subtract minimum value in each column in reduced cost table 1 from each value in the column. Test for optimally by drawing lines to cover zeros. These are shown in Table.

Table: Reduced Cost Table 2

Salesman	District				
	D_1	D_2	D_3	D_4	D_5
S_1	8	0	0	7	0
S_2	0	14	12	14	4
S_3	0	12	8	6	4
S_4	19	1	0	0	5
S_5	11	5	0	0	1

Since the number of lines covering all zeros is fewer than n, we select the least uncovered cell value, which equals 4. With this, we can modify the table as given in Table.

Steps 4, 5, 6

Find improved solution. Test for optimality and make assignments.

Table: Reduced Cost Table 3

Salesman	District				
	D_1	D_2	D_3	D_4	D_5
S_1	12	$\boxed{0}$	$\cancel{0}$	7	$\cancel{0}$
S_2	$\boxed{0}$	10	8	10	$\cancel{0}$
S_3	$\cancel{0}$	8	4	2	$\boxed{0}$
S_4	23	1	$\boxed{0}$	$\cancel{0}$	5
S_5	15	5	$\cancel{0}$	$\boxed{0}$	1

There are more than one optimal assignments possible in this case because of the existence of multiple zeros in different rows and columns. The assignments possible are:

S_1-D_2, S_2-D_5, S_3-D_1, S_4-D_3, S_5-D_4; or

S_1-D_2, S_2-D_1, S_3-D_5, S_4-D_3, S_5-D_4; or

S_1-D_2, S_2-D_5, S_3-D_1, S_4-D_4, S_5-D_3; or

S_1-D_2, S_2-D_1, S_3-D_5, S_4-D_4, S_5-D_3.

Each of these assignment patterns would lead to an expected aggregated sales equal to 231 thousand rupees.

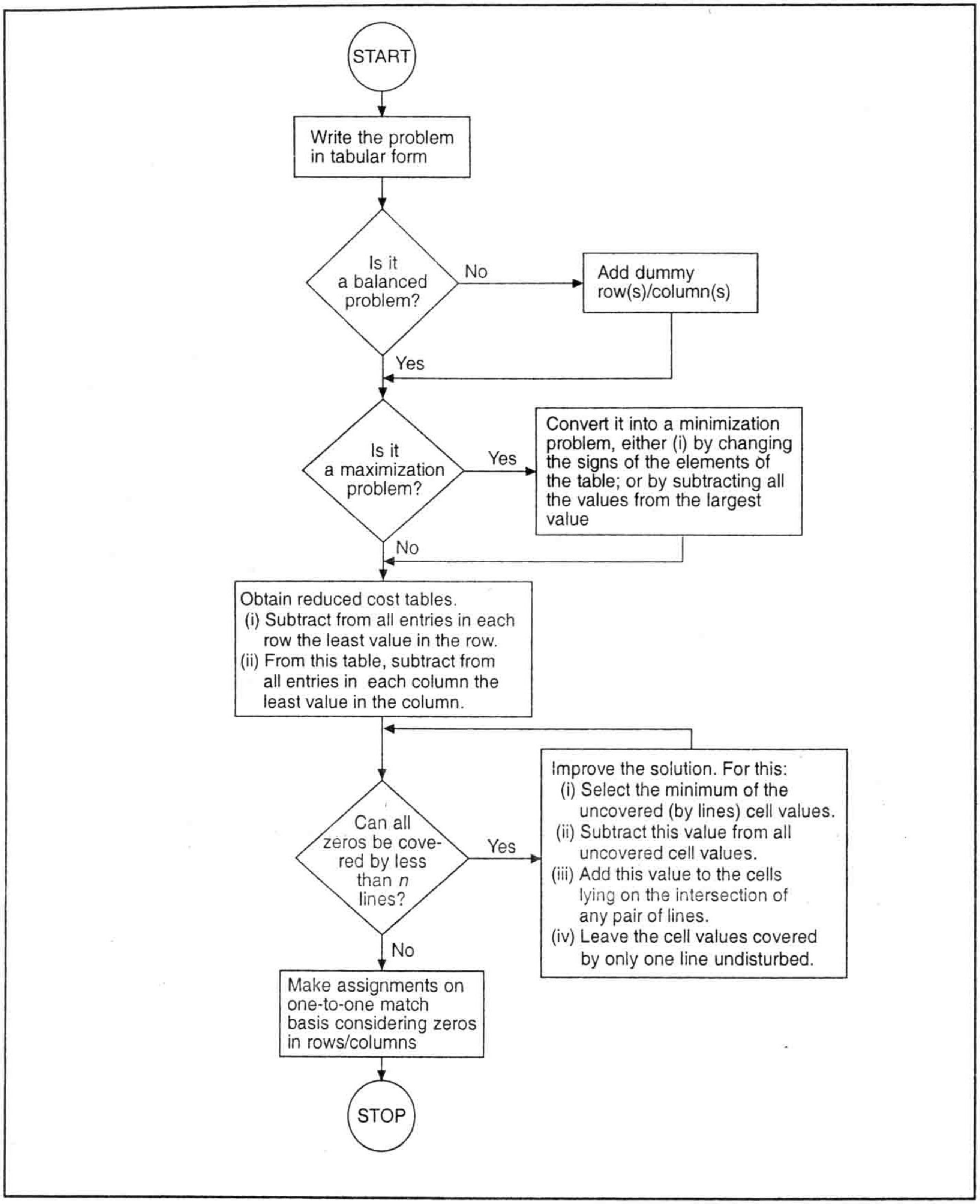


Fig. 2.9.2 Schematic Presentation of Hungarian Assignment Method

Illustrations 5:

To stimulate interest and provide an atmosphere for intellectual discussion, the finance faculty in a management school decides to hold special seminars on four contemporary topics—leasing, portfolio management, private mutual funds, swaps and options. Such seminars should be held once per week in the afternoons. However, scheduling these seminars (one for each topic, and not more than one seminar per afternoon) has to be done carefully so that the number of students unable to attend is kept to a minimum. A careful study indicates that the number of students who cannot attend a particular seminar on a specific day is as follows:

	Leasing	**Portfolio Management**	**Private Mutual Funds**	**Swaps and Options**
Monday	50	40	60	20
Tuesday	40	30	40	30
Wednesday	60	20	30	20
Thursday	30	30	20	30
Friday	10	20	10	30

Find an optimal schedule of the seminars. Also find out the total number of students who will be missing at least one seminar.

Solution:

Since this is an unbalanced problem, we first balance it by adding a dummy topic, as shown below:

	Leasing A	Portfolio Management B	Private Mutual Funds C	Swaps and Options D	Dummy E
Monday	50	40	60	20	0
Tuesday	40	30	40	30	0
Wednesday	60	20	30	20	0
Thursday	30	30	20	30	0
Friday	10	20	10	30	0

Subtracting the minimum value in each column from each of the values of the column (note that each row has a least value equal to zero already), we obtain RCT-1 as shown in Table.

Table Reduced Cost Table 1

A	B	C	D	E
40	20	50	0	0
30	10	30	10	0
50	0	20	0	0
20	10	10	10	0
0	0	0	10	0

The minimum number of lines covering all zeros is 4, which is less than the order of the given matrix (=5). Thus, we cannot obtain optimal solution from here. The revised table is given in Table below, which is obtained by subtracting the least uncovered cell value 10 from each of the uncovered values and adding to each of the values lying at the intersection of lines.

Table: Reduced Cost Table 2

A	B	C	D	E
30	20	40	$\boxed{0}$	$\cancel{0}$
20	10	20	10	$\boxed{0}$
40	$\boxed{0}$	10	$\cancel{0}$	$\cancel{0}$
10	10	$\boxed{0}$	10	$\cancel{0}$
$\boxed{0}$	10	$\cancel{0}$	20	10

Since the minimum number of lines to cover all zeros equals 5, we may make assignments. The assignments have been made in the following order: Row 5, Column 1; Row 3, Column 2; Row 4, Column 3; Row 1, Column 4; and Row 2, Column 5. Accordingly, the optimal schedule is:

Monday : Swaps and Options

Tuesday : No Seminar

Wednesday : Portfolio Management

Thursday : Private Mutual Finds

Friday: Leasing

No. of Students Missing = 20 + 0 + 20 + 20 + 10 = 70

Illustration 6:

A solicitor's firm employs typists on hourly piece-rate basis for their daily work. There are five typists and their charges and speed are different. According to an earlier understanding, only one job is given to one typist and the typist is paid for a full hour even when he works for a fraction of an hour. Find the least cost allocation for the following data:

Typist	Rate/hour(₹)	Number of Pages Typed/hour	Job	No. of Pages
A	5	12	P	199
B	6	14	Q	175
C	3	8	R	145
D	4	10	S	298
E	4	11	T	178

Solution:

Using the given information, we first obtain the cost matrix, when different jobs are performed by different typists. This table is shown in next page. The elements of the matrix are obtained as follows. To illustrate, if typist A is given job P, he would require 199/12 =16 hours and, hence, be paid for 17 hours @ ₹ 5 per hour. This results in a cost of ₹ 85 for this combination.

Table: Total Cost Matrix

Typist	Job				
	P	Q	R	S	T
A	85	75	65	125	75
B	90	78	66	132	78
C	75	66	57	114	69
D	80	72	60	120	72
E	76	64	56	112	68

Subtracting the minimum element of each row from all its elements, we obtain RCT-1, as shown in Table below.

Table: Reduced Cost Table 1

Typist	Job				
	P	Q	R	S	T
A	20	10	0	60	10
B	24	12	0	66	12
C	18	9	0	57	12
D	20	12	0	60	12
E	20	8	0	56	12

Now, subtracting the minimum element of each column from all the elements, we get RCT-2, given in Table below.

Table: Reduced Cost Table 2

Typist	Job				
	P	Q	R	S	T
A	2	2	0	4	0
B	6	4	0	10	2
C	0	1	0	1	2
D	2	4	0	4	2
E	2	0	0	0	2

Here, the minimum number of lines to cover all zeros is equal to 4, which is smaller than the order 5, of the given matrix. Accordingly, the revised table is prepared by considering the least uncovered value, equal to 1, and adjusting it with uncovered cell values and those lying at the intersection of lines. The Table next page contains RCT-3.

Table: Reduced Cost Table 3

Typist	Job				
	P	**Q**	**R**	**S**	**T**
A	2	1	0	3	$\boxed{0}$
B	6	3	$\boxed{0}$	9	2
C	$\boxed{0}$	0	0	0	2
D	2	3	0	3	2
E	3	$\boxed{0}$	1	0	3

In Table above as well, 4 lines can cover all zeros. Accordingly, RCT-4 is obtained drawn up as the revised table. This is given in Table below.

Table: Reduced Cost Table 4

Typist	Job				
	P	**Q**	**R**	**S**	**T**
A	2	1	2	3	$\boxed{0}$
B	4	1	$\boxed{0}$	7	$\times$
C	$\times$	$\boxed{0}$	2	$\times$	2
D	$\boxed{0}$	1	$\times$	1	$\times$
E	3	$\times$	3	$\boxed{0}$	3

In this case, the minimum number of lines to cover all zeros equals 5, which matches with the order of the matrix. Accordingly, assignments have been made as described below:

Typist	Job	Cost
A	T	75
B	R	66
C	Q	66
D	P	80
E	S	112
	Total	399

This optimal solution, however, is not unique.

Illustration 7:

WELLDONE Company has taken the third floor of a multi-storeyed building for rent with a view to locate one of their zonal offices. There are five main rooms in this to be assigned to five managers. Each room has its own advantages and disadvantages.

Some have windows, some are closer to the wash rooms or to the canteen or secretarial pool. The rooms are of all different sizes and shapes. Each of the five managers were asked to rank their room preferences amongst the rooms 301, 302, 303, 304 and 305. Their preferences were recorded in a table as indicated below:

MANAGER				
M_1	M_2	M_3	M_4	M_5
302	302	303	302	301
303	304	301	305	302
304	305	304	304	304
	301	305	303	
		302		

Most of the managers did not list all the five rooms since they were not satisfied with some of these rooms and they have left these from the list. Assuming that their preferences can be quantified by numbers, find out as to which manager should be assigned to which room so that their total preference ranking is a minimum.

Solution:

In the first step, we formulate the assignment problem using preference ranks. This is shown in Table below. Notice that the rooms not ranked by a manager are represented by M—as prohibited assignments.

Table: Assignment Problem

Room	Manager				
	M_1	M_2	M_3	M_4	M_5
301	M	4	2	M	1
302	1	1	5	1	2
303	2	M	1	4	M
304	3	2	3	3	3
305	M	3	4	2	M

Since greater preferences are shown by lower numbers, the optimal solution calls for minimising the total preference ranking. To solve, we obtain RCT-1 by subtracting the least value from each value of the row, for each of the rows. This is given in Table below.

Table: Reduced Cost Table 1

Room	Manager				
	M_1	M_2	M_3	M_4	M_5
301	M	3	1	M	0
302	0	0	4	0	1
303	1	M	0	3	M
304	1	0	1	1	1
305	M	1	2	0	M

Since each of the columns as well as rows has a zero, lines are drawn to cover all zeros. Further, the number of lines being equal to 5, the order of the given matrix, assignments can be made, as shown in the Table RCT-2.

Table: Assignment of Rooms to Managers

Room	Manager				
	M_1	M_2	M_3	M_4	M_5
301	M	3	1	M	$\boxed{0}$
302	$\boxed{0}$	$\xcancel{0}$	4	$\xcancel{0}$	1
303	1	M	$\boxed{0}$	3	M
304	1	$\boxed{0}$	1	1	1
305	M	1	2	$\boxed{0}$	M

Thus, the optimal assignment pattern is:

Room	Manager	Ranking
301	M_5	1
302	M_1	1
303	M_3	1
304	M_2	2
305	M_4	2

Illustration 8:

A company has four sales representatives who are to be assigned to four different sales territories. The monthly sales increase estimated for each sales representative for different sales territories (in lakhs of rupees), are shown in the following table:

Sales Representatives	Sales Territories			
	I	II	III	IV
A	200	150	170	220
B	160	120	150	140
C	190	195	190	200
D	180	175	160	190

Suggest optimal assignment and the total maximum sales increase per month.

If for certain reasons, sales representative cannot be assigned to sales territory III, will the optimal assignment schedule be different? If so, find that schedule and the effect on total sales.

Solution:

The given problem, being of the maximisation type, needs to be converted first into minimisation type. This is shown in Table below, wherein the various elements are obtained by subtracting each of the elements in the given table from 220.

Table: Opportunity Loss Matrix

	I	II	III	IV
A	20	70	50	0
B	60	100	70	80
C	30	25	30	20
D	40	45	60	30

Subtracting minimum value in each row from each of the row elements, we derive RCT-1, shown in Table below.

Table: Reduced Cost Table 1

	I	II	III	IV
A	20	70	50	0
B	0	40	10	20
C	10	5	10	0
D	10	15	30	0

Now, subtracting minimum value in each column from each of the column elements of RCT-1, we get RCT-2, as shown in Table below.

Table: Reduced Cost Table 2

	I	II	III	IV
A	20	65	40	0
B	0	35	0	20
C	10	0	0	0
D	10	10	20	0

Since the minimum number of lines to cover all zeros (3) is smaller than the matrix order (4), RCT-3 is derived as a revised table. This is given in Table below.

Table: Reduced Cost Table 3

	I	II	III	IV
A	10	55	30	$\boxed{0}$
B	$\boxed{0}$	35	0	30
C	10	0	$\boxed{0}$	10
D	0	$\boxed{0}$	10	0

With the number of lines to cover all zero being equal to the order of the given matrix, assignments can be made as shown in Table previous page. However, the problem has an alternative optimal solution as well. Both of these are given below:

Alternative 1			Alternative 2		
Salesman	**Territory**	**Sales**	**Salesman**	**Territory**	**Sales**
A	IV	220	A	IV	220
B	I	160	B	III	150
C	III	190	C	II	195
D	II	175	D	I	180
	Total	745		Total	745

If salesman B cannot be assigned to territory III (alternative 2), then alternative 1 above may be adopted without adverse effect on sale.

2.10 APPLICATION OF LINEAR PROGRAMMING TECHNIQUES FOR OPTIMUM ALLOCATION OF RESOURCES

Materials Planning

Materials planning is the scientific way of determining the requirements of raw materials, components, spares and other items that go into meeting the production needs within economic investment policies. Materials planning is a subset of the overall production planning and control system which has a broad perspective. Materials budgeting is an estimate of expenses to be incurred in the procurement of materials and it helps effective execution and control of materials plans.

Significance of Materials Planning

(i) Lack of proper materials planning and coordination leads to over-ordering or under-ordering of materials, over-ordering results in over-investment and unproductive use of costly working capital. It creates the need for extra storage facilities to hold unnecessary surplus stocks and may lead to deterioration and obsolescence of materials. Under-ordering results in material shortages that cause unnecessary delays and costly interruption in executing production commitments.

(ii) Poor planning for materials may lead to unwarranted emergency or rush orders, usually processed by costly means of transport.

(iii) Materials planning activity raises the level of the buyer from a mere order placer to a purchase executive or manager. Planning enables the purchase people to spend money in an optimum manner.

(iv) Materials planning aims at motivating people and saves as an effective control device.

(v) Efficiency in materials management function cannot be visulised without a sensible or effective materials planning function.

Benefits of Materials Planning

(i) Materials planning - both quantity and value in terms of rupees - for each item and overall, tries to avoid the practice of crisis management of struggling in the last minute to procure materials to meet the production requirements or pressurising unnecessarily the purchase people by sitting on their neck to get the materials in the last moment.

(ii) It helps to get things done efficiently and effectively by better forecasting of future material needs and working pro-actively rather than reacting to the situations.

(iii) A well-designed materials planning system provides steps for effective materials budgeting, follow-up of suppliers to procure materials in-time, thereby avoiding material shortages and its undesirable effects on production.

(iv) Purchase planning which is based on materials planning, if carried out properly, will enable the buyer to know not only the prices of the materials but also their costs.

Factors Influencing Materials Planning

The various factors influencing the materials planning process are classified as : (a) Macro factors and (b) Microfactors. Macro factors which affect materials planning are price trends, business cycle, import policy of the government, credit policy etc.

For example, the Government Committee headed by Mr. P.L. Tandon has given certain guide lines for inventory levels of raw materials, stock-in-process or work-in-process and finished goods inventories as well as for receivables and bills purchased and discounted. These guidelines are followed by banks while extending credit to industrial firms. Microfactors affecting materials planning include corporate objectives, working capital, seasonality, delegation of powers and communication systems used by the firm. **Table 2.10.1** lists A to Z influencing factors which influence materials planning process.

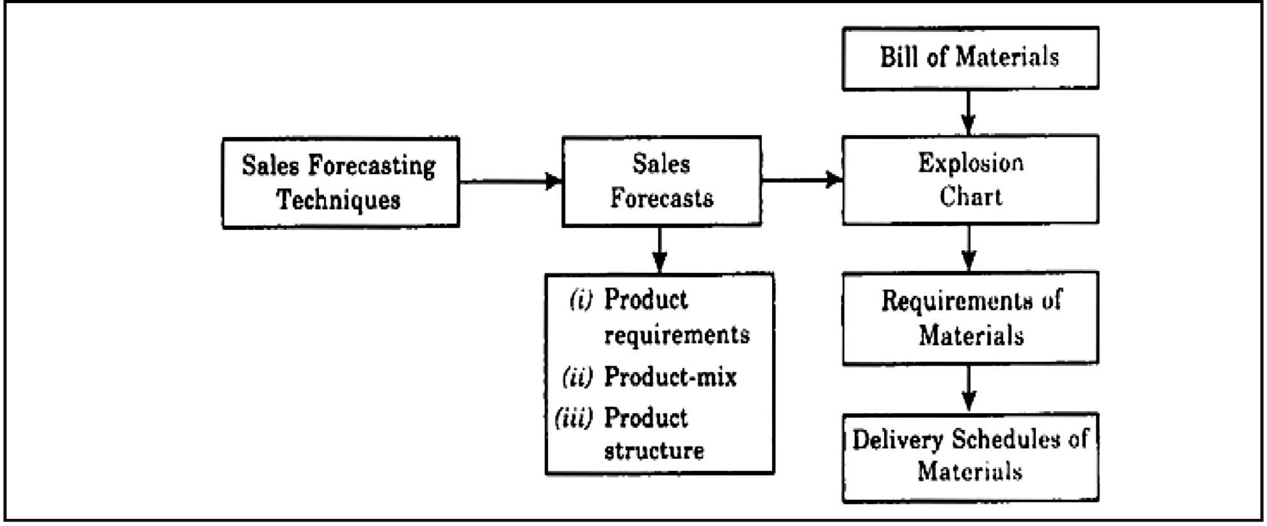
Table 2.10.1 : A to Z Influencing Factors

(a) State of health of national economy, (b) price trends, (c) credit policies, (d) direct and indirect taxes, (e) foreign exchange regulations, (f) import policy, (g) international market conditions, (h) business cycles, (i) corporate objectives, (j) technology availability, (k) demand for the item, (l) supply of the item, (m) transportation losses, (n) total procurement lead time, (o) rejection rate,	(p) working capital, (q) storage capacity, (r) plant utilization, (s) seasonal factors, (t) communication system, (u) delegation of power, (v) information available, (w) location of plant and location of supplies, (x) cost, criticality, reliability and availability of items, (y) information on substitute products, (z) demand forecasting techniques used.

The Approach to Materials Planning : The basis for materials planning is generally the firm wide annual production or operating plan which in turn is based on the demand or sales forecast for finished goods produced by the firm. The annual sales forecast may be further divided into quarterly or monthly sales forecast for each product line or individual product. The sales forecast is then translated into an aggregate production plan and master production schedule taking into consideration finished goods inventory levels as well as desired in-process inventory levels for specific items. Obviously short term sales forecasts (monthly, quarterly or yearly) can be converted into a production schedule more accurately than that is possible when intermediate or long term sales forecasts are used to prepare production plans.

All materials planning subsequently flow from the preliminary master production schedule. Requirements of various materials (raw materials, parts, components, subunits etc.,) are worked out by exploding the master production schedule for the planning period through the planning horizon. This technique is referred to as **"Bill of Materials Explosion".** Bill of materials is nothing but a document which shows for a given product or subunit, the list of materials required, unit consumption, and location code (for storage). The condition of supply such as **"boughtout"** or **"made in-house"** will also be indicated. Computers can be very effectively used for exploding bill of materials with demand forecasts as basis and the product structure (part lists) as the input data to the computer system. **Exhibit 2.10.1** illustrates the generation of bill of materials for a product.

Exhibit 2.10.1 : Bill of Materials Explosion



Another approach to materials planning is based on past consumption analysis. This method is used for items that are consumed on a continuous basis (i.e., independent demand items) and for which no bill of materials can be prepared. The past consumption data is analysed and a projection for the future is made, taking into account the past and future production programs for end products.

Certain guidelines are worked out for each item based on the "average" or mean consumption and the standard deviation on the mean assuming that the consumption follows a "normal distribution" (statistical) pattern. The stock levels to be held such as minimum stock levels, maximum stock levels, re-order levels and order quantities are computed using statistical formulae.

Problems Encountered in Materials Planning

(i) Even though materials planning is done based on the short-term sales forecast (usually for quarterly time periods) as the time-horizon (i.e., planning period) extends, sales forecasts become less reliable. Hence, material planners will always have some materials in short-supply or in excess supply and these must be rectified. The ordering is done on suppliers with firm commitments for the whole year and delivery schedules are scheduled on a need basis from time to time.

(ii) There are constraints regarding import policy of the Government, foreign exchange components of production requirements, credit availability etc., which affect the efficiency of materials planning.

In order to overcome the above problems, materials planning executives must consider the following :

(i) In working out the materials plan, anticipated lead times for procurement must be taken into account.

(ii) The external environment within which the firm is operating, must be carefully analysed to allow for errors or fluctuations in sales forecasts and/or the effects of seasonal variations in the trend of demand.

(iii) When materials planning extends beyond one year, it becomes more unrealistic because of many uncontrollable factors affecting demand and supply.

(iv) Without a computerised planning and information system, it may become difficult to revise the material estimates, rescheduling deliveries to accommodate changes in demand and consequent changes in production plans.

Guidelines to be Used for Effective and Reliable Materials Planning

(i) The planning horizon should cover the longest lead times anticipated.

(ii) If the demand fluctuates or show a seasonal variation, their effect on the planning must be taken care of.

(iii) For short planning horizons (say one year) if more planning periods are considered within the year, material plans will be more reliable. However, quarterly plans are more popular than monthly or weekly plans.

(iv) Computerisation of the materials planning process is advisable because computers are helpful to handle changes caused by fluctuations in demand and work out new or revised materials plans. For instance, the material plans may be revised within 24 hours of effecting a change in the product mix.

(v) Computerisation of materials planning results in savings in time and effort apart from obtaining accurate forecasts.

Purpose of Materials Budgets

The main purposes served by the materials budget are as follows :

(i) The financial resource availability is known exactly through materials budget provisions and hence the materials management department can plan its purchases and long term purchase contracts with suppliers optimally taking into consideration price trends, market position, trend in sales etc.

(ii) The prices of materials based on which budgets are prepared and the actual prices at which materials are bought are compared. This helps in understanding the controllable and uncontrolled elements that cause the budget variance.

(iii) The cash requirements for procuring materials can be clearly projected for the budgeted period (which is usually a year) and also for shorter time periods such as month or quarter in the planning horizon.

Benefits of Materials Budgets

(i) When a material budget is to be expressed in terms of rupees, the purchase manager has to provide the budget department with two types of information, (a) estimate of material prices during the coming year and (b) plans for the specific timing of purchases. These informations help the finance department to draw up a realistic schedule of cash requirements for each operating period (a month or a quarter).

(ii) In purchasing, reasonably precise knowledge of materials requirements over an extended period of time facilitates forward buying and permits the advantageous use of contract purchasing and blanket order purchasing techniques.

(iii) Inventory investment and its associated risks can be reduced by advance planning of material requirements.

(iv) Materials budget provide maximum purchasing lead time. This facilitates careful selection of qualified suppliers, negotiations without pressure of deadlines and an opportunity to obtain maximum value for each rupee spent.

(v) Additional lead time also produces savings by the use of routine rather than premium (costly) transportation, by a reduction in expediting costs and by smoothing of purchasing work load.

(vi) Supplier relationships can be improved and costs can be reduced because of availability of time to most purchasing requirements with the supplier's production schedule more effectively.

Material Control

The American Production and Inventory Control Society defines materials control as The function of maintaining constantly available supply of raw materials, purchased parts and supplies that are required for the manufacture of products. Functional responsibilities include the requisitioning of materials for purchase in economic quantities at the proper time, and their receipts, storage and production, the issuing of materials to production upon authorised request and the maintenance and verification of inventory records.

Importance of Materials Control

Providing raw materials and parts in proper quantities and when they are needed is one of the major concerns of any manufacturing organisation. If this is not done properly, workers and machines will be idle and delivery promises will not be met.

In **process industries** the procurement of raw materials and the follow-up to ensure that these materials arrive at the plant when they are needed is the responsibility of vice president of materials or director of purchase. In these industries large quantities of materials must be scheduled into the plant in sufficient quantities to meet the production needs but without excessive accumulation in stock piles.

The **materials control manager** who reports to the materials manager is responsible for ensuring supply of raw materials, parts and supplies to meet the needs of production departments to carry out their production programs. The materials control manager maintains the flow of materials into the plant through production and into finished products storage or into the shipping department. It is a completely centralised and integrated cycle.

To facilitate proper material control, materials are grouped into classes. Five such classes are : (I) raw materials, (ii) component parts, (iii) supplies, or indirect items, (iv) work in-process, (v) finished products.

Material control is usually concerned with the procuring of raw materials and purchased parts and supplying of these to production. Usually in-house manufactured parts, when they are completed, are returned to stores, where they are under the control of materials control department until they are issued to the assembly floor. Also, materials control section sometimes stores and controls supplies and indirect items, (consumables, stationery etc.) recording these when necessary. Work-in-progress is the primary concern of manufacturing department and finished goods may be stored in warehouses under the control of shipping department or sales department. Hence, these two classes of inventory are not a concern of the materials control section.

Materials Control Cycle

The material control cycle comprises all of those procedures which are necessary for the provision of materials for the manufacturing process with a minimum investment and at lowest cost possible. A knowledge of this cycle is fundamental to an understanding of the principles and practice of material control. The various steps in the **material control cycle** are as follows.

(i) Determining material needs.

(ii) Preparing requisitions for purchased items and requests for work orders for parts made in the shops.

(iii) Receiving purchased materials and finished parts into the plant.

(iv) Inspecting purchased material and parts and inspection of finished shop made parts. Delivering all parts and materials to the stores for storage.

(v) Entering receipts in stores records, apportioning material in the records to current orders, authorising requisitions of materials from stores for production of shop parts and requisitions of parts from stores for assembly into finished products.

(vi) Issuing of parts and materials to the shop for production and assembly.

(vii) Recording the issue in store records.

(viii) Entry of receiving and issuing transactions to cost and accounting records.

(ix) Determination of necessity for replacement of stores which leads to step number one and the cycle repeats.

Other activities of materials control section are :

(i) Determining the proper quantity to requisition for each item of material for each purchased and manufactured part.

(ii) Physical stock checking in stores to check quantity on hand of each part and material in order to verify the balances shown in stock on store records.

(iii) Standardising materials and parts for lowest cost manufacturing or purchasing.

Material Requirement Planning

Material Requirement Planning (MRP) refers to the basic calculations used to determine component requirements from end item requirements. It also refers to a broader information system that uses the dependence relationship to plan and control manufacturing operations.

MRP is a technique of working backward from the scheduled quantities and needs dates for end items specified in a master production schedule to determine the requirements for components needed to meet the master production schedule. The technique determines what components are needed, how many are needed, when they are needed and when they should be ordered so that they are likely to be available as needed. The MRP logic serves as the key component in an information system for planning and controlling production operations and purchasing. The information provided by MRP is highly useful in scheduling because it indicates the relative priorities of shop orders and purchase orders.

"Materials Requirement Planning (MRP) is a technique for determining the quantity and timing for the acquisition of dependent demand items needed to satisfy master production schedule requirements."

MRP is one of the powerful tools that, when applied properly, helps the managers in achieving effective manufacturing control.

MRP Objectives:

1. **Inventory reduction:** MRP determines how many components are required, when they are required in order to meet the master schedule. It helps to procure the materials/components as and when needed and thus avoid excessive build up of inventory.
2. **Reduction in the manufacturing and delivery lead times:** MRP identifies materials and component quantities, timings when they are needed, availabilities and procurements and actions required to meet delivery deadlines. MRP helps to avoid delays in production and priorities production activities by putting due dates on customer job orders.
3. **Realistic delivery commitments:** By using MRP, production can give marketing timely information about likely delivery times to prospective customers.
4. **Increased efficiency:** MRP provides a close coordination among various work centres and hence helps to achieve uninterrupted flow of materials through the production line. This increases the efficiency of production system.

Functions served by MRP

1. **Order planning and control:** When to release orders and for what quantities of materials.
2. **Priority planning and control:** How the expected date of availability is compared to the need date for each component.
3. Provision of a basis for planning capacity requirements and developing a broad business plans.

Input-output Ratio

Input-output analysis reflects a general theory of production based on the idea of economic interdependence Many input - output models are useful in forecasting. Input - output analysis takes into consideration the interdependence of the different sectors in the economy. This is because; the input to one sector is output of another sector. For example, the output of coal industry will be an input to the steel plant and the output of steel industry is an input to the construction industry and so on. There are many such cyclic relations within the various sectors of economy. Taking the data of outputs and inputs and studying the relationship between these two, we will be in a position to analyse the total demand for a product and the output required from industrial units. This type of analysis is very important because it takes into account all the intricate relationships in the economy. One of the limitations in this method is that the utility of an output is restricted to economic analysis, not considering the other business, governmental, technological and internal factors. It is limited but useful analysis. The analysis need not be limited to macro-level, speaking only in terms steel sector and coal sector etc. It may be mote 'micro', by considering the inputs and outputs within a general product group in the total economy. This type of analysis is very much used and is found more beneficial and useful. Three major assumptions in developing this technique are:

1. The total output of an industry is consumed as input by all industries for a time period, under consideration.
2. The input bought by each industry has usually been made dependent only on the industry's level of output.
3. The ration of an industry's input to its output, once established is fixed. This ratio is known as input output number or production coefficient.

Input-output analysis is a mathematical study of an economy in which different production sectors such as agriculture, industry and services etc. have interdependence. Thus, in input-output analysis, we try to analyse quantitatively the interdependence of inputs and outputs of various industries and find the equilibrium between the inputs and output of each industry, plant, sector or economy. The output of any industry depends very much on its inputs and these inputs are the outputs of other industries. This analysis signifies to foretell the total production per sector and its demand in other industries.

It can be presented as: Total output of all sectors = Total inputs of all sectors.

or, output of an industry = Total inputs of that industry.

This input-output analysis is also known as 'analysis of inter-industry or inter-sector flows or deliveries or analysis of inter-industry relations.'

Uses and Application of Linear Programming:

The linear programming technique is useful in the following cases:

(i) It helps in determining optimum combination of several variables with given constraints and thus selecting the best possible strategy among various alternatives available.

(ii) Linear programming provides additional information for proper planning and control over various operations in the organisation.

(iii) The management must understand the activities of the organisation for constructing suitable mathematical model visualising the relationship between variables, if any, and making improvement over them. The linear programming helps in better understanding the phenomenon.

(iv) Linear programming contributes to the development of executives through the techniques of model building and their interpretations.

(v) Linear programming provides standards for the management problems by defining (a) the objectives to be pursued, (b) various restrictions to be imposed, (c) various alternatives available and relationship between them, (d) the contribution of each alternative to the objectives.

Application: The linear programming technique may be fruitfully applied in the following spheres:

(i) The linear programming can be used in production scheduling and inventory control so as to produce the maximum out of the resources available to satisfy the needs of the public by minimising the cost of production and the cost of inventory control.

(ii) The technique of linear programming can also be fruitfully used in solving the blending problems.

Where basic components are combined to produce a product that has certain set of specifications and one may calculate the best possible combination of these compounds which maximise the profits or minimise the costs.

(iii) Other important applications of linear programming can be in purchasing, routing, assignment and other problems having selection problems such as(a) selecting the location of plant, (b) deciding the transportation route within the organisation, (c) utilising the godowns and other distribution centres to the maximising, (d) preparing low-cost production schedules, (e) determining the most profitable product-mix, and (f) analysing the effects of changes in purchase prices and sale prices.

Formulation of an L.P Problem: In formulating the linear programming problem, the basic step is to set up some mathematical model. For this purpose, the following considerations should be kept in mind: (i) unknown variables, (ii) objectives and (iii) constraints. This can be done with the help of the following terms:

1. **The objective function:** An objective function is some sort of mathematical relationship between variables under consideration. Under linear programming this relationship is always linear. The construction of objective function mainly depends upon abstraction. It is a process whereby the most important features of a system are considered.

   The objective function is always positive. The coefficients a_1, a_2 are certain constants and are known as prices associated to the variables X_1, X_2.

2. **Constraints on the variables of the objective function:** In practice, the objective function is to be optimised under certain restraints imposed on die variables or some combination of few or all the variables occurring in the objective function. These restrictions, in most of the cases, are never exact.

   Had these been exact, the objective function would have been easily optimised by die use of differential calculus. The restraints should be known and expressed in terms of linear algebraic expression.

3. **Feasible solution:** One of the essential features of linear programming problem is optimisation of linear objective function Z. It is subject to the linear constraints on the variables of the objective function.

   A set of values of X_1, X_2.........which satisfies the constraints and the non- negativity restrictions are called Feasible Solution. A feasible solution which optimises the objective function is known as Optimal Solution. Thus, a linear programming problem can be formulated in this way.

Formulation of Linear Programming Problems

1. **The maximisation case** Consider the following example.

   Illustration 1: A firm is engaged in producing two products, A and B. Each unit of product A requires 2 kg of raw material and 4 labour hours for processing, whereas each unit of product 6 requires 3 kg of raw material and 3 hours of labour, of the same type. Every week, the firm has an availability of 60 kg of raw material and 96 labour hours. One unit of product A sold yields ₹ 40 and one unit of product B sold gives ₹ 35 as profit.

   Formulate this problem as a linear programming problem to determine as to how many units of each of the products should be produced per week so that the firm can earn the maximum profit. Assume that there is no marketing constraint so that all that is produced can be sold.

   Solution:

   The objective function The first major requirement of an LPP is that we should be able to identify the goal in terms of the objective function. This function relates mathematically the variables with which we are dealing in the problem. For our problem, the goal is the maximisation of profit, which would be obtained by producing (and selling) products A and B. If we let x_1 and x_2 represent the number of units produced per week of the products A and B respectively, the total profit, Z, would be equal to $40x_1 + 35x_2$, because the unit profit on the two products is, respectively, ₹ 40 and ₹ 35. Now $Z = 40x_1 + 35x_2$ is, then, the objective function, relating the profit and the output level of each of the two items. Notice that the function is a linear one. Further, since the problem calls for a decision about the optimal values of x_1 and x_2, these are known as the decision variables.

   The constraints As has been laid, another requirement of linear programming is that the resources must be in limited supply. The mathematical relationship which is used to explain this limitation is inequality. The limitation itself is known as a constraint.

   Each unit of product A requires 2 kg of raw material while each unit of product B needs 3 kg. The total consumption would be $2x_1 + 3x_2$, which cannot exceed the total availability of 60 kg every week. We can express this constraint as $2x_1 + 3x_2 \le 60$. Similarly, it is given that a unit of A requires 4 labour hours for its production and one unit of B requires 3 hours. With an availability of 96 hours a week, we have $4x_1 + 3x_2 \le 96$ as the labour hours constraint.

   It is important to note that for each of the constraints, inequality rather than equation has been used. This is because the profit maximising output might not use all the resources to the full—leaving some unused. Hence the ≤ sign. However, it may be noticed that all the constraints, like objective function are also linear in nature.

   Non-negativity condition Quite obviously, x_1 and x_2, being the number of units produced, cannot have negative values. Thus, both of them can assume values only greater-than-or-equal-to zero. This is the non-negativity condition, expressed symbolically as $x_1 \ge 0$ and $x_2 \ge 0$.

   Now, we can write the problem in complete form as follows.

Maximise	$Z = 40x_1 + 35x_2$	Profit
Subject to		
	$2x_1 + 3x_2 \le 60$	Raw material constraint
	$4x_1 + 3x_2 \le 96$	Labour hours constraint
	$x_1, x_2 \ge 0$	Non-negativity restriction

2. The minimisation case Consider the following example.

Ilustration 2:

The Agricultural Research Institute suggested to a farmer to spread out at least 4800 kg of a special phosphate fertiliser and not less than 7200 kg of a special nitrogen fertiliser to raise productivity of crops in his fields. There are two sources for obtaining these—mixtures A and B. Both of these are available in bags weighing 100 kg each and they cost ₹ 40 and ₹ 24 respectively. Mixture A contains phosphate and nitrogen equivalent of 20 kg and 80 kg respectively, while mixture B contains these ingredients equivalent of 50 kg each.

Write this as a linear programming problem and determine how many bags of each type should the farmer buy in order to obtain the required fertiliser at minimum cost.

Solution:

The objective function In the given problem, such a combination of mixtures A and B is sought to be purchased as would minimise the total cost. If x_1 and x_2 are taken to represent the number of bags of mixtures A and B respectively, the objective function can be expressed as follows:

Minimise $Z = 40x_1 + 24x_2$ Cost

The constraints In this problem, there are two constraints, namely, a minimum of 4800 kg of phosphate and 7200 kg of nitrogen ingredients are required. It is known that each bag of mixture A contains 20 kg and each bag of mixture B contains 50 kg of phosphate. The phosphate requirement can be expressed as $20x_1 + 50x_2 \geq 4800$. Similarly, with the given information on the contents, the nitrogen requirement would be written as $80x_1 + 50x_2 \geq 7200$.

Non-negativity condition As before, it lays that the decision variables, representing the number of bags of mixtures A and B, would be non-negative. Thus, $x_1 > 0$ and $x_2 > 0$.

The linear programming problem can now be expressed as follows:

Minimise	$Z = 40x_1+24x_2$	Cost
Subject to		
	$20x_1 + 50x_2 \geq 4,800$	Phosphate requirement
	$80x_1 + 50x_2 \geq 7,200$	Nitrogen requirement
	$x_1, x_2 \geq 0$	Non-negativity restriction

General Statement of Linear Programming Problems

In general terms, a linear programming problem can be written as

Maximise $Z = c_1x_1 + c_2x_2 + \ldots + c_nx_n$ Objective Function

Subject to

$$\left.\begin{array}{l} a_{11}x_1 + a_{12}x_2 + \ldots + a_{1n}x_n \leq b_1 \\ a_{21}x_1 + a_{22}x_2 + \ldots + a_{2n}x_n \leq b_2 \\ . \\ . \\ . \\ a_{m1}x_1 + a_{m2}x_2 + \ldots + a_{mn}x_n \leq b_m \end{array}\right\} \text{Constraints}$$

$x_1, x_2, \ldots x_n \geq 0$ Non-negativity Restriction where c_j, a_{ij}, bi (i =1,2,... m; j = 1, 2, . . ., n) are known as constants and x_j are decision variables. The c_j's are termed as the profit coefficients, a_{ij}'s the technological coefficients and b_i's the resource values. In shorter form, the problem can be written as:

Maximise $Z = \sum_{j=1}^{n} c_j x_j$

Subject to $\sum_{j=1}^{n} a_{ij} x_j \le b$ for i = 1, 2, ..., m

$x_j \ge 0$ for j = 1, 2, ..., n

Where the objective is to minimise a function, the problem is,

Minimise $Z = \sum_{j=1}^{n} c_j x_j$

Subject to $\sum_{j=1}^{n} a_{ij} x_j \ge b$ for i = 1, 2, ..., m

$x_j \ge 0$ for j = 1, 2, ..., n

In matrix notation, an LPP can be expressed as follows:

Maximisation Problem		Minimisation Problem	
Maximise	Z = cx	Minimise	Z=cx
Subject to		Subject to	
ax ≤ b		ax ≥ b	
x ≥ 0		x ≥ 0	

where

c = row matrix containing the coefficients in the objective function,

x = column matrix containing decision variables,

a = matrix containing the coefficients in the constraints,

b = column matrix containing the RHS values of the constraints.

Notes

1. Generally, the constraints in the maximisation problems are of the ≤ type, and of the ≥ type in the minimisation problems. But a given problem may contain a mix of the constraints, involving the signs ≤ , ≥ and/or = .
2. Usually, the decision variables are non-negative. However, they need not always be so. To illustrate, in an investment problem, if we let x_1 represent the amount to be invested in the shares of a particular company, then variable x_1 shall be non-negative since we may decide to invest ($x_1 > 0$) or not to invest ($x_1 = 0$). But, if we already hold such shares which may be sold, if the need be, then x_1 may take positive value (more investment), zero value (indicating no new investment in it) or negative value (implying disinvestment in this share). Hence, x_1 shall be unrestricted in sign or a free variable.

There are number of ways of finding the optimal solution for a given linear programming problems. The following three methods are mainly used for this purpose.

(1) Graphic Method

(2) Simplex Method

Apart from this some specially structured linear programming problems are solved by methods like

(3) Transportation Method

(4) Assignment Method

1. **Graphic method**. This method is generally used for solving the problems having two or three variables.

   Due to this limitation of handling only two or three variables at a time this method has limited application in industrial problems. In practice, two variable cases are easy to solve by this method because three dimensional geometry becomes too complicated to find accurate results.

2. **Simplex Method.** This is the most powerful and popular method for solving linear programming problems. Any problem can be solved by this method which satisfies the conditions of linearity and certainty irrespective of the number of variables. It is an iterative procedure which ultimately gives the optimal solution.

3. **Transportation Method.** This method is used to know the minimum cost of transportation of a product from various origins to different distribution and consumption centres.

4. **Assignment Method**. This method is used to determine the optimum allocation of different jobs (n jobs) to different workers (n workers) in such a manner that the total cost/ total time for completing all the jobs is minimum (one job is to be assigned to one worker).

Solution to Linear Programming Problems—Graphic Method

Now we shall consider the solution to the linear programming problems. They can be solved by graphic method or by applying algebraic method, called the Simplex Method. The graphic approach is restricted in application—it can be used only when two variables are involved. Nevertheless, it provides an intuitive grasp of the concepts that are used in the simplex technique.

The graphic method To use the graphic method for solving linear programming problems, the following steps are required:

(a) Identify the problem—the decision variables, the objective function, and the constraint restrictions.

(b) Draw a graph that includes all the constraints/restrictions and identify the feasible region.

(c) Obtain the point on the feasible region that optimises the objective function—the optimal solution.

(d) Interpret the results.

We shall demonstrate the graphical approach first in respect of the maximisation and then for the minimisation problems.

Illustration 3:

The maximisation case We consider **Illustration 1** again. For this problem, the decision variables are x_1 and x_2, the number of units of the products A and B respectively. The objective function and the constraints are reproduced as,

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

$x_1, x_2 \geq 0$

Solution:

Graphing the restrictions We shall first chart the given restrictions on the graph. The constraint of raw material availability, $2x_1 + 3x_2 \leq 60$, states that any combination of $2x_1 + 3x_2$ that does not exceed 60 is acceptable. With varying values of x_1 and x_2, the combination can assume a maximum value equal to 60. This constraint can be depicted graphically by plotting the straight line $2x_1 + 3x_2 = 60$. Since only two points are needed to obtain a straight line, we can get the two points by setting one of these variables in turn equal to zero, and calculating the value of the other. Thus, when $x_1 = 0$, x_2 would equal 60/3 = 20, and when x_2 is set equal to 0, x_1 would be equal to 60/2 = 30. Joining the points (0, 20) and (30, 0) we get the required straight line which is shown in **Figure 2.10.1** as line PT. Any point (representing a combination of x_1, and x_2) that falls on this line or in the area below it, is acceptable insofar as this constraint is concerned. Since it is laid that both, x_1 and x_2, are non-negative, the triangle OPT formed by two axes and the line representing the equation $2x_1 + 3x_2 = 60$ is the region containing acceptable values of x_1 and x_2 in respect of this constraint.

Similarly, the other constraint $4x_1 + 3x_2 \leq 96$ can be plotted. The line JR in **Figure 2.10.1** represents the equation $4x_1 + 3x_2 = 96$. The triangle formed by OJR, formed by the two axes and this line represents the area in which any point would satisfy this constraint of labour hours.

Now, since both the constraints are to be satisfied, we have to consider the area on the graph which is bound by both of the constraints. A point like C' on the graph would be unacceptable because only first of the constraints would be satisfied and not the other. Similarly, a point like D would also not be acceptable as it represents a combination of x_1 and x_2 which satisfies the second, and not the first, of the constraints. In fact, all points lying in the shaded area are the points of interest. They represent the combinations of x_1 and x_2 that would satisfy the given constraints. This region of acceptable values of the decision variables in relation to the given constraints (and the non-negativity restrictions) is called the feasibility region. In general terms,

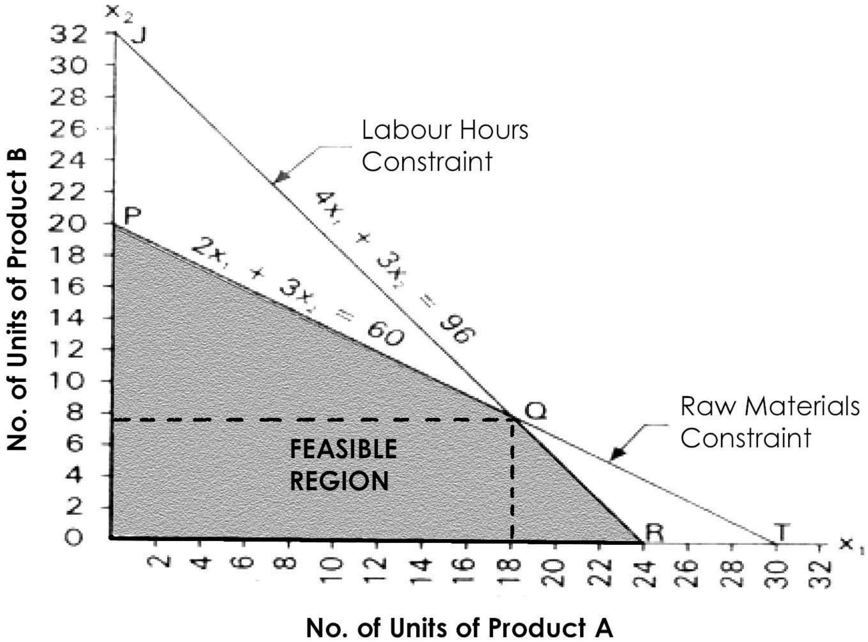


Fig. 2.10.1: Graphic Plot of Constraints

then, all inequalities of a linear programming problem, when plotted on the graph, define a space such that all points that lie within, or on the boundaries of that space simultaneously satisfy all the constraints, and the space is known as the feasible region. Thus, each point within this region would yield values of X_1 and X_2 as will satisfy all the constraints given in the problem. As such, corresponding to each point in the feasible region, we get a feasible solution. The feasible region of an LPP, therefore, gives a set of feasible solutions. Any point other than the one from this region will yield an infeasible solution—which would fail to satisfy one or more of the constraints.

Obtaining the optimal solution Now we shall see as to how can the optimal solution to the problem be obtained. Although all points in the feasible region represent feasible decision alternatives, they are not all equally attractive. Some provide a greater profit contribution than others. We have to select the best point from among the infinite number of points in the feasible region. In other words, we seek to obtain the feasible solution which optimises. It requires adding one more line to the graph, called an iso-profit or constant-profit line.

As its name implies, all the points on an iso-profit line yield the same profit. Suppose, for our example, that we want to find an iso-profit line representing a profit of ₹ 280. For this, we put $40x_1 + 35x_2 = 280$, and plot the line on the graph. We have $x_1 = 7$ when $x_2 = 0$, and $x_2 = 8$ when $x_1 = 0$. Joining the points (7, 0) and (0, 8), we get the iso-profit line EF in **Figure 2.10.2.** which is a reproduction of **Figure 2.10.1.** All points on this line, representing the various combinations of the variables x_1 and x_2 shall yield a profit of ₹ 280.

It may be observed that all the points that fall on this line (in the first quadrant of course) lie in the feasible region. So it is clearly possible for the firm to realise a profit of ₹ 280. In fact, even greater profit can be realised by moving to other iso-profit lines, corresponding to higher profit values. Look at the ₹ 840 iso-profit line, GH. Some of the points on this line fall outside the feasible region and, therefore, do not provide legitimate alternatives. However, other parts of this line fall in the feasible region. Therefore, a profit of ₹ 840 is attainable. The iso-profit line, JK corresponding to the profit of ₹ 1,120 lies beyond the feasible region, indicating that this profit cannot be attained.

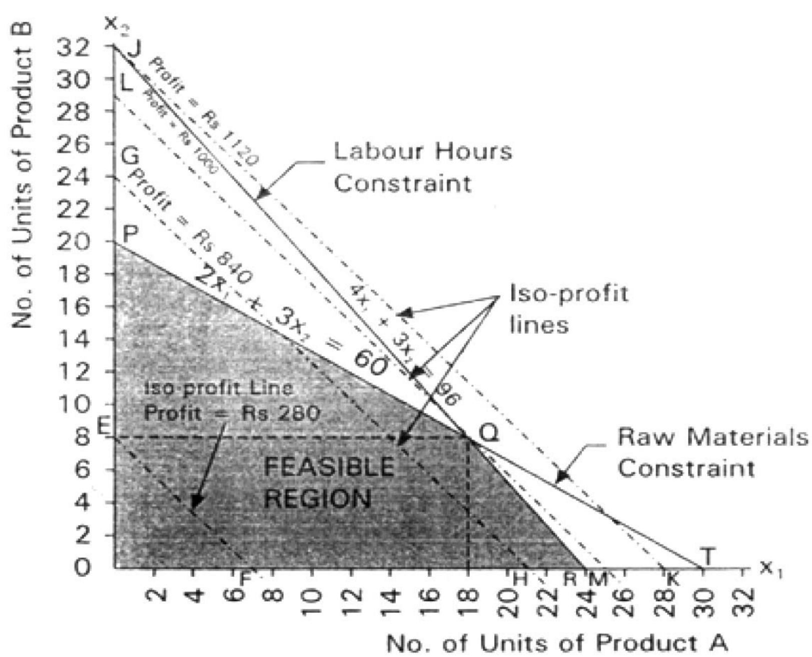


Fig. 2.10.2: Determination of Optimal Solution using Iso-profit Line

Notice that the iso-profit lines are all parallel to each other and the further are the lines removed from the origin of the graph, the greater is their contribution. Since all the lines have the same slope, the final step in the analysis is to continue constructing iso-profit lines that are successively farther away from the origin. This process would stop when a movement away from the origin would cause the line to lie beyond the feasible region. For our example, the line that would yield the maximum profit is LM that passes through the point Q. This point gives a maximum contribution and thus represents the optimal solution. This decision is for the production of 18 units of product A and 8 units of product B, for a total profit of ₹ 1,000.

The production of 18 units of A and 8 units of B will consume 2 x 18 + 3 × 8 = 60 kg of raw material and 4x18 + 3x8 = 96 labour hours. Hence, both the resources shall be fully utilised by this production plan.

The minimisation case Now, we shall consider the graphical solution to the linear programming problems of the minimisation nature. Here, **Illustration 2** is reconsidered.

Minimise $Z = 40x_1 + 24x_2$ Total cost

Subject to

$20x_1 + 50x_2 \geq 4800$ Phosphate Requirement

$80x_1 + 50x_2 \geq 7200$ Nitrogen Requirement

Here the decision variables x_1, and x_2 represent, respectively, the number of bags of mixture A and of mixture B, to be bought.

Graphing the restrictions. The constraints are plotted in **Figure 2.10.3**. The first constraint of phosphate requirement, $20x_1 + 50x_2 \geq 4800$ can be represented as follows. We set $20x_1 + 50x_2 = 4800$. Putting $x_1 = 0$,

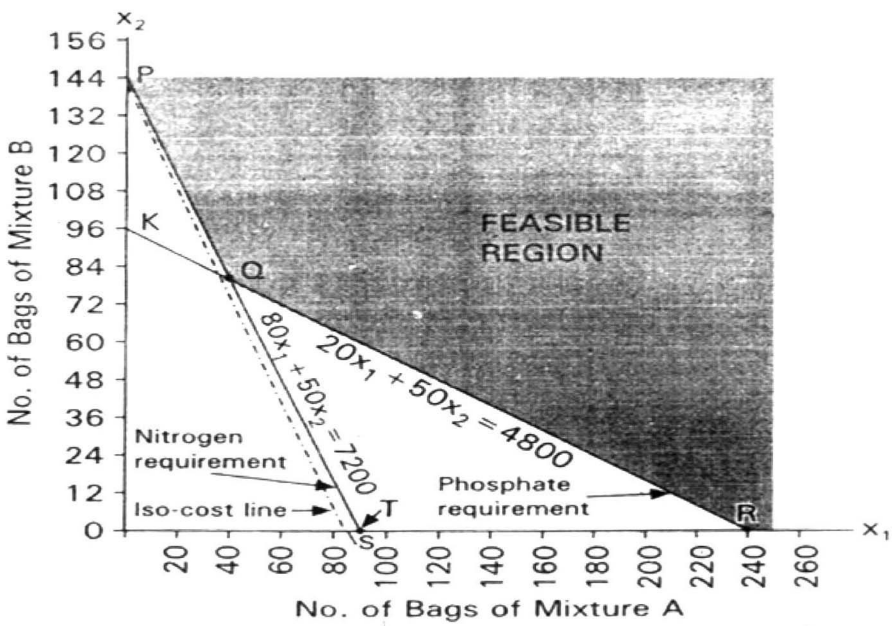


Fig. 2.10.3: Graphic Solution to the LLP

we get $x_2 = 96$ and putting $x_2 = 0$, we have $x_1 = 240$. Joining the two points (0, 96) and (240, 0), we get the straight line corresponding to the above equation. The area beyond this line represents the feasible area in respect of this constraint—any point on the straight line or in the region above this line would satisfy the constraint.

Similarly, the second constraint can be depicted by plotting the straight line corresponding to the equation $80x_1 + 50x_2 = 7200$. Line PT in the figure represents the equation. The points falling on this line and in the area beyond it indicate the feasible values of x_1 and x_2 in respect of this constraint.

Since both the requirements are to be met, the feasible region in respect of the problem is as represented by the shaded area.

The feasible region here represents a convex set. However, it is not bounded from all the sides, as was in case of the maximisation problem. The region is unbounded on the upper side because none of the restrictions in the problem places an upper limit on the value of either of the decision variables. Obviously, if such limits are placed, the feasible region would be bounded one.

Obtaining the optimal solution As in case of maximisation problems, the optimal solution can also be obtained by plotting the objective function on the graph in the form of iso-cost lines. For drawing an iso-cost line, we assume some cost value, equate the objective function with it, and plot the straight line corresponding to that equation on the graph. Obviously, each point on an iso-cost line would imply same cost value.

Since the total cost is to be minimised, the iso-cost line touching the feasible region, which is closest to the origin shall be the line that would provide optimal solution. In our example, the iso-cost line PS, which entails a cost of ₹ 3,456, is such line. Since it touches point P, the ordinates of this point (0, 144) provide the optimal solution.

With the optimal solution of 144 bags of mixture E only, the supply of phosphate would be 20 x 0 + 50 x 144 = 7,200 kg, which is in excess of the minimum requirement of 4,800 kg. On the other hand, the nitrogen supply would equal 80 x 0 + 50 x 144 = 7,200 kg, the required minimum.

Alternately, the optimal solution to the problem may be seen to be located at an extreme point- at point P, Q, or R in our example. We can evaluate the ordinates at each of these points as follows:

Point	x_1	x_2	$Z = 40x_1 + 24x_2$
P	0	144	3,456 ← Minimum
Q	40	80	3,520
R	240	0	9,600

Since the total cost is minimum at point P, the optimal solution to the problem is to buy 144 bags of mixture B only and none of mixture A. This would entail a total cost of ₹ 3,456.

Binding and non-binding constraints Once the optimal solution to an LPP is obtained, we may classify the constraints as being binding or non-binding. A constraint is termed as binding if the left hand side and right hand side of it are equal when optimal values of the decision variables are substituted into the constraint. On the other hand, if the substitution of the decision variables does not lead to an equality between the left and the right hand sides of the constraint, it is said to be non-binding. In **Illustration 1,** the optimal values of decision variables are: x_1 = 18 and x_2 = 8. Substituting these values in the two constraints we get

$2x_1 + 3x_2$ or $2 \times 18 + 3 \times 8 = 60$ = RHS, and

$4x_1 + 3x_2$ or $4 \times 18 + 3 \times 8 = 96$ = RHS

Thus, both the constraints are binding in nature. In **Illustration 2,** on the other hand, x_1 = 0 and x_2 = 144, the optimal values, may be substituted in the two constraints to get

$20x_1 + 50x_2$ or $20 \times 0 + 50 \times 144 = 7{,}200 \neq 4{,}800$ RHS, and

$80x_1 + 50x_2$ or $80 \times 0 + 50 \times 144 = 7{,}200$ = RHS

Accordingly, the first of the constraints is non-binding and the second one is a binding one.

Redundant constraint(s) As we have observed, plotting of each of the constraints on the graph serves to determine the feasible region of a given problem. If and when a constraint, when plotted, does not form part of the boundary marking the feasible region of the problem, it is said to be redundant. The inclusion or exclusion of a redundant constraint obviously does not affect the optimal solution to the problem.

Illustration 4:

Continuing with **Illustration 1,** suppose that each of the products are required to be packed. Every unit of product A requires 4 hours while every unit of product B needs 3.5 hours for packaging. Suppose that in the packaging department, 105 hours are available every week. Under these conditions, what product mix would maximise the profit?

Solution:

The problem can be restated as follows:

Maximise $Z = 40x_1 + 35x_2$ Profit

Subject to

$2x_1 + 3x_2 \le 60$ Raw material constraint

$4x_1 + 3x_2 \le 96$ Labour hours constraint

$4x_1 + 3.5x_2 \le 105$ Packaging hours constraint

$x_1, x_2 \ge 0$

The constraints and the objective function (in the form of iso-profit line) are charted in **Figure 2.10.4.**

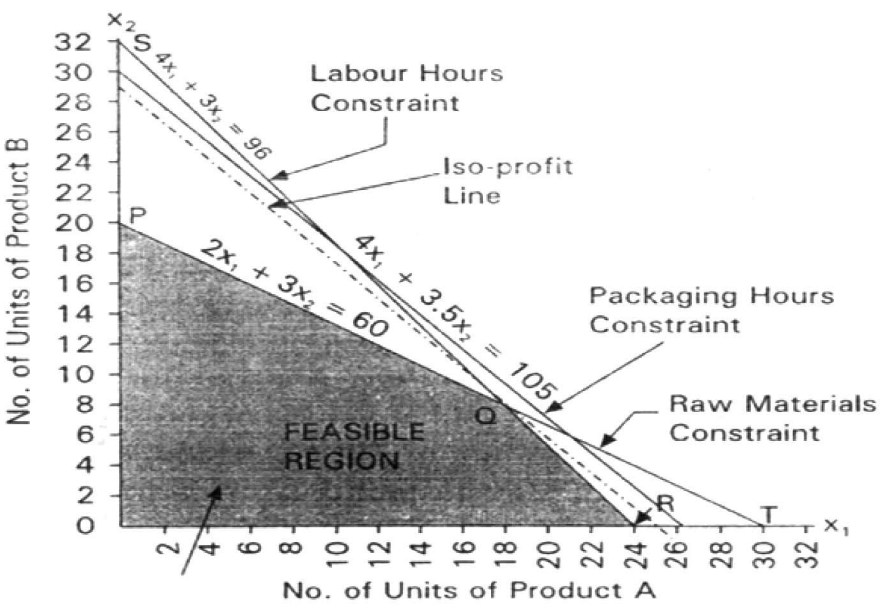


Fig. 2.10.4: Graphic Solution to LPP

We observe that the inclusion of the packaging hours constraint does not provide a side of the polygon representing the feasible region. Thus, this constraint is of no consequence and hence is redundant. The optimal solution to the problem is the same as the optimal solution to the problem in **Illustration 1.** Thus, we have $x_1 = 18$, $x_2 = 8$ representing the optimal solution. The product mix given by this shall consume the entire 60 kg of raw material and 96 labour hours, but shall leave an unused capacity of 105 - (4 x 18 + 3.5 x 8) = 5 hours in the packaging department.

Some Special Cases

In each of the three examples discussed so far, we have obtained a unique optimal solution. We now consider three types of linear programming problems which do not have unique optimal solutions. These are, respectively, problems having multiple optimal solutions, no feasible solution, and unbounded solutions.

1. Multiple optimal solutions As stated above, in each of the three examples that we have considered, we have observed that the optimal solution is given by an extreme point of the feasible region and the solution is unique. The uniqueness implies that no other solution to the given problem shall yield the same value of the objective function as given by that solution. It is, of course, possible that in a given problem there may be more than one optimal solution. Each of the multiple optima would naturally

yield the same objective function value.

The solution (if it exists) to a linear programming problem shall always be unique if the slope of the objective function (represented by the iso-profit lines) is different from the slopes of the constraints. In case the objective function has slope which is same as that of a constraint, then multiple optimal solutions might exist. There are two conditions that should be satisfied in order that multiple optimal solutions exist.

(a) The objective function should be parallel to a constraint that forms an edge or boundary on the feasible region; and

(b) The constraint should form a boundary on the feasible region in the direction of optimal movement of the objective function. In other words, the constraint must be a binding constraint.

To fully understand, let us consider the following examples.

Illustration 5:

Solve graphically the following LPP:

Maximise $Z = 8x_1 + 16x_2$

Subject to

$$x_1 + x_2 \le 200$$
$$x_2 \le 125$$
$$3x_1 + 6x_2 \le 900$$
$$x_1, x_2 \ge 0$$

Solution:

The constraints are shown plotted on the graph in **Figure 2.10.5.** Also, iso-profit lines have been graphed.

We observe that iso-profit lines are parallel to the equation for third constraint $3x_1 + 6x_2 = 900$. As we move the iso-profit line farther from the origin, it coincides with the portion BC of the constraint line that forms the

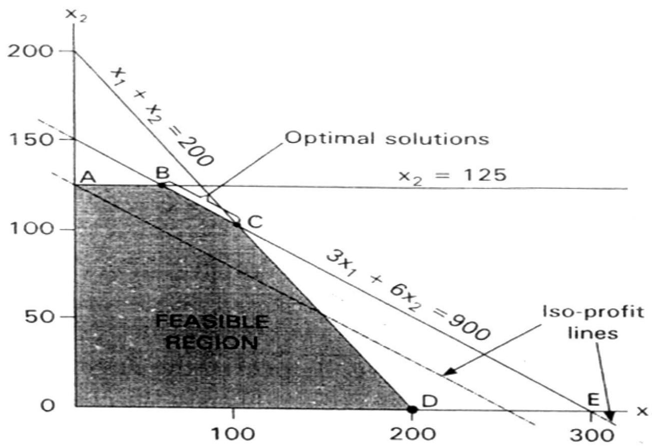


Fig. 2.10.5: Graphic Solution — Multiple Optima

boundary of the feasible region. It implies that there are an infinite number of optimal solutions represented by all points lying on the line segment BC, including the extreme points represented by B (50, 125) and C (100, 100). Since the extreme points are also included in the solutions, we may disregard all other solutions and consider only these ones to establish that the solution to a linear programming problem shall always lie at an extreme point of the feasible region.

The extreme points of the feasible region are given and evaluated here.

Point	x_1	x_2	$Z = 8x_1 + 16x_2$
O	0	0	0
A	0	125	2,000
B	50	125	2,400 } ← Maximum
C	100	100	2,400 }
D	200	0	1,600

The points B and C clearly represent the optima.

In this example, the constraint to which the objective function was parallel, was the one which formed a side of the boundary of the space of the feasible region. As mentioned in condition (a), if such a constraint (to which the objective function is parallel) does not form an edge or boundary of the feasible region, then multiple solutions would not exist. In **Illustration 3** for instance, the objective function has the same slope as that of the packaging hours constraint (see **Figure 2.10.4**), which is a redundant constraint. Since it does not contribute to the determination of the feasible region, the problem has an optimal solution that is unique and there are no multiple solutions.

Illustration 6:

Solve graphically:

MInimise $Z = 6x_1 + 14x_2$

Subject to

$$5x_1 + 4x_2 \leq 60$$

$$3x_1 + 7x_2 \leq 84$$

$$x_1 + 2x_2 \leq 18$$

$$x_1, x_2 \geq 0$$

The restrictions in respect of the given problem are depicted graphically in **Figure 2.10.6.** The feasible area has been shown shaded. It may be observed here that although the iso-cost line is parallel to the second constraint line represented by $3x_1 + 7x_2 = 84$, and this constraint does provide a side of the area of feasible solutions, yet the problem has a unique optimal solution, given by the point D. Here condition (b) mentioned earlier, is not satisfied. This is because, being a minimisation problem, the optimal movement of the objective function would be towards the origin and the constraint forms a boundary on the opposite side. Since the constraint is not a binding one, the problem does not have multiple optima.

We can show the uniqueness of the solution by evaluating various extreme points as done here.

Point	x_1	x_2	$Z = 6x_1 + 14x_2$
A	8	5	118
B	84/23	240/23	168
C	28	0	148
D	18	0	108 ← Minimum

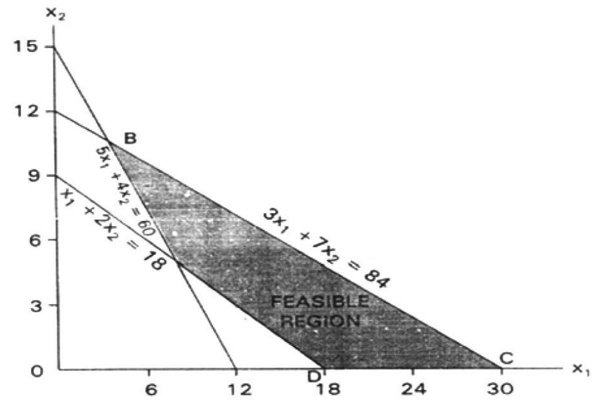


Fig. 2.10.6: Graphic Solution to LPP

2. Infeasibility It has already been stated that a solution is called feasible if it satisfies all the constraints and the non-negativity conditions. Sometimes it is possible that the constraints may be inconsistent so that there is no feasible solution to the problem. Such a situation is called infeasibility.

   In the graphic approach to the solution to an LPP, the infeasibility is evident if its feasible region is empty so that there is no feasible region in which all the constraints may be satisfied simultaneously. Consider the following example.

Illustration 7:

Maximise $Z = 20x_1 + 30x_2$

Subject to

$$2x_1 + x_2 \leq 40$$
$$4x_1 - x_2 \leq 20$$
$$x_1 \leq 30$$
$$x_1, x_2 \geq 0$$

Solution:

It is represented graphically in **Figure 2.10.7.** The feasible region corresponding to the first two constraints is bound by the convex set OABC, while the feasible region in respect of the third constraint is also shown shaded separately. We can easily observe that there is no common point in the areas shaded.

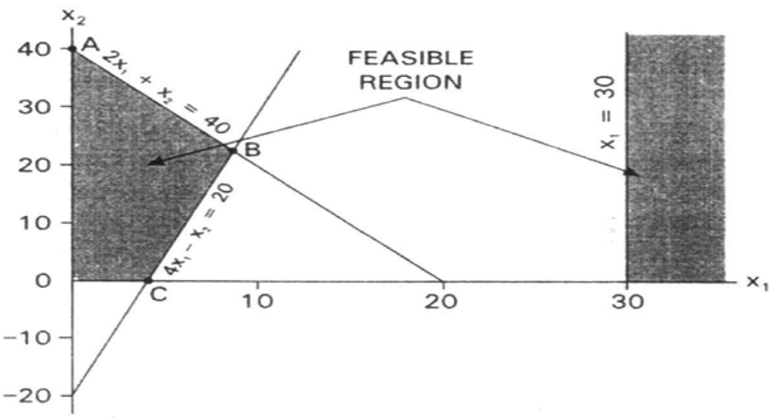


Fig. 2.10.7: Infeasibility

Therefore all the constraints cannot be satisfied and, as such, there is no feasible solution to the given problem.

3. **Unboundedness** For a maximisation type of linear programming problem, unboundedness occurs when there is no constraint on the solution so that one or more of the decision variables can be increased indefinitely without violating any of the restrictions (constraints). Thus, an unbounded LPP occurs if it is possible to find points in the feasible region with arbitrarily large Z-values (may be profit or revenue). This suggests that practically if we find the solution to be unbounded for a profit-maximising linear programming problem, it may be concluded that the problem has not been correctly formulated. Consider the following example.

Illustration 8:

Maximise $Z = 10x_1 + 20x_2$

Subject to

$$2x_1 + 4x_2 \le 16$$
$$x_1 + 5x_2 \le 15$$
$$x_1, x_2 \ge 0$$

Solution:

This is represented graphically in **Figure 2.10.8**.

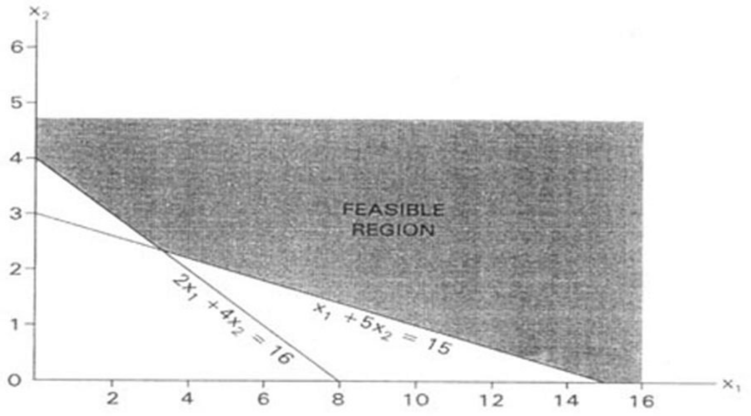


Fig. 2.10.8: Unboundedness

Clearly, here the objective function is not bound over the feasible region and we can move the iso-profit line upward without any limit. The problem has, therefore, unbounded solution.

For a minimisation LPP, unboundedness occurs when there are points in the feasible region with arbitrarily small values. To conclude, a maximisation LPP is unbounded if, moving parallel to the original iso-profit line in the direction of increasing Z, we never entirely leave the feasible region and, on the other hand, a minimisation problem is unbounded if we never leave the feasible region while moving in the direction of decreasing Z.

Infeasibility vs Unboundedness

Both infeasibility and unboundedness have a similarity in that there is no optimal solution in either case. But there is a striking difference between the two, while in infeasibility there is not a single feasible solution, in unboundedness there are infinite feasible solutions but none of them can be termed as the optimal.

Illustrations 9:

A 24-hour supermarket has the following minimal requirements for cashiers:

Period	1	2	3	4	5	6
Time of day (24-hour clock)	3-7	7-11	11-15	15-19	19-23	23-03
Minimum number required	7	20	14	20	10	5

Period 1 follows immediately after period 6. A cashier works eight consecutive hours, starting at the beginning of one of the six time periods. Determine a daily employee worksheet which satisfies the requirements with the least number of personnel. Formulate the problem as a linear programming problem.

Solution:

Let x_1, x_2, x_3, x_4, x_5 and x_6 be the number of cashiers joining at the beginning of periods 1, 2, 3, 4, 5 and 6, respectively. Using the information given, the LPP may be expressed as follows:

Minimise $\quad Z = x_1 + x_2 + x_3 + x_4 + x_5 + x_6$

Subject to

$$
\begin{aligned}
x_1 + \qquad\qquad\qquad\quad x_6 &\geq 7 \\
x_1 + x_2 \qquad\qquad\qquad &\geq 20 \\
x_2 + x_3 \qquad\qquad &\geq 14 \\
x_3 + x_4 \qquad &\geq 20 \\
x_4 + x_5 &\geq 10 \\
x_5 + x_6 &\geq 5
\end{aligned}
$$

$x_i \geq 0$, for i = 1,2,…………6

Illustration 10:

An agriculturist has a 125-acre farm. He produces radish, muttar and potato. Whatever he raises is fully sold in the market. He gets ₹ 5 for radish per kg, ₹ 4 for muttar per kg and ₹ 5 for potato per kg. The average per acre yield is 1500 kg of radish, 1800 kg of muttat and 1200 kg of potato. To produce each 100 kg of radish and muttar and 80 kg of potato, a sum of ₹ 12.50 has to be used for manure. Labour required for each acre to raise the crop is 6 man-days for radish and potato each and 5 man-days for mutter. A total of 500 man-days of labour at a rate of ₹ 40 per man-day are available.

Formulate this as a Linear programming model to maximize the agriculturist's total profit.

Solution:

Let x_1, x_2, x_3 be the acrage for radish, muttar and potato, respectively. From the given information,

Output: Output of radish = 1500 x_1 kg

Output of muttar = 1800 $x_2$kg

Output of potato = 1200 x_3 kg

Cost of Manure: Radish : ₹ 12.50 per 100 kg

Muttar : ₹ 12.50 per 100 kg

Potato : ₹ 12.50 per 80 kg

Accordingly,

Total cost of manure = $\frac{12.50}{100} \times 1500x_1 + \frac{12.50}{100} \times 1800x_2 + \frac{12.50}{100} \times 1200x_3$

$= 187.5x_1 + 225x_2 + 187.5x_3$

Labour cost:

Radish : $6x_1 \times 40 = 240\ x_1$

Muttar : $5x_2 \times 40 = 200\ x_2$

Potato : $6x_3 \times 40 = 240\ x_3$

Now,

Total Profit = Revenue - (Cost of Manure + Labour Cost)

$= 5 \times 1500x_1 + 4 \times 1800x_2 + 5 \times 1200x_3 - (187.5x_1 + 225x_2 + 187.5x_3 + 240x_1 + 200x_2 + 240x_3)$

$= 7072.5x_1 + 6775x_2 + 5572.5x_3$

Now, with constraints on land availability and man-days availability, the LPP may be expressed as follows:

Maximise $Z = 7072.5x_1 + 6775x_2 + 5572.5x_3$

Subject to

$x_1 + x_2 + x_3 \leq 125$ (Land availability)

$6x_1 + 5x_2 + 6x_3 \leq 500$ (Man-days availability)

$x_1, x_2, x_3 \geq 0$

Illustration 11:

A manufacturing firm needs 5 component parts. Due to inadequate resources, the firm is unable to manufacture all its requirements. Thus, the management is interested in determining as to how many, if any, units of each component should be purchased from outside and how many should be produced internally. The relevant data are given here.

Component	M	A	T	TR	PP	PC
C_1	4	1	1.5	20	48	30
C_2	3	3	2	50	80	52
C_3	1	1	0	45	24	18
C_4	3	1	0.5	70	42	31
C_5	2	0	0.5	40	28	16

M: Per unit milling time in hours

A: Per unit assembly time in hours

T: Per unit testing time in hours

TR: Total requirement in units

PP: Price per unit quoted in the market

PC: Per unit direct costs (including materials, labour etc.)

Resources available are as follows:

Milling hours : 300

Assembly hours : 160

Testing hours : 150

Formulate this as an LPP, taking the objective function as maximisation of saving by producing the components internally.

Solution:

Let x_1, x_2, x_3, x_4, and x_5 represent the number of C_1, C_2, C_3, C_4, and C_5, respectively, produced internally.

Information Summary

Resources/ Constraints	Component					Total Availability
	C_1	C_2	C_3	C_4	C_5	
Milling hrs (per unit)	4	3	1	3	2	300
Assembly hrs (per unit)	1	3	1	1	0	160
Testing hrs (per unit)	1.5	2	0	0.5	0.5	150
Requirement (units)	20	50	45	70	40	
Saving (per unit) (PP-PC)	18	28	6	11	12	

The problem would be:

Maximise $Z = 18x_1 + 28x_2 + 6x_3 + 11x_4 + 12x_5$

Subject to

$$4x_1 + 3x_2 + x_3 + 3x_4 + 2x_5 \leq 300$$
$$x_1 + 3x_2 + x_3 + x_4 \leq 160 \quad \text{Capacity constraints}$$
$$1.5x_1 + 2x_2 + 0.5x_4 + 0.5x_5 \leq 150$$

$$x_1 \leq 20$$
$$x_2 \leq 50$$
$$x_3 \leq 45 \quad \text{'Total requirements' constraints}$$
$$x_4 \leq 70$$
$$x_5 \leq 40$$

$$x_1, x_2, x_3, x_4, x_5 \geq 0 \quad \text{Non-negativity condition}$$

Illustration 12:

A firm produces three products A, B and C. It uses two types of raw materials I and II of which 5,000 and 7500 units, respectively, are available. The raw material requirements per unit of the products are given below:

	Requirement per Unit of Product		
	A	B	C
I	3	4	5
II	5	3	5

The labour time for each unit of product A is twice as that of product B and three times that of product C. The entire labour force of the firm can produce the equivalent of 3000 units. The minimum demand for the three products is 600, 650 and 500 units respectively. Also, the ratio of the number of units produced must be equal to 2 : 3 : 4. Assuming the profits per unit of A, B and C are 50, 50 and 80, respectively, formulate the problem as a linear programming problem in order to determine the number of units of each product which will maximise the profit.

Solution:

Let, x_1, x_2 and x_3 be the output of products A, B and C, respectively. The LPP, using the given information, may be expressed as follows:

Maximise $\quad Z = 50x_1 + 50x_2 + 80x_3 \quad$ Total Profit

Subject to

$$3x_1 + 4x_2 + 5x_3 \leq 5000 \quad \text{Raw Material I}$$

$$5x_1 + 3x_2 + 5x_3 \leq 7500 \quad \text{Raw Material II}$$

$$x_1 \geq 600$$

$$x_2 \geq 650 \quad \text{Minimum demand}$$

$$x_3 \geq 500$$

$$x_1 + \frac{1}{2}x_2 + \frac{1}{3}x_3 \leq 3{,}000 \quad \text{Labour}$$

$$\frac{x_1}{2} = \frac{x_2}{3} = \frac{x_3}{4} \quad \text{Output proportionality}$$

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

Notes:

I. In the absence of a statement to the contrary, it is assumed that availability of labour is sufficient to produce equivalent to 1000 units of product A.

2 In a given case, if the output of two products A and B, is desired to be in a given ratio, say 2 : 3, we may express it as 3A = 2B or A/2 = B/3. For example, if the outputs are 10 and 15 (in the ratio 2 : 3), then we have 3 x 10 = 2 x 15 or 10/2 = 15/3. Accordingly, when three products have to be in the ratio 2 : 3 : 4, we write $x_1/2 = x_2/3 = x_3/4$.

Illustration 13:

The Marketing Department of Everest Company has collected information on the problem of advertising for its products. This relates to the advertising media available, the number of families expected to be reached with each alternative, cost per advertisement, the maximum availability of each medium and the expected exposure of each one (measured as the relative value of one advertisement in each of the media): The information is as given here:

Advertising Media	No. of Families Expected to Cover	Cost per Ad (₹)	Maximum Availability (No. of times)	Expected Exposure (Units)
TV (30 sec)	3,000	8,000	8	80
Radio (15 sec)	7,000	3,000	30	20
Sunday edition of daily ($\frac{1}{4}$ page)	5,000	4,000	4	50
Magazine (1 page)	2,000	3,000	2	60

Other information and requirements:

(a) The advertising budget is ₹ 70,000.

(b) At least 40,000 families should be covered. (The families receiving messages could be common. But a family receiving three messages, for example, would be taken to be equivalent to three).

(c) At least 2 insertions be given in Sunday edition of Daily but not more than 4 ads should be given on the TV.

Draft this as a linear programming problem. The company's objective is to maximise the expected exposure.

Let x_1 : the number of ads in TV,

x_2 : the number of ads in Radio,

x_3 : the number of ads in Sunday edition of Daily, and

x_4 : the number of ads in Magazine.

Information Summary

Constraints	Advertising Media				Total
Resources	**TV**	**Radio**	**Daily**	**Magazine**	
No. of families (per ad)	3,000	7,000	5,000	2,000	40,000
Cost (per ad) and Budget (₹)	8,000	3,000	4,000	3,000	70,000
Max. Availability (No.)	8	30	4	2	
Other information:					
(i) at least two ads in Daily					
(ii) at most four ads on TV					
Expected Exposure (Units per ad)	80	20	50	60	

The problem would be as under:

Maximise $Z = 80x_1 + 20x_2 + 50x_3 + 60x_4$

Subject to

$$3000x_1 + 7000x_2 + 5000x_3 + 2000x_4 \geq 40000$$
$$8000x_1 + 3000x_2 + 4000x_3 + 3000x_4 \leq 70000$$
$$x_1 \leq 8$$
$$x_2 \leq 30$$
$$x_3 \leq 4$$
$$x_4 \leq 2$$
$$x_3 \geq 2$$
$$x_1 \leq 4$$
$$x_1, x_2, x_3, x_4 \geq 0$$

Illustration 14:

The Orient Manufacturing Company produces three types of typewriters: Tik-Tik, Mik-Mik, and Pik-Pik. All the three types are required first to be machined and then to be assembled. The time requirements for the various types are as follows:

Type	Machine Time (in hours)	Assembly Time (in hours)
Tik-Tik	15	4.4
Mik-Mik	13	3.5
Pik-Pik	12	4.0

The total available machine time and assembly times are, respectively, 4,000 and 1,240 hours per month.

The data regarding selling price, costs, and the contribution margin for the three are:

	Tik-Tik (₹)	Mik-Mik (₹)	Pik-Pik (₹)
Selling prices:	11,000	5,000	3,000
Labour, material & other variable expenses:	8,000	2,400	1,500
Contribution margin:	3,000	2,600	1,500

The company sells all the three on one month credit basis, but labour, material and other variable expenses must be paid in cash. Some further information follows. The company has taken a loan of ₹ 40,000 from a co-operative bank and has just been informed by the bank that the loan is not likely to be renewed when it expires at the beginning of the next month, viz. 1st January. The Good Bank-of India, from whom the company has borrowed ₹ 60,000, has expressed its willingness to renew the loan provided that the company maintains a quick ratio (i.e. the ratio of cash to the short term liabilities) of at least 1.

The balance sheet of the company as on 31st December is as follows:

Balance Sheet as on 31st December

Liabilities	₹	Assets	₹
Loan from Coop. Bank	40,000	Cash	2,00,000
Loan from Good Bank of India	 60,000	Receivables Plant & Machinery	50,000 2,50,000
Long Term Debt	2,50,000		
Net Worth	150,000		
	5,00,000		5,00,000

It is further given that the company has to pay a fixed sum of ₹ 10,000 each for interest on debt and for top management salaries every month.

Now, upon being informed about the co-operative bank's decision, the senior manager of the company requires this problem to be put as a linear programming problem, assuming that (a) he wants to maximise the profits, and (b) he wants to maximise the total revenue from sales. Do it for him.

Solution:

Let x_1, x_2, x_3 be the number of units of Tik-Tik, Mik-Mik, and Pik-Pik produced.

Information Summary

Constraints/Resources		Typewriter		Total
	Tik-Tik	**Mik-Mik**	**Pik-Pik**	
Machine Hours	15/unit	13/unit	12/unit	4,000
Assembly Hours	4.4/unit	3.5/unit	4.0/unit	1,240
Cash (₹) (for labour, materials and other various expens-es)	8,000	2,400	1,500	1,30,000*
Selling Price per unil (₹)	1,1000	5,000	3,000	
Contribution Margin (₹) per unit				
(Selling Price - Variable Exp.)	3,000	2,600	1,500	

*Cash available is calculated as:

Cash Balance + Amt. from Receivables (to be received in January) - Co-operative Bank loan to be paid off - cash required for debt interest and top management salaries - cash required for matching the loan from Good Bank of India (which wants the quick ratio to be equal to 1) = 2,00,000 + 50,000 - 40,000 - 20,000 - 60,000 = 1,30,000

(a) When the objective is to maximise profits:

Maximise $Z = 3{,}000x_1 + 2{,}600x_2 + 1{,}500x_3$

Subject to

$15x_1 + 13x_2 + 12x_3 \leq 4{,}000$

$4.4x_1 + 3.5x_2 + 4.0x_3 \leq 1240$ Capacity constraints

$8{,}000x_1 + 2{,}400x_2 + 1{,}500x_3 \leq 1{,}30{,}000$ Cash constraint

$x_1, x_2, x_3, x_4 \geq 0$ Non-negativity condition

(b) When the objective is to maximise total revenue, the objective function would be:

Maximise $Z = 11,000x_1 + 5,000x_2 + 3,000x_3$

While all other constraints would be the same as shown in (a).

Illustration 15:

A leading Chartered Accountant is attempting to determine a "best" investment portfolio and is considering six alternative investment proposals. The following table indicates point estimates for the price per share, the annual growth rate in the price per share, the annual dividend per share and a measure of the risk associated with each investment.

Portfolio Data

Shares under	**Consideration**					
	A	B	C	D	E	F
Current Price per share (₹)	80	100	160	120	150	200
Projected Annual Growth Rate	0.08	0.07	0.10	0.12	0.09	0.15
Projected Annual Dividend per Share (₹)	4.00	4.50	7.50	5.50	5.75	0.00
Projected Risk in Return	0.05	0.03	0.10	0.20	0.06	0.08

The total amount available for investment is ₹ 25 lakhs and the following conditions are required to be satisfied.

(i) The maximum rupee amount to be invested in alternative F is ₹ 250,000.

(ii) No more than ₹ 5,00,000 should be invested in alternatives A and B combined,

(iii) Total weighted risk should not be greater than 0.10 where

$$\text{Total Weighted Risk} = \frac{\text{(Amount invested in Alternative j) (Risk of Alternative j)}}{\text{(Total amount invested in all the Alternative)}}$$

(iv) For the sake of diversity, at least 100 shares of each stock should be purchased.

(v) At least 10 percent of the total investment should be in alternatives A and B combined.

(vi) Dividends for the year should be at least ₹ 10,000.

Rupee return per share of stock is defined as price per share one year hence less current price per share plus dividend per share. If the objective is to maximise total rupee return, formulate the linear programming model for determining the optimal number of shares to be purchased in each of the shares under consideration. You may assume that the time horizon for the investment is one year. The formulated LP problem is not required to be solved.

Solution:

Let x_1, x_2, x_3, x_4, x_5 and x_6 be the number of shares of companies A, B, C, D, E and F, respectively. The rupee-return for various shares is shown below.

	Share					
	A	**B**	**C**	**D**	**E**	**F**
Projected growth per share (₹)	6.40	7.00	16.00	14.40	13.50	30.00
Projected Dividend	4.00	4.50	7.50	5.50	5.75	0.00
Rupee-return per share	10.40	11.50	23.50	19.90	19.25	30.00

Accordingly, the objective function is:

Maximise $\quad Z = 10.40x_1 + 11.50x_2 + 23.50x_3 + 19.90x_4 + 19.25x_5 + 30.00x_6$

The constraints are as follows :

$80x_1 + 100x_2 + 160x_3 + 120x_4 + 150x_5 + 200x_6 \le 25{,}00{,}000$ funds availability

$200x_6 \le 2{,}50{,}000$ condition (i)

Total Weighted Risk

$$\frac{(80x_1)(0.05)+(100x_2)(0.03)+(160x_3)(0.10)+(120x_4)(0.20)+(150x_5)(0.06)+(200x_6)(0.08)}{80x_1+100x_2+160x_3+120x_4+150x_5+200x_6} \le 0.10$$

On simplification, it gives

$- 4x_1 - 7x_2 + 12x_4 - 6x_5 - 4x_6 \le 0$

From condition (iv), $x_i \ge 100$ for i = 1,2, 3, 4,5, 6

Condition (v) requires $80x_1 + 100x_2 \ge 0.10\ (80x_1 + 100x_2 + 160x_3 + 120x_4 + 150x_5 + 200x_6)$

This becomes, $72x_1 + 90x_2 + 6x_3 - 12x_4 - 15x_5 - 20x_6 \ge 0$

The dividend requirement states that

$4x_1 + 4.50x_2 + 7.50x_3 + 5.50x_4 + 5.75x_5 \ge 10{,}000$

Accordingly, the LPP may be stated as follows:

Maximise $\quad Z = 10.40x_1 + 11.50x_2 + 23.50x_3 + 19.90x_4 + 19.25x_5 + 30.00x_6$

Subject to

$$\begin{array}{lll}
80x_1 + 100x_2 + 160x_3 + 120x_4 + 150x_5 + 200x_6 & \le 25{,}00{,}000 & \\
200x_6 & \le 2{,}50{,}000 & \\
80x_1 + 100x_2 & \le 5{,}00{,}00 & \\
-4x_1 - 7x_2 + 12x_4 - 65x_5 - 4x_6 & \le 0 & \\
72x_1 + 90x_2 - 16x_3 - 12x_4 - 15x_5 - 20x_6 & \ge 0 & \\
4x_1 + 4.5x_2 + 7.5x_3 + 5.50x_4 + 5.75x_5 & \ge 10{,}000 & \\
x_1 & \ge 100 & \\
x_2 & \ge 100 & \\
x_3 & \ge 100 & \\
x_4 & \ge 100 & \\
x_5 & \ge 100 & \\
x_6 & \ge 100 & \\
x_1, x_2, x_3, x_4, x_5 \ge 0 & & \text{Non-negativity condition}
\end{array}$$

Illustration 16:

A company engaged in producing tinned food delicacies has 300 trained employees on rolls each of whom can produce one can of food in a week. Due to the developing taste of the public for this kind of food, the company plans to add the existing labour force by employing 150 people, in a phased manner, over the next five weeks. The newcomers would have to undergo a two-week training programme before being put to work. The training is to be given by employees from amongst the existing ones and it is known that one employee can train three trainees. Assume that there would be no production coming forth from the trainers and the trainees during training period as the training is off-the-job. However, the trainees would be remunerated at the rate of ₹ 300 per week, the same rate as is for the trainers.

The company has booked the following number of cans to supply during the next five weeks.

Week	:	1	2	3	4	5
No. of Cans	:	280	298	305	360	400

Assume that the production in any week would not be more than the number of cans ordered for so that every delivery of the food delicacy would be 'fresh'.

Using this information, draft a LPP to develop a training schedule that will minimise the labour costs over the five week period.

Solution:

Let x_1, x_2, x_3, x_4, and x_5 be the number of trainees appointed in beginning of week 1, 2, 3, 4, and 5 respectively.

Information Summary

	Week				
	1	2	3	4	5
Cost required	280	298	305	360	400

Other Information :

(a) every trainee to be trained for 2 weeks

(b) one employee required to train 3 trainees

(c) every trained worker producing 1 can per week but no production from trainers and trainees during training

(d) number of people to be employed = 150

(e) the production in any week not to exceed the cans required

No. of weeks for which newcomer would be employed* 5 4 3 2 1

*Thus, workers employed at the beginning of the first week would get salary for all 5 weeks under consideration, those employed at the beginning of the second week would get it for 4 weeks, and like that. The problem would be:

Minimise $Z = 5x_1 + 4x_2 + 3x_3 + 2x_4 + x_5$

Subject to

$$\left.\begin{array}{ll} 300 - \frac{1}{3}x_1 & \geq 280 \\ 300 - \frac{1}{3}x_1 - \frac{1}{3}x_2 & \geq 298 \\ 300 + x_1 - \frac{1}{3}x_2 - \frac{1}{3}x_3 & \geq 305 \\ 300 + x_1 + x_2 - \frac{1}{3}x_3 - \frac{1}{3}x_4 & \geq 360 \\ 300 + x_1 + x_2 + x_3 - \frac{1}{3}x_4 - \frac{1}{3}x_5 & \geq 400 \end{array}\right\} \text{Capacity constraints}$$

$$x_1 + x_2 + x_3 + x_4 + x_5 = 150 \quad \text{New Employment condition}$$

$$x_1, x_2, x_3, x_4, x_5 \geq 0 \quad \text{Non-negativity condition}$$

Notes (a) All along, the 300 employees, capable of producing 300 cans a week remain employed. The production capacity in different weeks (as shown on LHS of the constraints) is affected (negatively) by the fact that some of them are away for training and is affected (positively) by the fact that newcomers join the team of experienced workers.

(b) Inequalities have been used in the constraints because some workers might remain idle in some week(s).

(c) The training schedule as obtained by solving this problem would involve minimum cost in respect of the trainees. The cost would be obtained by multiplying the objective function by 300 because each person would get a salary of Rs 300 per week.

Illustration 17:

Solve graphically:

Maximise $Z = 10x_1 + 15$

Subject to

$$2x_1 + x_2 \leq 26$$
$$2x_1 + 4x_2 \leq 56$$
$$x_1 - x_2 \geq -5$$
$$x_1, x_2, \geq 0$$

Solution:

This problem is exhibited graphically in **Figure 2.10.9**. The feasible region is shaded. This is significant to note here that we have not considered the area below the line corresponding to $x_1 - x_2 = -5$ for the negative values of x_1. This is because of the non negativity condition $x_1 \geq 0$, which implies that negative values of x_1 should not be considered.

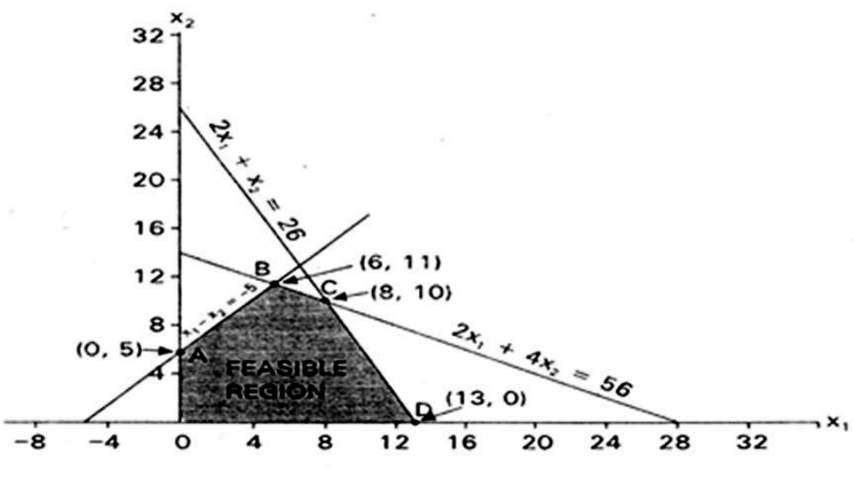


Fig. 2.10.9: Grade Solution to the LPP

The Z-values at different points are given here:

Point	x_1	x_2	$Z=10\,x_1 + 15\,x_2$
A	0	5	75
B	6	11	225
C	8	10	230
D	13	0	130

Thus Z is maximum (it is equal to 230) when $x_1 = 8$ and $x_2 = 10$.

Illustration 18:

Solve graphically the following linear programming problem:

MInimise $Z = 3x_1 + 5x_2$

Subject to

$$-3x_1 + 4x_2 \leq 12$$
$$2x_1 + 3x_2 \geq 12$$
$$2x_1 - x_2 \geq -2$$
$$x_1 \leq 4 \; ; x_2 \geq 2$$
$$x_1, x_2 \geq 0$$

The given problem is depicted graphically in **Figure 2.10.10**. The feasible region is shaded and is bounded by ABCDE.

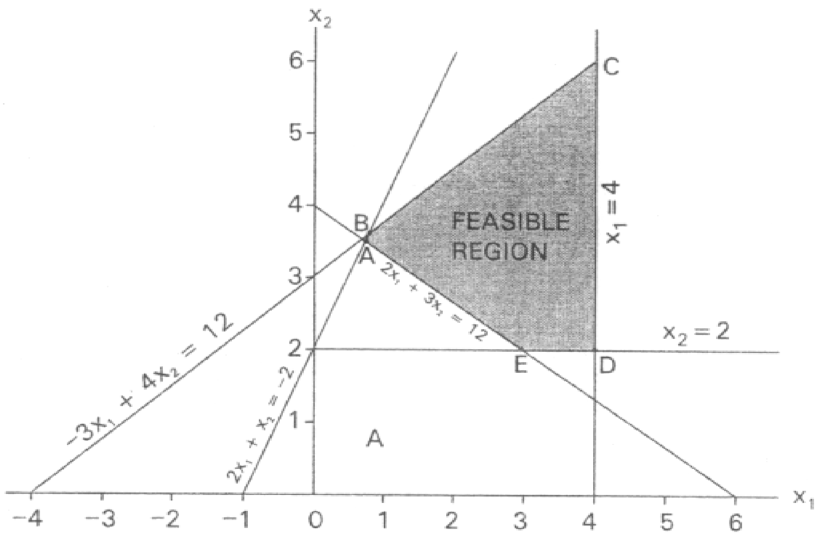


Fig. 2.10.10: Graphic Solution to the LLP

The different points are evaluated here:

Point	x_1	x_2	$Z= 3x_1 + 5x_2$
A	0.75	3.5	19.75
B	0.8	3.6	20.40
C	4.0	6.0	42.00
D	4.0	2.0	22.00
E	3.0	2.0	19.00*

Thus Z is minimum at x_1 = 3 and x_2 = 2. Its value is 19.

Illustration 19:

A retired person wants to invest upto an amount of ₹ 30,000 in fixed income securities. His broker recommends investing in two bonds : Bond A yielding 7% and Bond B yielding 10%. After some consideration, he decides to invest at most ₹ 12,000 in Bond B and at least ₹ 6,000 in Bond A. He also wants the amount invested in Bond A to be at least equal to the amount invested in Bond B. What should the broker recommend if the investor wants to maximise his return on investment? Solve graphically.

Solution:

Let, x_1 and x_2 be the amount invested in Bonds A and B, respectively. Using the given data, we may state the problem as follows:

Maximise $Z = 0.07x_1 + 0.10x_2$

Subject to

$$x_1 + x_2 \leq 30000$$
$$x_1 \geq 6000$$
$$x_2 \leq 12000$$
$$x_1 - x_2 \geq 0$$
$$x_1, x_2, \geq 0$$

The constraints are plotted graphically in **Figure 2.10.11**. The feasible region is shown shaded and is bound by points A, B, C, D and E.

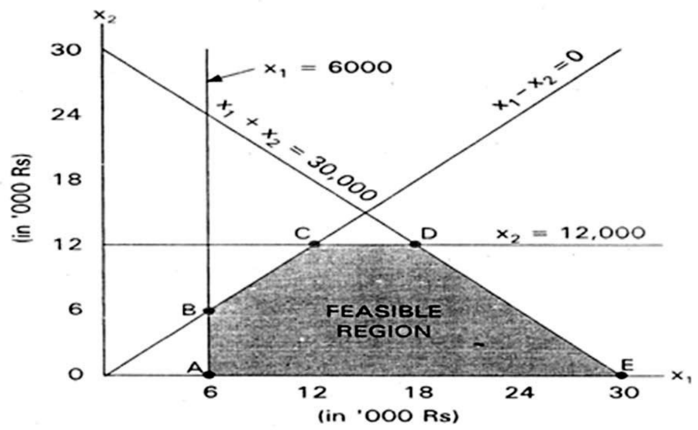


Fig. 2.10.11: Graphic Determination of Investment Mix

The extreme points are evaluated here.

Point	x_1	x_2	$Z= 0.07x_1 + 0.10x_2$
A	6000	0	420
B	6000	6000	1020
C	12000	12000	2040
D	18000	12000	2460
E	30000	0	2100

The Z-value is maximum at point D. Accordingly, the optimal solution is: invest ₹ 18,000 in Bond A and ₹ 12000 in Bond B. It would yield a return of ₹ 2,460.

Illustration 20:

A local travel agent is planning a charter trip to a major sea port. The eight day/seven night package includes the fare for round trip, surface transportation, board and lodging and selected tour options. The charter trip is restricted to 200 persons and the past experience indicates that there will not be any problem for getting 200 clients. The problem for the travel agent is to determine the number of Deluxe, Standard and Economy tour packages to offer for this charter. These three plans differ according to seating and service for the flight, quality of accommodations, meal plans and tour options. The following table summarizes the estimated prices for the three packages and the corresponding expenses for the travel agent. The travel agent has hired an aircraft for the flat fee of ₹ 2,00,000 for the entire trip. In planning the trip, the following considerations must be taken into account:

(i) At least 10% of the packages must be of the Deluxe type.

(ii) At least 35% but not more than 70% must be of the Standard type.

(iii) At least 30% must be of the Economy type.

(iv) The maximum number of Deluxe packages available in any aircraft is restricted to 60.

(v) The Hotel desires that at least 120 of the tourists should be on the Deluxe and Standard packages taken together.

Price and Costs for Tour Packages per Person

Tour Plan	**Price**	**Hotel Costs**	**Meal and Other Expenses**
Deluxe	10,000	3,000	4,750
Standard	7,000	2,200	2,500
Economy	6,500	1,900	2,200

The travel agent wishes to determine the number of packages to offer in each type so as to maximize the total profit.

(a) Formulate this as a linear programming problem.

(b) Restate the above LPP in terms of two decision variables, taking advantage of the fact that 200 packages will be sold.

(c) Find the optimal solution using graphical method for the restated problem and interpret your results.

Solution:

(a) x_1, x_2, and x_3 be the number of packages of Deluxe, Standard and Economy types, respectively. From the given information, unit profits for each of the three types can be obtained as under:

Deluxe Package : 10,000 - (3,000 + 4,750) = 2,250

Standard Package : 7,000 - (2,200 + 2,500) = 2,300

Economy Package : 6,500 - (1,900+ 2,200) = 2,400

With a hiring fee of ₹ 2,00,000, the objective function can be expressed as:

Maximise $Z = 2{,}250x_1 + 2{,}300x_2 + 2{,}400x_3 - 2{,}00{,}000$

From the conditions given in the question, we have

$x_1 \geq 20$ condition (i)

$x_2 \geq 70$ and $x_2 \leq 140$ condition (ii)

$x_3 \geq 60$ condition (iii)

$x_1 \leq 60$ condition (iv) and

$x_1 + x_2 \geq 120$ condition (v)

Also, $x_1 + x_2 + x_3 = 200$

Accordingly, the LPP can be stated as follows:

Maximise $Z = 2{,}250x_1 + 2{,}300x_2 + 2{,}400x_3 - 2{,}00{,}000$

From the conditions given in the question, we have

$$20 \le x_1 \le 60$$
$$70 \le x_2 \le 140$$
$$x_3 \ge 60$$
$$x_1 + x_2 \ge 120$$
$$x_1 + x_2 + x_3 = 200$$
$$x_1, x_2, x_3 \ge 0$$

(b) Since $x_1 + x_2 + x_3 = 200$, we have $x_3 = 200 - x_1 - x_2$. Substituting it in the above relations, the LPP can be re-expressed as follows:

Maximise $Z = -150x_1 - 100x_2 + 2{,}80{,}000$

Subject to

$$20 \le x_1 \le 60$$
$$70 \le x_2 \le 140$$
$$120 \le x_1 + x_2 \le 140$$
$$x_1, x_2 \ge 0$$

(c) The problem is solved graphically as shown in **Figure 2.10.12**.

Point	x_1	x_2	$Z(=-150x_1 - 100x_2 + 2{,}80{,}000)$
A	50	70	2,65,500
B	60	70	2,64,000
C	60	80	2,63,000
D	20	120	2,65,000
E	20	100	2,67,000

Thus, maximum profit of ₹ 2,67,000 can be achieved when $x_1 = 20$, $x_2 = 100$, and $x_3 = 80$.

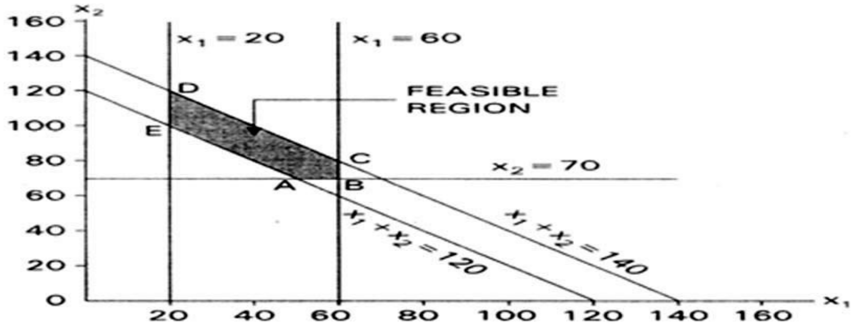


Fig. 2.10.12: Graphic Solution to the LLP

Illustration 21:

Let us assume that you have inherited ₹ 100,000 from your father-in-law that can be invested in a combination of only two stock portfolios, with the maximum investment allowed in either portfolio set at ₹ 75,000. The first portfolio has an average return of 10%, whereas the second has 20%. In terms of risk factors associated with these portfolios, the first has a risk rating of 4 (on a scale from 0 to 10), and the second has 9. Since you want to maximise your return, you will not accept an average rate of return below 12% or a risk factor above 6. Hence, you then face the important question. How much should you invest in each portfolio?

Formulate this as a linear programming problem and solve it by graphic method.

Solution:

Let x_1 : Investment in Portfolio 1

x_2: Investment in Portfolio 2

The LPP may be expressed as under:

Maximise $Z = 0.10x_1 + 0.20x_2$ Total Return

Subject to

$x_1 + x_2 \leq 1,00,000$	Total Investment
$x_1 \leq 75,000$	Investment Ceiling
$x_2 \leq 75,000$	
$-2x_1 + 3x_2 \leq 0$	Risk Requirement
$-2x_1 + 8x_2 \geq 0$	Return Requirement
$x_{1,} x_2 \geq 0$	Non-negativity

Notes:

1. The average risk is not to be exceeding 6. Thus, we have,

$$\frac{4x_1 + 9x_2}{x_1 + x_2} \leq 6$$

Or $4x_1 + 9x_2 \leq 6x_1 + 6x_2$

It simplifies to $2x_1 + 3x_2 \leq 0$

2. It is desired to have an average return of at least 12 percent. Thus,

$$0.10x_1 + 0.20x_2 \geq 0.12(x_1 + x_2)$$

which simplifies to

$$-2x_1 + 8x_2 \geq 0$$

The given constraints are plotted in **Figure 2.10.13**.

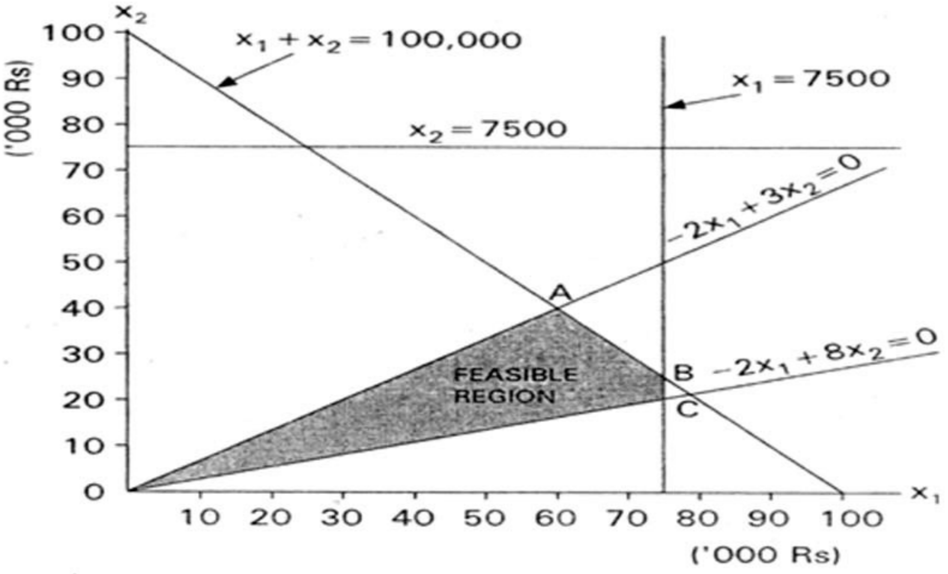


Fig. 2.10.13: Graphic Solution to Investment Problem

The feasible region is given by the shaded region with vertices 0, A, B and C. These points are evaluated below.

Point	x_1	x_2	Z
0	0	0	0
A	60,000	40,000	14,000
B	75,000	25,000	12,500
C	75,000	18,750	11,250

Evidently, ₹ 60,000 should be invested in Portfolio 1 and ₹ 40,000 in Portfolio 2. It would yield ; maximum return of ₹ 14,000, while meeting all the given requirements.

Illustration 22:

A furniture manufacturer produces two types of desks: Standard and Executive. These desks are sold to an office furniture wholesaler, and for all practical purposes, there in an unlimited market for any mix of these desks, at least within the manufacturer's production capacity. Each desk has to go through four basic operations: cutting of the lumber, joining of the pieces, pre-finishing, and final finish. Each unit of the Standard desk produced takes 48 minutes of cutting time, 2 hours of joining, 40 minutes of pre-finishing, and 4 hours of final finishing time. Each unit of the Executive desk required 72 minutes of cutting, 3 hours of joining, 2 hours of pre-finishing and 5 hours and 20 minutes of final finishing time. The daily capacity for each operation amounts to 16 hours of cutting, 30 hours of joining, 16 hours of pre-finishing and 64 hours of final finishing time. The profit per unit produced is ₹ 40 for the Standard desk and ₹ 50 for the Executive desk. Determine the product mix that maximizes total revenue.

Solution:

Let x_1 and x_2 represent the number of standard and executive desks, respectively. With a unit profit of ₹ 40 for a standard desk and ₹ 50 for an executive desk, and other requirements, the linear programming problem may be stated as follows:

Maximise $Z = 40x_1 + 50x_2$ Total profit

Subject to

$$\frac{4}{5}x_1 + \frac{6}{5}x_2 \quad \leq 16 \quad \text{Cutting time}$$

$$2x_1 + 3x_2 \quad \leq 30 \quad \text{Joining time}$$

$$\frac{2}{3}x_1 + 2x_2 \quad \leq 16 \quad \text{Pre-finishing time}$$

$$4\,x_1 + \frac{16}{3}x_2 \quad \leq 64 \quad \text{Final finishing time}$$

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

The problem may be solved graphically now. The constraints are plotted in **Fig. 2.10.14**. Notice that the cutting and final finishing time constraints are redundant here.

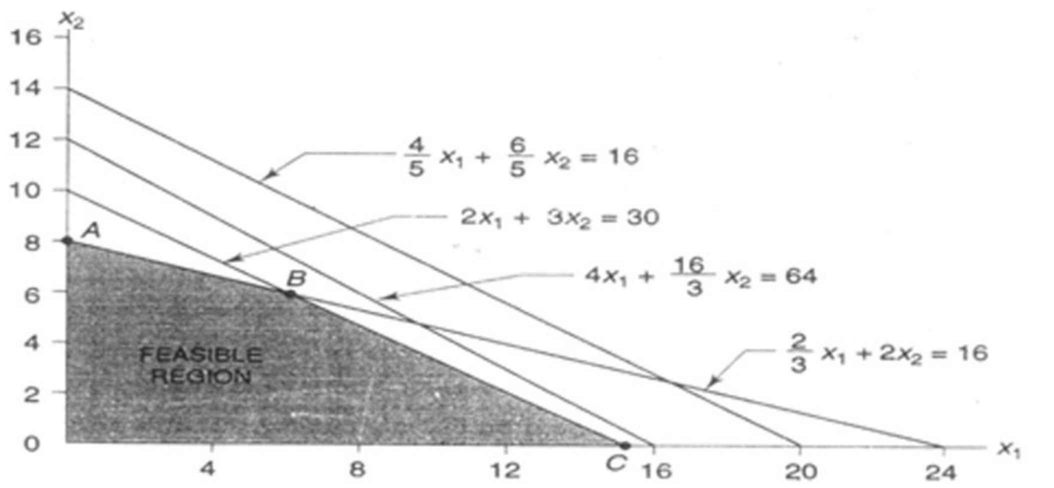


Fig. 2.10.14: Graphic Determination of Optimal Product Mix

The feasible region is shown shaded and has vertices as 0(0, 0), A(0, 8), B(6, 6), and C(15,0). These are evaluated below to obtain the optimal solution.

Point	x_1	x_2	$Z = 40x_1 + 50x_2$
0	0	0	0
A	0	8	400
B	6	6	540
C	15	0	600

The optimal solution is to produce 15 units of standard desk and none of the executive desk, per day.

Simplex method of linear programming. Simplex method of linear programming is a very important technique to solve the various linear problems. Under this method, algebraic procedure is used to solve any problem which satisfies the test of linearity and certainty. It is an iterative procedure which ultimately gives the optimal solution. Several variables can be used under this method. However, the simplex method is more complex and involves somewhat unsophisticated complex mathematics.

Note : The will be discussed on Final course.

Duality Theory

Associated with every linear programming problem (LPP) there is another intimatedly related LPP, called the dual problem of the original LPP. The original LPP is called the primal problem. According to the duality theorem:

"For every maximization (or minimization) problem in linear programming, there is a unique similar problem of minimization (or maximization) involving the same data which describes the original problem."

Customarily, the given problem is called primal or direct, and the corresponding intimatedly related problem is called its dual problem. In fact, either of the problems can be considered original as both originate from the same data, consequently the other becomes its dual.

The possibility of solving a LPP by starting from two different points of view. (i.e., primal and dual) brings considerable advantages. The variables of the dual linear programming problem also known as dual variables have important economic interpretations which can be used by a decision maker for planning his resources. Under certain circumstances the dual problem is easier to solve than the primal problem. The solution of the dual problem leads to the solution of the primal problem and thus efficient computational techniques can be developed through the concept of duality.

RELATIONSHIP BETWEEN PRIMAL AND DUAL PROBLEMS

Consider the general linear programming problem, which we will call the primal problem.

Primal Problem:

Find $X_j \geq 0$, (j = 1, 2 ....n) in order to maximize :

$Z = c_1x_1 + c_2x_2 + ... + c_nx_n$

Subject to the constraints

$$\left.\begin{array}{l} a_{11}x_1 + a_{12}x_2 + ... + a_{ln}x_n \leq b_1 \\ a_{21}x_1 + a_{22}x_2 + ... + a_{2n}x_n \leq b_2 \\ \;:\qquad :\qquad\quad :\quad\; : \\ a_{m1}x_1 + a_{m2}x_2 + ... + a_{mn}x_z \leq b_m \end{array}\right\}$$

The corresponding dual problem is obtained by transposing the rows and columns of constraint coefficients, transposing the coefficients of the objective function and the right hand side of the constraints, reversing the inequalities and minimizing instead of maximizing.

Dual Problem:

Find $y_j \geq 0$, (j = 1, 2, ... m) in order to minimize :

$Z^* = b_1y_1 + b_2y_2 + ... + b_my_m$

Subject to the constraints

$$\left.\begin{array}{l} a_{11}y_1 + a_{21}y_2 + ... + a_{mi}y_n \geq c_1 \\ a_{12}y_1 + a_{22}y_2 + ... + a_{m2}y_m \geq c_2 \\ \;:\qquad :\qquad\quad :\quad\; : \\ a_{1n}y_1 + a_{2n}y_2 + ... + a_{mn}y_m \geq c_n \end{array}\right\}$$

Thus, the coefficients in the jth constraints of the dual problem are the coefficients of X_j in the primal problem constraints, and vice versa. Furthermore, the right hand side of the jth dual problem constraint is the coefficient of x_i in the primal problem objective function, and vice versa. Hence, there is one dual variable for each primal variable.

The symmetrical relationship between the primal and dual problem is summarized below (assuming the primal to be a 'minimization' problem):

Primal	**Dual**
Maximization	Minimization
No. of variables	No. of constraints
No. of constraints	No. of variables
≤ type constraint	Non-negative variable
= type constraint	Unrestricted variable
Unrestricted variable	= type constraint
R.H.S. constant for the ith constraint	Objective function coefficient for ith variable
Objective function coefficient for jth variable	R.H.S. constraint for jth constraint
Coefficient (a_{ij}) for ith variable in jth constraint	Coefficient (a_{ij}) for jth variable in ith constraint

The above points are summarized in the following table:

PRIMAL AND DUAL RELATIONSHIP

Dual variables	Primal				Relation	Constraint
	$X_1 \geq 0$	$x_2 \geq 0$	…	$X_n \geq 0$		
$y_1 \geq 0$	a_{11}	a_{12}	…	a_{1n}	≤	b_1
$y_2 \geq 0$	a_{21}	a_{22}	…	a_{2n}	≤	b_2
$y_m \geq 0$	a_{m1}	a_{m2}	…	a_{mn}	≤	b_m
Relation	≥	≥	…	≥		Minimum Z*
Constraint	c_1	c_2	…	c_n	Maximum Z	

These symmetrical characteristics between primal and its dual help us to formulate certain rules for translating primal into its dual or vice versa.

CONSTRUCTION OF A DUAL PROBLEM

The rules for constructing the dual from the primal (or primal from the dual) are:

1. If the objective of one problem is to be maximized, the objective of the other is to be minimized.
2. The maximization problem should have all ≤ constraints and the minimization problem has all ≥ constraints.
3. All primal and dual variables must be non-negative (≥ 0).
4. The elements of right hand side of the constraints in one problem are the respective coefficients of the objective function in the other problem.
5. The matrix of constraints coefficients for one problem is the transpose of the matrix of constraint coefficients for the other problem. In other words :

"The co-efficients (a_{ij}) for the dual decision variables in the constraints are the coefficients of the primal decision variables in the constraints, with rows and columns interchanged (transpose), i.e., the rows in primal become column in the dual."

SHADOW PRICE

The shadow price of a resource is the unit price that is equal to the increase in profit to be realized by one additional unit of the resource. Thus the dual variable is also referred to as the shadow price or computed price of a resource. This is the highest price the manufacturer would be willing to pay for the resource.

SENSITIVITY ANALYSIS

The solution obtained from linear programming model is based on the assumption that the input data such as availability of resources, consumption of resources per unit, profit or cost contribution, equipment capability, etc. are assumed to remain constant and known with certainty during the planning period. However, in real situation the input data may change over time and subjected to uncertainty because of the dynamic nature of the basis. The optimal solution obtained may not remain optimal due to these changes. Thus, the management is usually interested in knowing the impact of the changes in the value of input on the final solution and the validity of the optimal solution.

The Investigation carried out to find the sensitivity of the optimal solution to the changes in the original input data values is called sensitivity analysis. It is also known as post optimality analysis since it is carried out after the optimal solution is obtained.

Thus sensitivity analysis determines how sensitive the optimal solution is to making changes in the original linear programming model. The degree of sensitivity of the solution due to these changes may range from no change at all to a substantial change in optimal solution of the given linear programming model.

In sensitivity analysis we determine the range over which the linear programming model parameters can change without affecting the current optimal solution.

Sensitivity analysis usually deals with the effect of changes in the following parameters:

(i) Change in the coefficient of the objective function (profit or cost per unit) associated with basic or non-basic variables.

(ii) Changes in the right hand side of the constraints (availability of resources).

(iii) Addition of new variable.

(iv) Deletion of an existing variable.

(v) Consumption of resources per unit of decision variables X_j, coefficients of decision variables on the left hand side of the constraints a_{ij}.

(vi) Addition of new constraint to the original linear programming model.

Illustration 23:

Find the dual of the following problem:

Minimize $Z = 4x_1 + 2x_2 + 3x_3$

Subject to the constraints

$x_1+2x_2 \geq 3$

$x_2 - 3x_3 \geq 6$

$-x_1 + 3x_3 - 2x_3 \leq 3$

$X_1, x_2, x_3 \geq 0$

Solution:

To write its dual, first multiply both sides of third constraint by -1, so that the primal can be written in the form:

Minimize $z_x = 4x_1 + 2x_2 + 3x_3$

Subject to the constraints

$x_1 + 2x_2 + 0x_3 \geq 3$

$0x_1 + x_2 - 3x_3 \geq 6$

$x_1 - 3x_2 + 2x_3 \geq -3$

$x_1, x_2, x_3 \geq 0$

Then the dual to the problem is written as:

Maximize $z_y = 3y_1 + 6y_2 - 3y_3$

Subject to the constraints

$y_1 + y_3 \quad \leq 4$

$2y_1 + y_2 - 3y_3 \quad \leq 2$

$-3y_2 + 2y_3 \quad \leq 3$

$y_1, y_2, y_3, \quad \geq 0$

Illustration 24:

Find the dual of the following problem:

Minimize $Z = 2x_2 + 5x_3$

Subject to the constraints

$x_1+x_2 \quad \geq 2$

$2x_1 +x_2 +6x_3 \quad \leq 6$

$x_1 - x_2 + 3x_3 \quad = 4$

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

Solution:

The equation $x_1 - x_2 + 3x_3 = 4$ can be expressed as a pair of inequalities:

$$\left.\begin{array}{ll} x_1 - x_2 + 3x_3 & \leq 4 \\ x_1 - x_2 + 3x_3 & \geq 4 \end{array}\right\} \text{ or } \begin{array}{ll} -x_1 + x_2 - 3x_3 & \geq -4 \\ x_1 - x_2 + 3x_3 & \geq 4 \end{array}$$

The primal problem then becomes:

Minimize $z = 2x_2 + 5x_3$

Subject to the constraints

$x_1+ x_2 \quad \geq 2$

$-2x_1 - x_2 - 6x_3 \quad \leq -6$

$-x_1+x_2 -3x_3 \geq \quad -4$

$x_1 -x_2+ 3x_3 \geq \quad 4$

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

The dual problem is given by:

Maximize $z^* = 2y_1 - 6y_2 - 4y_3 + 4y_4$

Subject to the constraints

$y_1 - 2y_2 - y_3 + y_4 \quad \leq 0$

$y_1 - y_2 + y_3 - y_4 \quad \leq 2$

$-6y_2 - 3y_3 + 3y_4 \quad \leq 5$

Put $y_5 = y_3 - y_4$, the dual problem becomes:

Maximize $z^* = 2y_1 - 6y_2 - 4y_5$

Subject to the constraints

$y_1 - 2y_2 - y_5 \quad \leq 0$

$y_1 - y_2 + y_5 \quad \leq 2$

$-6y_2 - 3y_5 \quad \leq 5$

$y_1, y_2 \quad \geq 0$; y_5 is unrestricted in sign.

Illustration 25:

Find the dual of the following problem:

Minimize $\quad Z = x_1 + x_2 + x_3$

Subject to the constraints

$x_1 - 3x_2 + 4x_3 \quad = 5$

$x_1 - 2x_2 \quad \leq 3$

$x_1, x_2 \geq 0$ and x_3 is unrestricted.

Solution:

Let $x_3 = x_4 - x_5$, Where $x_4, x_5 \geq 0$. This reduces the primal problem to:

Minimize $\quad z = x_1 + x_2 + x_4 - x_5$

Subject to the constraints

$x_1 - 3x_2 + 4x_4 - 4x_5 \quad \leq 5$

$x_1 - 3x_2 + 4x_4 - 4x_5 \quad \geq 5$

$x_1 - 2x_2 \quad \leq 3$

$x_1, x_2, x_3, x_4, x_5 \quad \geq 0$

Further conversion leads to

Minimize $z = x_1 + x_2 + x_4 - x_5$

Subject to the constraints

$x_1 - 3x_2 + 4x_4 - 4x_5 \quad \leq 5$

$-x_1 + 3x_2 - 4x_4 + 4x_5 \quad \leq -5$

$x_1 - 2x_2 \quad \leq 3$

$x_1, x_2, x_3, x_4, x_5 \quad \geq 0$

Illustration 26:

Find the dual problem for the following:

Minimize $z = 5x_1 - 6x_2 + 4x_3$

Subject to the constraints

$3x_1 + 4x_2 + 6x_3 \geq 9$

$x_1 + 3x_2 + 2x_3 \quad \geq 5$

$7x_1 - 2x_2 - x_3 \quad \leq 10$

$x_1 - 2x_2 + 4x_3 \quad \geq 4$

$2x_1 + 5x_2 - 3x_3 \quad \geq 3$

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

Solution:

Primal

Minimize $Z = 5x_1 - 6x_2 + 4x_3$

Subject to the constraints

$3x_1 + 4x_2 + 6x_3 \geq 9$

$x_1 + 3x_2 + 2x_3 \geq 5$

$-7x_1 + 2x_2 + x_3 \leq -10$

$x_1 - 2x_2 + 4x_3 \geq 4$

$2x_1 + 5x_2 - 3x_3 \geq 3$

$-2x_1 - 5x_2 + 3x_3 \geq -3$

$x_1, x_2, x_3 \geq 0$

Dual

Maximize $z^* = 9y_1 + 5y_2 - 10y_3 + 4y_4 + 3y_5 - 3y_6$

Subject to the constraints

$3y_1 + y_2 - 7y_3 + y_4 + 2y_5 - 2y_6 \leq 5$

$4y_1 + 3y_2 + 2y_3 - 2y_4 + 5y_5 - 5y_6 \leq -6$

$6y_1 + 2y_2 + y_3 + 4y_4 - 3y_5 + 3y_6 \leq 4$

$y_1, y_2, y_3, y_4, y_5, y_6 \geq 0$

By substituting $y_5 - y_6 = y_7$, the dual can alternatively be expressed as:

Maximize $z^* = 9y_1 + 5y_2 - 10y_3 + 4y_4 + 3y_7$

Subject to the constraints

$3y_1 + y_2 - 7y_3 + y_4 + 2y_7 \leq 5$

$-4y_1 - 3y_2 - 2y_3 + 2y_4 - y_7 \geq 6$

$6y_1 + 2y_2 + y_3 + 4y_4 - 3y_7 \leq 4$

$y_1, y_2, y_3, y_4 \geq 0$, y_7 unrestricted in sign.

Transportation

Transportation applications relate to a LPP where goods are to be transported from "m" production locations (factories) to "n" sales locations (warehouses). The objectives are (a) To meet the differing availabilities and requirements of these locations and (b) To minimise the total transportation costs.

A typical transportation problem is like this. Suppose that a manufacturer of refrigerators has three plants situated at places called A, B and C. Suppose further that his buyers are located in three regions X, Y and Z where he has to supply them the goods. Also, assume that the demands in the three regions and the production in different plants per unit time period are known and equal in aggregate, and further that the cost of transporting one refrigerator from each plant to each of the requirement centres is given and constant. The manufacturer's problem is to determine as to how he should route his product from his plants to the market places so that the total cost involved in the transportation is minimised. In other words, he has to decide as to how many refrigerators should be supplied from A to X, Y, and Z; how many from B to X, Y, and Z; and how many from C to X, Y, and Z, to achieve it at the least cost. This is illustrated in **Fig. 2.10.15.**

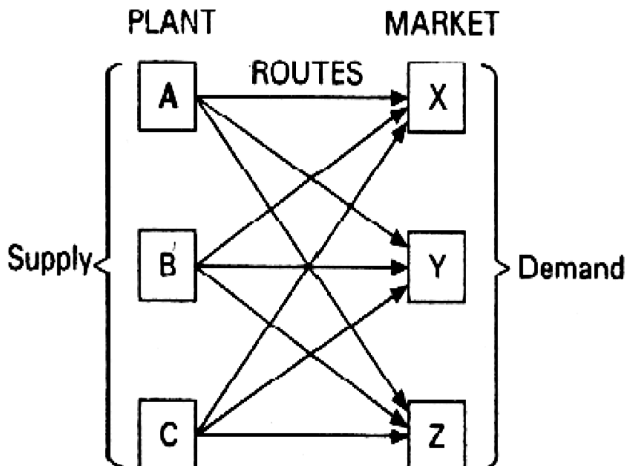


Fig. 2.10.15: Transportaton Problem

The places where the goods originate from (the plants in our example) are called the sources or the origins and places where they are to be supplied are the destinations. In this terminology, the problem of the manufacturer is to decide as to how many units be transported from different origins to different destinations so that the total transportation cost is the minimum.

Problem Statement

The classical transportation problem can be stated mathematically as follows:

Let a_i = quantity of product available at origin i

b_j = quantity of product required at destination j

c_{ij} = the cost of transporting one unit of product from source/origin i to destination j

x_{ij} = the quantity transported from origin i to destination;

Assume that $\sum_{i=1}^{m} a_i = \sum_{j=1}^{n} b_j$ which means that the total quantity available at the originsis precisely equal to the total amount required at the destinations.

With these, the problem can be stated as a linear programming problem as:

Minimise Total Cost, $Z=\sum_{i=1}^{m}\sum_{j=1}^{n} c_{ij}.x_{ij}$

Subject to $\sum_{j=1}^{n} x_{ij} = ai$ for i=1, 2 ,……,n

$\sum_{i=1}^{m} x_{ij} = bj$ for j=1, 2 ,……,n

And $x_{ij} > 0$ for all i=1,2,….,m, and

j=1,2,….,n

The transportation model can also be portrayed in a tabular form by means of a transportation tableau, shown in **Table 2.10.2.**

This tableau can be thought of as a matrix within a matrix, of the dimension m x n. The one is the per unit cost matrix which represents the unit transportation costs for each of the possible transportation routes.

Its elements are given by c_{ij} indicating the cost of shipping a unit from the ith origin to the jth destination. Superimposed on this matrix is the matrix in which each cell contains a transportation variable—that is, (he number of units shipped from the row-designated origin to the column-designated destination. Each such variable is represented by ,xij, the amount shipped from ith source to jth destination. Right and bottom sides of the transportation tableau show, respectively, the amount of supplies ai available at source i and the amount demanded b_j at each destination j. The a1's and b_j's represent the supply and demand constraints.

The aggregate transportation cost is determined by multiplying the various x_{ij}'s with corresponding c_{ij}'s and then adding them up all. The solution to the transportation problem calls for determining values of x_{ij}'s as would yield the minimum aggregate transportation cost. When a problem is solved, some of the x_{ij}'s would assume positive values indicating utilized routes. The cells containing such values are called occupied or filled cells and each of them represents the presence of a basic variable. For the remaining cells, called the empty cells, x_{ij}'s would be zero. These are the routes that are not utilized by the transportation pattern and their corresponding variables (x_{ij}'s) are regarded to be non-basic.

Table 2.10.2 Transportation Tableau

Origin (i)	Destination (j)				Supply, a_i
	1	2		n	
1	x_{11} c_{11}	x_{12} c_{12}	...	x_{1n} c_{1n}	a_1
2	x_{21} c_{21}	x_{22} c_{22}	...	x_{2n} c_{2n}	a_2
...	...	...	...	...	...
m	x_{m1} c_{m1}	x_{m2} c_{m2}	...	x_{mn} c_{mn}	a_m
Demand, b_j	b_1	b_2	...	b_n	$\Sigma a_i = \Sigma b_j$

Remember that the transportation costs are assumed to be linear in nature. Further, it is assumed here that the aggregate supply at sources ($\sum a_i$) is equal to the aggregate demand at destinations. ($\sum b_j$) We shall consider later the situation when they do not match.

As observed earlier, the number of constraints in a transportation tableau is m + n (the number of rows plus the number of columns). The number of variables required for forming a basis is one less, i.e. m + n - 1. This is so, because there are only m + n - 1 independent variables in the solution basis. In other words, with values of any m + n - 1 independent variables being given, the remaining would automatically be determined on the basis of those values. Also, considering the conditions of feasibility and non-negativity, the number of basic variables representing transportation routes that are utilized equals m + n - 1, and all other variables be non-basic, or zero, representing the unutilized routes. It means that a basic feasible solution of a transportation problem has exactly m + n - 1 positive components in comparison to the m + n positive components required for a basic feasible solution in respect of a general linear programming problem in which there are m + n structural constraints to satisfy.

Solution to the Transportation Problem

A transportation problem can be solved by two methods, using (a) simplex method, and (b) transportation method. We shall illustrate these with the help of an example.

Illustration 27:

A firm owns facilities at six places. It has manufacturing plants at places A, B and C with daily production of 50, 40, and 60 units respectively. At point D, E, and F it has three warehouses with daily demands of 20, 95, and 35 units respectively. Per unit shipping costs are given in the following table. If the firm wants to minimise its total transportation cost, how should it route its products?

		Warehouse		
		D	**E**	**F**
Plant	A	6	4	1
	B	3	8	7
	C	4	4	2

Solution:

(a) The simplex method The given problem can be expressed as an LPP as follows:

Let X_{ij} represent the number of units shipped from plant i to warehouse j. With Z representing the total cost we can state the problem as follows:

Minimise $Z = 6x_{11} + 4x_{12} + 1x_{13} + 3x_{21} + 8x_{22} + 7x_{23} + 4x_{31} + 4x_{32} + 2x_{33}$

Subject to

$x_{11}+x_{12}+x_{13} = 50$

$x_{21}+x_{22}+x_{23} = 40$ Supply constraints

$x_{31}+x_{32}+x_{33} = 60$

$x_{11}+x_{12}+x_{13} = 20$

$x_{21}+x_{22}+x_{23} = 95$ Demand constraints

$x_{31}+x_{32}+x_{33} = 35$

$x_{ij} > 0$ for i=1,2,3 and j=1,2,3

Now, this problem can be solved as any other problem using the simplex algorithm. But the solution is going to be very lengthy and a cumbersome process because of the involvement of a large number of decision and artificial variables. Hence, we look for an alternate solution procedure called the transportation method which is an efficient one that yields results faster and with less computational effort. A significant point of difference between the simplex and the transportation methods is regarding the determination of initial basic feasible solution. As we use simplex method to solve a minimisation problem, we must add artificial variables to make the solution artificially feasible. As we progress from one tableau to another, the artificial variables are dropped one after the other as they become non-basic. Then, eventually an optimal solution is obtained where all the artificial variables are excluded. The transportation method obviates the need to use artificial variables because with this method it is fairly easy to find an initial solution that is feasible, without using the artificial variables.

(b) The transportation method The transportation method is shown schematically in **Figure 2.10.16.** The method consists of the following three steps:

(i) Obtaining an initial solution, that is to say making an initial assignment in such a way that a basic feasible solution is obtained; (ii) ascertaining whether it is optimal or not, by determining opportunity costs associated with the empty cells, and if the solution is not optimal; (iii) revising the solution until an optimal solution is obtained.

Step 1: Obtaining the initial feasible solution. The first step in using the transportation method is to obtain a feasible solution, namely, the one that satisfies the rim requirements (i.e. the requirements of demand and supply). The initial feasible solution can be obtained by several methods. The commonly used are the North-West Corner (NWC) Rule, Least Cost Method (LCM) and the Vogel's Approximation Method (VAM). We shall discuss these methods in turn.

1. North-West Corner Rule. The North-West Corner rule (N-W Corner rule) may be stated as follows.

Start with the north-west corner of the transportation tableau and consider the cell in the first column and the first row. Corresponding to this cell are the values a1 and b1 respectively in row 1 and column 1. Proceed as follows:

If is, $a_1 > b_1$, then assign quantity b_1, in this cell. This implies that we put $x_{11} = b_1$. If $a_1 < b_1$, then assign a_1 in the cell so that $x_{11} = a_1$. Simply speaking, put the lower of a_1 and b_1, as x_{11}. If $a_1 = b_1$, then $x_{11} = a_1 = b_1$. To illustrate, if supply $a_1 = 50$ and demand $b_1 = 30$, then assign 30 units as the quantity to be supplied from first source to the first destination. If supply, $a_1 = 30$ and demand, $b_1 = 50$, then $x_{11} = a_1 = 30$ and if $a_1 = 30$, $b_1 = 30$, then $x_{11} = 30$.

Now. if $a_1 > b_1$, then move horizontally to the next column in the first row; if $a_1 < b_1$, move vertically in the same column to the. next row; and if $a_1 = b_1$, then move diagonally to the next column and next row. In operational terms, if $a_1 > b_1$, so that the supply is greater than demand, then having assigned quantity equal to demand (b_1), the remaining quantity is considered along with demand at the next destination (b_2), whereas if supply falls short of demand ($a_1 < b_1$), then having exhausted the available supply at source 1, consider obtaining from the next source (a_2). Obviously, if supply and demand match, then consider the next source and next destination (a_2 and b_2).

Once in the next cell, again compare the supply available at the source and demand at the destination, corresponding to the cell chosen, and assign lower of the two values. Move to the next cell appropriately as explained earlier and again assign the quantity considering demand and available supply.

Continue in the zig zag manner until the last source and last destination are covered, so that the south-east corner of the tableau is reached.

For **Illustration 27,** the initial basic feasible solution using this method is obtained as follows. First start with the cell on the intersection of A and D. The column total corresponding to this cell is 20 while the row total is 50. So allocate 20 to this cell. Now, the destination requirement having been satisfied, move horizontally in the row to the cell AE. The column total is 95 while a total of 30 is left in the row. Thus assign 30 to this cell. With this, the supply of the row origin is exhausted. Next, move vertically to the cell BE. For this cell, the destination requirement being 65 and the source supply being 40, assign 40 to this cell and exhaust the supply at source B. Then move to the cell CE and allocate 25 units. The remaining supply of 35 at source C is sufficient to meet the demand at destination F. So assign 35 to the cell CF. These assignments are shown in **Table below**.

Table : Initial Basic Feasible Solution —NW Corner Method

From \ To	D	E	F	Supply
A	$\boxed{20}$ 6	$\boxed{30}$ 4	1	50
B	3	$\boxed{40}$ 8	7	40
C	4	$\boxed{25}$ 4	$\boxed{35}$ 2	60
Demand	20	95	35	150

Total cost : 6 × 20 + 4 × 30 + 8 × 40 + 4 × 25 + 2 × 35 = ₹ 730

This routing of the units meets all the rim requirements and entails 5= (3 + 3 - 1) shipments as there are 5 occupied cells. It involves a total cost of ₹ 730.

2. Least Cost Method (LCM). The NW corner rule described earlier considers only the availability and supply requirements in making assignments. It takes no account of the shipping costs given in the tableau. It is therefore not a sound method as it ignores the very factor (cost) which is sought to be minimised. The least cost method and the Vogel's Approximation method consider the shipping costs while making allocations. The former of these is discussed now.

As the name suggests, of all the routes (that is, combinations of sources and destinations) select the one where shipping cost is the least. Now, consider the supply available at the corresponding source and demand at the corresponding destination and put the lower of the two as the quantity to be transported through that route. After this, delete the source/destination, whichever is satisfied. Consider the remaining routes and again choose the one with the smallest cost and make assignments. Continue in this manner until all the units are assigned.

It may be mentioned that at any stage, if there is a tie in the minimum cost, so that two or more routes have the same least cost of shipping, then, conceptually, either of them may be selected. However, a better initial solution is obtained if the route chosen is the one where largest quantity can be assigned. Thus, if there are three cells for which the (least) cost value is equal, then consider each one of these one by one and determine the quantity (by reference to the; demand and supply quantities given) which can be despatched, and choose the cell with the largest quantity. If there is still a tie, then either of them may be selected.

For **Illustration 27,** the initial solution by using least cost method is obtained in following. To begin with, the lowest of all cost elements is 1, for the cell AF, with corresponding supply and demand being 50 and 35. Accordingly, assign 35 to this cell, delete the column and reduce the quantity available to 15. Of the remaining cost elements (excluding the column values of 1, 7 and 2), the least is 3 corresponding to the cell BD. The quantity for this cell is 20, being lower of 20 (demand) and 40 (supply). Delete the column headed D as well and adjust the available supply at B to 20. Now, since only one market remains, its requirement is met by transferring the available supply at different sources. Accordingly, it gets the 15 units remaining at A, 20 remaining at B and 60 from C.

Table: Initial Feasible Solution—Least Cost Method

From ↓ / To →	D	E	F	Supply
A	6	4 [15]	1 [35]	~~50~~ 15
B	3 [20]	8 [20]	7	~~40~~ 20
C	4	4 [60]	2	60
Demand	20	95	35	150

The transportation schedule obtained is reproduced in following. It involves a total cost of ₹ 555.

3. Vogel's Approximation Method (VAM). Like the Least Cost Method, the Vogel's Approximation Method (VAM) also considers the shipping costs, but in a relative sense, when making allocations. This method is given here.

First, consider each row of the cost matrix individually and find the difference between two least cost cells in it. Then repeat the exercise for each of the columns. Identify the column or row with the largest difference value. Now, consider the cell with the minimum cost in that column (or row, as the case may be) and "assign the maximum units possible, looking to the demand and availability corresponding to that cell. In case of a tie in the largest cost difference, although either of them may be chosen but it is preferable to choose the cost difference corresponding to which the largest number of units may be assigned or corresponding to which the cell chosen has minimum cost. To illustrate, suppose the largest cost difference is found to be tied for a row and a column. In applying first of the rules, determine the quantity (considering supply availability and demand) which can be assigned in each case and select the one where larger quantity can be assigned. In the other case, compare unit cost values of the two least cost cells, in the row and the column, and choose the one which has a lower value.

Delete the column/row which has been satisfied. Again, find out the differences and proceed in the same manner as discussed earlier. Continue until all units have been assigned. The VAM is shown schematically in **Fig. 2.10.16.**

For **Illustration 27,** the initial feasible solution by using this method is given in **Table below.**

The differences between the two least-cost cells are calculated for each row and column. The largest ol these being 4 (= 7 - 3), the row designated as B is selected. In the lowest cost cell of the row, BD, a value 20 is assigned and the column D is deleted as the demand is satisfied. In the second iteration, again the cost differences are calculated and the first row is selected as it shows the greatest difference value of 3. In the cell AF, 35 is assigned and column F is deleted. Now, only one column is left and therefore no differences need be calculated. The assignments can be easily made having reference to the supply at various origins. The assignment made by VAM involves a total cost of ₹ 555-a solution same as that by LCM, and better than the one obtained by NW corner rule involing a total cost of ₹ 730.

Table: Initial Basic Feasible Solution—VAM

From ↓ / To →	*D*	*E*	*F*	Supply	Iteration I	Iteration II
A	6	4 [15]	1 [35]	~~50~~ 15	3	3
B	3 [20]	8 [20]	7	~~40~~ 20	4	1
C	4	4 [60]	2	60	2	2
Demand	20	95	35	150		
I	1	0	1			
II	–	0	1			

Total cost: 4 x 15 + 1 x 35 + 3 x 20 + 8 x 20 + 4 x 60 = ₹ 555

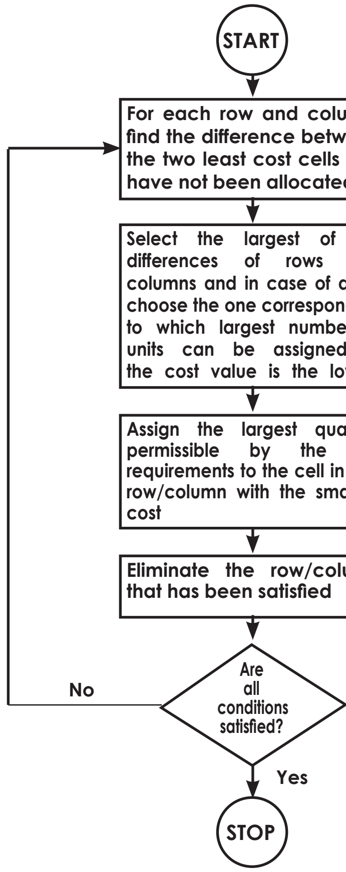


Fig. 2.10.16 Schematic Presentation of VAM

The Vogel's approximation method is also called the Penalty Method because the cost differences that it uses are nothing but the penalties of not using the least-cost routes. Since the objective function is the minimisation of the transportation cost, in each iteration that route is selected which involves the maximum penalty of not being used.

From ↓ \ To →	D	E	F	Supply	Iteration I	Iteration II
A	6	4 $\boxed{15}$	1 $\boxed{35}$	~~50~~ 15	3	3
B	3 $\boxed{20}$	8 $\boxed{20}$	7	~~40~~ 20	4	1
C	4	4 $\boxed{60}$	2	60	2	2
Demand	20	95	35	150		
I	1	0	1			
II	–	0	1			

Total cost: 4 × 15 + 1 × 35 + 3 × 20 + 8 × 20 + 4 × 60 = ₹555

Step 2: Testing the optimality. After obtaining the initial basic feasible solution, the next step is to test whether it is optimal or not. There are two methods of testing the optimality of a basic feasible solution. The first of these is called the stepping-stone method in which the optimality test is applied by calculating the opportunity cost of each empty cell. The second method employed for testing optimality is called the modified distribution method (MODI). This method is easier and more efficient than the stepping-stone method. It is based on the concept of the dual variables that are used to evaluate the empty cells. Using these dual variables the opportunity cost of each of the empty cells is determined. The opportunity cost values in both the methods indicate the optimality or otherwise of a given solution.

Step 3: Improving the solution. By applying either of these method, if the solution is found to be optimal, then the problem is solved. If the solution is not optimal, then a new and better basic feasible solution is obtained. It is done by exchanging a non-basic variable for one basic variable. In simple terms, rearrangement is made by transferring units from an occupied cell to an empty cell that has the largest opportunity cost, and then shifting the units from other related cells so that all the rim requirements are satisfied. This is achieved by first tracing a closed loop (discussed in detail later).

The solution so obtained is again tested for optimality (step 2) and revised if necessary. We continue in this manner until an optimal solution is finally obtained.

We shall now discuss the stepping-stone and the MODI methods in turn.

1. Stepping-stone Method: This is a procedure of determining the potential, if any, for improving each of the non-basic variables in terms of the objective function. To determine this potential, each of the non-basic variables (empty, cells) is considered one-by-one. For each such cell we find out as to what effect on the lotal cost would be if one unit is assigned to this cell. With this information, then, we come to know whether the solution is optimal or not. If not, we improve that.solution. To understand it, we refer to the **Table** nextwhich is a reproduction of the **Table** containing the initial basic feasible solution obtained by NW corner rule.

In this table, there are four empty cells: BD, CD, AF and BF, with corresponding non-basic variables as x_{21},x_{31},x_{13} and x_{23}. To start with, let us assess the potential for improvement of the non-basic variable x_{21}. A shipment of one unit of the item on this route would mean an increase of ₹ 3 but also it will mean a reduction of one unit from x_{22} and, thereby, a reduction of ₹ 8 in the cost. However, to maintain feasibility, we should subtract one unit from x11 and add one unit to x12 (notice that otherwise the column totals are disturbed). This has the effect of decreasing the cost by ₹ 6 in respect of the former and increasing ₹ 4 for the latter. The net effect of this operation would be a reduction of ₹ 7 in the cost. It is shown as follows:

Increase	in	cost	by	increasing x_{11}	by 1	unit	= +3
Decrease	in	cost	by	decreasing x_{12}	by 1	unit	= -8
Increase	in	cost	by	increasing x_{13}	by 1	unit	= +4
Decrease	in	cost	by	decreasing x_{14}	by 1	unit	= -6
					Net effect on the cost		= -7

A reduction in the cost of ₹ 7 per unit can be effected by adopting the route BD, implies that the opportunity cost of this route is +7. Since the opportunity cost here is positive, it means that it is worth considering making variable x_{21} a basic variable.

Table Initial Basic Feasible Solution: Testing for Optimality

From \ To	D	E	F	Supply
A	$\boxed{20}$ 6 −	$\boxed{30}$ 4 +	1	50
B	3 +	$\boxed{40}$ 8 −	7	40
C	4	$\boxed{25}$ 4	$\boxed{35}$ 2	60
Demand	20	95	35	150

It is significant to note that the net cost effect that has been calculated is an evaluation of the marginal (or per unit) effect on the total cost function of using a transportation route which is not adopted hitherto. Such a change in the routes involves tracing the effects from one utilized route, which constitutes a stepping stone, to another in such a way that the rim requirements are satisfied. Because of the dependency relationships involved, we start with an empty cell and then proceed through the succession of stepping-stones to reach back at the empty cell being evaluated. Since the path we adopt always leads, via the stepping stones, back to the empty cell, the pattern is called the closed loop. We shall digress on the drawing of a closed loop a little later.

For the problem under investigation, we would evaluate each of the other empty cells in the manner we did for cell BD. This is done here.

Cell	Closed Loop	Net Cost Change	Opportunity Cost
AF	AF-CF-CE-AE	+1-2 + 4-4 = -1	+1
BF	BF-CF-CE-BE	+7-2 + 4-8 = +1	-1
CD	CD-AD-AE-CE	+4-6 + 4-4 =-2	+2

The rule for testing the optimality is: if none of the empty cells has a positive opportunity cost, the solution is optimal. And, if one (or more) of the empty cells have a positive opportunity cost, the solution is not optimal and calls for revision. For the purpose of revising a given solution, the cells for which the opportunity cost is negative are not considered at all because their inclusion would increase the transportation cost. If a cell has a zero opportunity cost, it has the implication that inclusion of that particular route would leave the objective function value unaffected. We concentrate, therefore, only on the cells that have positive opportunity cost and would select the one with the highest value.

In our illustration, the most favoured cell is BD for it has the largest opportunity cost. We decide, therefore, to include x_{21} as a basic variable in the solution. Now, since each unit shifted has the effect of cost-saving of ₹ 7, we should transfer the maximum number of units to the route BD. It would be equal to the least of the x_{ij} values of the cells on the closed loop involving a minus sign. For the loop under consideration, (he cells AD and BE involve minus signs with quantities equal to 20 and 40 respectively. Twenty being the lower of the two, we shall transfer 20 units along this path. Note that the variable x_{21} replaces the variable x_{11}, the resulting solution is shown in following **Table** below.

Table Improved Solution: Optimal

From \ To	D	E	F	Supply
A	6	4 [50]	1	50
B	3 [20]	8 [20]	7	40
C	4	4 [25]	2 [35]	60
Demand	20	95	35	150

Total cost: 4 × 50 + 3 × 20 + 8 × 20 + 4 × 25 + 2 × 35 = ₹ 590

This plan also has 5 (= 3 + 3 - 1) allocations. It involves a total cost of ₹ 590. We will again apply step 2 to determine whether this solution is optimal or not, and then apply step 3 if it is found to be non-optimal. Application of step 2 yields the following results:

Cell	Closed Loop	Net Cost Change	Opportunity Cost
AD	AD-AE-BE-BD	+6 – 4 + 8 - 3 = +7	-7
AF	AF-CF-CE-BE	+1 - 2 + 4 - 4 = -1	+1
BF	BF-CF-CE-BE	+7 - 2 + 4 - 8 = +1	-1
CD	CD-BD-BE-CE	+4 - 3 + 8 - 4 = +5	-5

Since only the cell AF has a positive opportunity cost, we shall include it in the transportation schedule. The maximum number of units that can be routed through AF is 35. Accordingly, the revised solution is given in **Table** below.

Table Improved Solution : Optimal

From \ To	D	E	F	Supply
A	6	4 [15]	1 [35]	50
B	3 [20]	8 [20]	7	40
C	4	4 [60]	2	60
Demand	20	95	35	150

Total cost: 4 × 15 + I × 35 + 3 × 20 + 8 × 20 + 4 × 60 = ₹ 555

This solution also involves 5 assignments at a total cost of ₹ 555. This solution would now be tested for optimality. This is done here:

Cell	Closed Loop	Net Cost Change	Opportunity Cost
AD	AD-AE-BE-BD	+6-4+8-3=+7	-7
BF	BF-BE-AE-AF	+7-8+4-1=+2	-2
CD	CD-BD-BE-CE	+4-3+8-4=+5	-5
CF	CF-CE-AE-AF	+2-4+4-1=+1	-1

Since the opportunity costs of all the empty cells are negative, the solution obtained is the optimal one. In a similar fashion, we can test the initial basic feasible solution obtained by LCM or VAM. If we compare it with the solution contained in **Table** before we find that the two are identical. Clearly, therefore, the solution we obtained by VAM is optimal.

Before we discuss the MODI method for testing the optimality of a transportation solution, a few words on the tracing of a closed loop follow.

Tracing a loop: When a closed loop is to be traced, start with the empty cell which is to be evaluated (or to be included in the solution). Then, moving clockwise, draw an arrow from this cell to an occupied cell in the same row or column, as the case may be. After that, move vertically (or horizontally) to another occupied cell and draw an arrow. Follow the same procedure to other occupied cells before returning to the original empty cell. In the process of moving from one occupied cell to another, (a) move only horizontally or vertically, but never diagonally; and (b) step over empty or occupied cells, if the need be, without changing them. Thus, a loop would always have right angled turns with corners only on the occupied cells. Having traced the path, place plus and minus signs alternately in the cells on each turn of the loop, beginning with a plus (+) sign in the empty cell. An important restriction is that there must be exactly one cell with a plus sign and one cell with a minus sign in any row or column in which the loop takes a turn. This restriction ensures that the rim requirements would not be violated when units are shifted among cells.

The following points may also be noted in connection with the closed loops:

(a) An even number of at least four cells must participate in a closed loop and an occupied cell can be considered only once and not more.

(b) If there exists a basic feasible solution with m + n - 1 positive variables, then there would be one and only one closed loop for each cell. This is irrespective of the size of the matrix given,

(c) All cells that receive a plus or a minus sign, except the starting empty cell, must be the occupied cells.

(d) Closed loops may or may not be square or rectangular in shape. In larger transportation tables, the closed loops may have peculiar configurations and a loop may cross over itself.

(e) Although, as mentioned earlier, movement on the path set by the loop is generally clockwise, even if the progression on the path is anticlockwise, it would not affect the result.

2. The Modified Distribution Method (MODI): As mentioned previously, the MODI method is an efficient method of testing the optimality of a transportation solution. It may be recalled that in the application of the stepping stone method, each of the empty cells is evaluated for the opportunity cost by drawing a closed loop. In situations where a large number of sources and destinations are involved, this would be a very time consuming and intricate exercise. The MODI method avoids this kind of extensive scanning and reduces the number of steps required in the evaluation of the empty cells. This method gives a straightforward computational scheme whereby we can determine the opportunity cost of each of the empty cells.

Step 1: Add to the transportation table a column on the RHS titled u_i and a row in the bottom of it labeled v_j.

Step 2:

(a) Assign any value arbitrarily to a row or column variable ui or vj. Generally, a value 0 (zero) is assigned to the first row, i.e. $u_1 = 0$.

(b) Consider every occupied cell in the-first row individually and assign the column value vj (when the occupied cell is in the jth column of the row) which is such that the sum of the row and the column values is equal to the unit cost value in the occupied cell. With the help of these values, consider other occupied cells one by one and determine the appropriate values of u_j's and v_j's, taking in each case $u_j + v_j = c_{ij}$. Thus, if ut is the row value of the jth row and v_j is the column value of the jth column and c_{ij} is the unit cost of the cell in the jth row and jth column, then the row and column values are obtained using the following equation:

$$u_i + v_j = C_{ij}$$

The initial basic feasible solution to **Illustration 33** is reproduced in **Table** below.

Table Intial Basic Feasible Solution: NW Corner Rule

From \ To	D	E	F	Supply	u_i
A	20 / 6	30 / 4	(1) 1	50	0
B	(+7) 3	40 / 8	(−1) 7	40	4
C	(2) 4	25 / 4	35 / 2	60	0
Demand	20	95	35	150	
v_j	6	4	2		

For this solution, let $u_1 = 0$. Using the equation given earlier, we have, for the occupied cell (1,1) $u_1 + v_1 = C_{11}$, or $0 + v_1 = 6$, or $v_1 = 6$.

Similarly, $u_1 + v_2 = c_{12}$ or $0 + v_2 = 4$ or $v_2 = 4$. With $v_2 = 4$, we get $u_2 = 4$ ($\because u_2 + 4 = 8$) and $u_3 = 0$. From $u_3 = 0$, we get $v_3 = 2$. This is how u_i, values of 0, 4 and 0, and v_j values of 6, 4 and 2 are determined.

It may be mentioned that this method of assigning row and column values is workable only when solution is non-degenerate, that is to say, for a matrix of the order m x n, there are exactly m+n-1 non-zero (occupied) cells. We shall consider the problem of degenerate solution later.

Step 3: Having determined all u_i and v_j values, calculate for each unoccupied cell $\Delta_{ij} = u_i + v_j - c_{ij}$. The Δ_{ij}'s represent the opportunity costs of various cells. After obtaining the opportunity Costs, proceed in the same way as in the stepping stone method. If all the empty cells have negative opportunity cost, the solution is optimal and unique. If some empty cell(s) has a zero opportunity cost but if none of the other empty cells have positive opportunity cost, then it implies that the given solution is optimal but that it is not unique—there exists other solution(s) that would be as good as this solution.

However, if the solution contains a positive opportunity cost for one or more of the empty cells, the solution is not optimal. In such a case, the cell with the largest opportunity cost value is selected, a closed loop traced and transfers of units along the route are made in accordance with the method discussed earlier. Then the resulting solution is again tested for optimality and improved if necessary. The process is repeated until an optimal solution is obtained.

For our example, the Δ_{ij} values are given in circles in the empty cells in the above Table. They are:

Δ_{13}=0 + 2 -1 = 7, Δ_{21}= 4 + 6 -3 = 7,

Δ_{23} = 4 + 2-7 = -1 , and Δ_{31}= 0 + 6-4 = 2.

Here the cell (2,1) has the largest positive opportunity cost and therefore we select ,v21 for inclusion as a basic variable. The closed loop starting with this cell has been shown in the table. The revised solution is shown in next below.

Table Improved Solution: Non-optimal

From \ To	D	E	F	Supply	u_i
A	6 (−7)	4 [50]	1 (1)	50	0
B	3 [20]	8 [20]	7 (−1)	40	4
C	4 (−5)	4 [25]	2 [35]	60	0
Demand	20	95	35	150	
v_j	−1	4	2		

This solution is tested for optimality and is found to be non-optimal. Here the cell (1, 3) has a positive opportunity cost and therefore a closed loop is traced starting with this. The solution resulting is shown in **Table.** This, when tested, is found to be optimal, involving a total transportation cost 3

of ₹ 555.

Table Improved Solution: Optimal

From \ To	D	E	F	Supply	u_i
A	6 (−7)	4 [50]	1 [35]	50	0
B	3 [20]	8 [20]	7 (−2)	40	4
C	4 (−5)	4 [60]	2 (−1)	60	0
Demand	20	95	35	150	
v_j	−1	4	1		

Some Special Topics

A. Unbalanced Transportation Problems

The methods we have discussed for solving a transportation problem require that the aggregate supply ($\sum a_i$) is equal to the aggregate demand ($\sum b_j$). In practice, however, situations may arise when the two are unequal. The two such possibilities are, first, when the aggregate supply exceeds the aggregate demand (i.e. $\sum a_i > \sum b_j$) and, second, when aggregate supply falls short of the aggregate demand (i.e. $\sum a_i < \sum b_j$). Such problems are called unbalanced transportation problems. Balancing must be done before they can be solved.

When the aggregate supply exceeds the aggregate demand, the excess supply is assumed to go to inventory and costs nothing for shipping. A column of slack variables is added to the transportation tableau which represents a dummy destination with a requirement equal to the amount of excess supply and the transportation costs equal to zero. On the other hand, when the aggregate demand exceeds the aggregate supply in a transportation problem, balance is restored by adding a dummy origin. The row representing it is added with an assumed total availability equal to the difference between the total demand and supply, and with each of the cells having a zero unit cost. In some cases, however, when the penalty of not satisfying the demand at a particular destination(s) is given, then such penalty value should be considered and not zero.

Once the transportation problem is balanced, its solution proceeds in exactly the same manner as discussed earlier.

B. Prohibited Routes

Sometimes in a given transportation problem some route(s) may not be available. This could be due to a variety of reasons like the unfavourable weather conditions on a particular route, strike on a particular route etc. In such situations, there is a restriction on the routes available for transportation. 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. The effect of adding a large cost element would be that such routes would automatically be eliminated in the final solution.

C. Unique vs Multiple Optimal Solutions

The optimal solution to a given problem may, or may not, be unique. Recall that the solution to a transportation problem is optimal if all the A_{ij} values (in terms of the MODI method) are less than, or equal to zero. For a given solution, if all the Δ_{ij} values are negative, then it is unique. If, however, some cell (or cells) has $\Delta_{ij} = 0$, then multiple optimal solutions are indicated so that there exist transportation pattern(s) other than the one obtained which can satisfy all the rim requirements for the same cost.

To obtain an alternate optimal solution, trace a closed loop beginning with a cell having $\Delta_{ij} = 0$, and get the revised solution in the same way as a solution is improved. It may be observed that revised solution would also ential the same total cost as before. It goes without saying that for every 'zero' value of Δ_{ij} value in the optimal solution tableau, a revised solution can be obtained.

Illustration 28:

A Company is spending ₹1,000 on transportation of its units from these to four warehouses the supply and demand of units with the units cost of transportation are as:

A Company is spending ₹1,000 on transportation of its units from these to four warehouses the supply and demand of units with the units cost of transportation are as:

	W1	W2	W3	W4	Supply
P1	19	30	50	12	7
P2	70	30	40	60	10
P3	40	10	60	20	18
Demand	5	8	7	15	35

What can be the maximum saving by optimum scheduling?

Solution:

Using VAM and determine the initial basic feasible solution as shown in the Table 1 below:

Table I.

Plant or factory	Warehouse				Capacity	Row Number U_i
	W1	W2	W3	W4		
P1	$\boxed{19}$ 5	$\boxed{30}$	$\boxed{50}$	$\boxed{12}$ 2	~~7~~ ~~2~~ 0	~~7~~ ~~18~~ 38
P2	$\boxed{70}$	$\boxed{30}$	$\boxed{40}$ 7	$\boxed{60}$ 3	~~10~~ ~~3~~ 0	~~10~~ 20
P3	$\boxed{40}$	$\boxed{10}$ 8	$\boxed{60}$	$\boxed{20}$ 10	~~18~~ ~~10~~ 0	~~10~~ ~~40~~
Demand	5 0	8 0	7 0	15 5 0	35	
Row Penalty	21	20	10	8 48		

The transportation cost, according to the above solution is

= 5 × 19 + 2 × 12 + 7 × 40 + 3 × 60 + 8 × 10 + 10 × 20 = ₹ 859.

Further, the solution is the basic feasible solution as there are (m+n-1) i.e. 4+3 -1=6 allocations in the independent positions.

Now we determine the set of values for each row and each column, the row and column numbers are computed by means of the unit cost of in the respective occupied cell. We select U_2 and assign a zero value to it. With U_1 = 0, we can identify the values of the remaining variables in the next relationship as given below:

$U_1 + V_1 = 19$	$\longrightarrow$ $0 + V_1 = 19$	$\longrightarrow$ $V_1 = 19$
$U_1 + V_4 = 12$	$\longrightarrow$ $0 + V_4 = 12$	$\longrightarrow$ $V_4 = 12$
$U_2 + V_4 = 60$	$\longrightarrow$ $U_2 + 12 = 60$	$\longrightarrow$ $U_2 = 48$
$U_2 + V_3 = 40$	$\longrightarrow$ $48 + V3 = 40$	$\longrightarrow$ $V_3 = -8$
$U_3 + V_4 = 20$	$\longrightarrow$ $U_3 + 12 = 20$	$\longrightarrow$ $U_3 = 8$
$U_3 + V_2 = 10$	$\longrightarrow$ $8 + V_2 = 10$	$\longrightarrow$ $V_2 = 2$

After the row and column, numbers have been computed the next step is to evaluate the opportunity cost for each of the unoccupied cells by using the relationship

Cost change = C_{ij}- (U_i - V_j) as follows:-

Unoccupied cell	C_{ij}- (U_i - V_j)	Net cost change
(P_1, W_2)	30-(0+2)	28
(P_1, W_3)	50-(0-8)	58
(P_2, W_1)	70-(48+19)	3
(P_2, W_2)	30-(48+2)	-20
(P_3, W_1)	40-(8+19)	13
(P_3, W_3)	60-(8-8)	60

Since the opportunity cost in P2 W2 is negative, the current basic feasible solution is not optimal and can be further improved towards optimality.

Table II

Plant or factory	**Warehouse**				**Capacity**	**Row Number U_i**
	W1	**W2**	**W3**	**W4**		
P1	19 / (5)	30 / 28	50 / 58	12 / (2)	7	U_1=0
P2	70 / 3	30 / + -20	40 / (7)	60 / - (3)	10	U_2=48
P3	40 / 13	10 / - (8)	60 / 50	20 / + (10)	18	U_3=48
Demand	5	8	7	15	35	
Row Penalty	V_1=19	V_2=2	V_3=-8	V_4=12		

Since the unoccupied cell P2 W2 has the largest improvement potential, we trace a close path or loop that begins- with and ends at cell.

Since one of the assigned cell will now be converted into unoccupied cell, we examine the assigned cell having (-) sign select the one with the least number of units (3 units) here will be transferred to the new cell and cell P2 W2 will be treated as the occupied cell and the cell P2 W4will be treated as unoccupied cell. The improved feasible solution is given in the Table III.

Table III

Plant or factory	**Warehouse**				**Capacity**
	W1	**W2**	**W3**	**W4**	
P1	19 / (5)	30	50	12 / (2)	7
P2	70	30 / (3)	40 / (7)	60	10
P3	40	10 / (5)	60	20 / (13)	18
Demand	5	8	7	15	35

The transportation cost, according to the above solution is

= 5 × 19 + 2 × 12 + 3 × 30 + 7 × 40 + 5 × 10 + 13 × 20 = ₹ 799, which is, less then the initial solution.

To test this solution for further improvement, we recalculate the values of U_i and V_j Thus, first using occupied cells we have the following equations

$U_1 + V_1 = 19$	$\longrightarrow$ $0 + V_1 = 19$	$\longrightarrow$ $V_1 = 19$
$U_1 + V_4 = 12$	$\longrightarrow$ $0 + V_4 = 12$	$\longrightarrow$ $V_4 = 12$
$U_2 + V_2 = 30$	$\longrightarrow$ $U_2 + 12 = 30$	$\longrightarrow$ $U_2 = 28$
$U_2 + V_3 = 40$	$\longrightarrow$ $28 + V_3 = 40$	$\longrightarrow$ $V_3 = -12$
$U_3 + V_2 = 10$	$\longrightarrow$ $8 + V_2 = 10$	$\longrightarrow$ $U_2 = 2$
$U_3 + V_4 = 20$	$\longrightarrow$ $U_3 + 12 = 20$	$\longrightarrow$ $V_3 = 8$

New row and column number with second solution is given in table IV.

Table IV

Plant or factory	Warehouse				Supply	Row Number U_i
	W1	W2	W3	W4		
P1	$\boxed{19}$ 5	$\boxed{30}$	$\boxed{50}$	$\boxed{12}$ 2	7	$U_1=0$
P2	$\boxed{70}$	$\boxed{30}$ 3	$\boxed{40}$ 7	$\boxed{60}$	10	$U_2=28$
P3	$\boxed{40}$	$\boxed{10}$ 5	$\boxed{60}$	$\boxed{20}$ 13	18	$U_3=8$
Demand	5	8	7	15	35	
Column Number	$V_1=19$	$V_2=2$	$V_3=12$	$V_4=12$		

Now we use the relationship Cost change = $C_{ij}- (U_i - V_j)$ as for the unoccupied cells as follows:

Unoccupied cell	$C_{ij}- (U_i - V_j)$	Net cost change
(P_1, W_2)	30-(0+2)	28
(P_1, W_3)	50-(0+12)	38
(P_2, W_1)	70-(28+19)	23
(P_2, W_4)	60-(28+12)	20
(P_3, W_1)	40-(8+19)	13
(P_3, W_3)	60-(12+8)	40

From the above analysis, we can see that there is no negative value in the unoccupied cell therefore the solution given in the table IV is the optimum solution with the transportation cost of ₹. 799.

Thus saving by optimal scheduling = ₹ 1000 - ₹ 799 = ₹ 201.

What is a "Just-in-Time System"?

JIT is defined as "a philosophy of manufacturing based on planned elimination of all waste and continuous improvement of productivity. It encompasses the successful execution of all manufacturing activities required to produce a final product, from design engineering to delivery and including all stages of conversion from raw materials onward. The primary elements of JIT are to have only the required inventory when needed, to improve quality to zero defects, to reduce lead times by reducing set-up times, queue lengths and lot sizes, to incrementally revise the operations themselves and to accomplish these things at minimum cost. In the broad sense, it applies to all forms of manufacturing, job-shop, process as well as repetitive".

Table 2.10.3: Romantic JIT and Pragmatic JIT	
Two views of JIT are: (i) romantic JIT and (ii) pragmatic JIT. Romantic JIT consist of various slogans and idealistic goals such as lot sizes of one, zero inventories and zero defects. JIT is seen as a "revolution" for manufacturing, one that is relatively simple to install and maintain and one that can lead to dramatic reduction in work-in-process (WIP) inventory and competitive advantage. Pragmatic JIT on the other hand consist of a set of techniques, some fairly technical, that relate to machine change-overs, lay-out design, product simplification, quality training, equipment maintenance and so on. While senior managers are attracted by the promise of inventory reductions and higher quality, they view JIT as a quickfix to their	Problems and look forward to lower WIP levels and increased inventory turnovers. Thinking that JIT is relatively simple concept, they expect that lower level managers and workers will quickly and easily convert to this new way of thinking and soon achieve results, not comprehending the complexity that is involved and the time needed to achieve meaningful results (It took 20 years for Toyota to perfect its JIT system). Adopting the romantic view of JIT can lead to much frustration and disappointment to shop floor people who struggle to achieve what senior managers perceive to be relatively easy. Moreover, cutting backs WIP inventories without dealing with the reasons for WIP can quickly lead to chaos on the shop floor, with delays and missed deliveries.

Not all companies use the term JIT. IBM uses the term continuous flow manufacture; Hewlett-Packard calls it both stock-less production and the repetitive manufacturing system, GE calls it management fay sight, Boeing calls it lean manufacturing, Motorola calls it short cycle manufacturing and several Japanese use the term "The Toyota System". Some companies use the term Time Based Competition (TBC). Just-in-time systems are also known as "zero inventory", "synchronous manufacturing", "material as needed" and "Kan-ban system".

Lean Production and JIT

Lean production 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 a 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 is a key element of lean production, (conceived by Taiichi Ohno, the former president of Toyota Motor Co. of Japan in the 1980s). The Japanese manufacturing success, with increased productivity, low product cost and often superior quality products can very much be attributed to JIT manufacturing.

JIT means

(i) Producing the quantity of units that is needed, no more, no less.

(ii) Producing them on the date and at the time required, not before and not after.

(iii) That a supplier delivers the exact quantity demanded, at the scheduled time and date.

Any deviations from these requirements mean that either resources are being unnecessarily wasted or that customers' needs are not being respected.

JIT is simply an acronym for being efficient, organised and rigorous, having the ability to be flexible, with an ultimate objective of satisfying the customer, respecting delivery time, having the specified quality and producing at minimum cost.

Just-in-time Philosophy

JIT is a philosophy of continuous and forced problem solving. With JIT, supplies and components are "pulled" through a system to arrive where they are needed and when they are needed. When good units do not arrive in time (just as needed), a "problem" has been identified. This makes JIT an excellent tool to help operations managers add value by driving out waste and unwanted variability. Because there is no excess inventory or excess time in a JIT system, costs associated with unneeded inventory are eliminated and throughput improved. Consequently, the benefits of JIT are particularly helpful in supporting strategies of rapid response and low cost.

Table 2.10.4: Just-in-Time— Broad Concept?	
Casually informed people some times view JIT as an inventory reduction technique. Most authoritative sources, including companies with nature JIT applications, view it more broadly. JIT aims most directly at reducing cycle times, secondarily at improving quality, flexibility and various costs. In these pursuits, the JIT concept employs cross-trained employees, organisation of resources into	self-contained "work cells", reduced inventories precisely positioned and labelled, quick change over of equipment, high levels of maintenance and housekeeping, close partnerships with suppliers and customers, schedules closely synchronized to demand, simplified product designs and customers and high levels of quality.(Quality and flexibility facilitate JIT as well as derive from it)

Concepts of Jit

The three fundamental concepts of JIT are :

(i) Elimination of waste and variability

(ii) "Pull" versus "Push" system and

(iii) Manufacturing cycle time (or "throughput" time).

These concepts are discussed below:

Waste Reduction and Variability Reduction

Waste Reduction : 'Any thing that does not add value' is described as waste in the production of goods or services. Products being stored, inspected or delayed, products waiting in queue and defective products do not add value and hence, they are 100 per cent waste. Moreover, any activity that does not add value to a product from the customer's perspective is waste. JIT speeds throughput, allowing faster delivery times and reducing work-in-process. Reduced work-in-process releases capital tied up in inventory for other more productive purposes.

Variability Reduction : To achieve just-in-time material movement, it is necessary that variability caused by both internal and external factors are reduced. Variability is any deviation from the optimum process that delivers perfect product on time, every time. Inventory hides variability or in other words problem. The less variability in a system, the less waste in the system. Most of the variability is caused by tolerating waste or by poor management.

Reasons for occurrence of variability are:

(i) Employees, machines and suppliers, produce units that do not conform to standards, are late or are not the proper quantity.

(ii) Engineering drawings or specifications are inaccurate.

(iii) Production personnel try to produce before drawings or specifications are complete.

(iv) Customer demands are unknown.

Variability may often go unseen when inventory exists. The JIT philosophy of continuous improvement removes variability, which allows movement of good materials just-in-time for use. JIT reduces materials throughout the supply chain.

Push versus Pull System : The concept behind JIT is that of a pull system. It is a JIT concept that results in material being produced or supplied only when requested and moved to where it is needed just as it is needed. A pull system uses signals to request production and delivery from upstream sections to the station that has production capacity available. This concept is used both within the immediate production process and with suppliers. By pulling material through the system in very small lots, just as it is needed, the cushion of inventory that hides problems is removed, problems become evident and continuous improvement is emphasised. Removing the cushion of inventory also reduces both investments in inventory and manufacturing cycle time.

Push system is a system that pushes materials into downstream workstations, regardless of their timeliness or availability of resources to perform the work. Push systems are the antithesis of JIT.

Manufacturing cycle time is the time between the arrival of raw materials and the shipping of finished products. JIT helps in reducing the manufacturing cycle time.

Little JIT and Big JIT

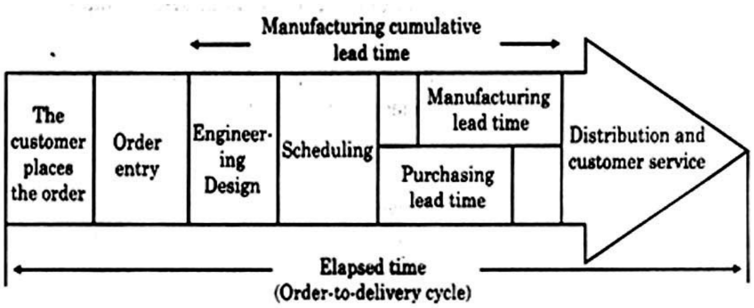
Little JIT is a form of production scheduling and inventory management whereby products are produced only to meet actual demand, and materials for each stage of production are received or produced "just-in-time" for use in the next stage of production or for delivery to a customer. This limited definition of JIT has been called Little JIT.

Big JIT encompasses the full range of organisational and operational improvements practiced by many Japanese companies (i.e., the entire way products are designed, work is organised and responsibilities are assigned) and is called Japanese production or lean production. Big JIT is the philosophy of operations management that seeks to eliminate waste in all aspects of a firm's production activities : human relations, vendor relations, technology and the management of materials and inventories.

Importance of JIT System

For years, manufacturing firms sought to provide products with the most values for the lowest cost. Now the leading firms provide products with the most value for the lowest cost with the fastest response time. Quick response to market demands provide a powerful, sustainable competitive advantage. Time has emerged as a dominant dimension of global competition, fundamentally changing the way organisations compete. It is no longer good enough for firms to be high-quality and low-cost producers. To succeed today, they must also be first in getting products and services to the customer fast. Hence, leading US and Japanese firms are using JIT as a weapon in speeding market responsiveness. To compete in today's environment, the order-to-delivery (the elasped time between the moment that a customer places an order until the customer receives the order) must be drastically reduced. **Exhibit 2.10.2** illustrates this important concept. JIT is a weapon of choice today in reducing the elapsed time of this cycle.

Exhibit 2.10.2 : The Time-Form-Order-to-Delivery Cycle



JIT has another major tenet in its philosophy-utilising the full capability of the worker. Workers in the JIT system are charged with the responsibility of producing quality parts just in time to support the next production process. If they cannot meet this responsibility they are required to stop the production process and call for help. In addition to greater responsibility for production, workers are also charged with improving the production process. Through quality teams, suggestion systems and other forms of participation, workers offer improvement to the production processes. Thus, the capabilities of workers are used to a much greater extent in the JIT system than in traditional production approaches.

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.

Relevance of JIT to TQM

The achievement of JIT may sometimes be a spin-off or by product of a company-wide quality improvement (CWQI) programme or it may be one of a number of specific goals in such a programme. Either way, CWQI is fundamental to the achievement of JIT. While JIT may or may not be one of the outcomes of CWQI, JIT cannot reasonably be achieved without it. JIT is one of the goals of CWQI.

Basically, CWQI is a concept well established in Japanese organisations from the bottom to the top. The objective is to form an organisation where everyone at all levels and in all functions can work together and make their company the best in its field of operation. The overview of just-in-time manufacturing indicates that there are many activities which are common to Total Quality Management (TQM).

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 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.

An Ideal Production System and JIT Production

An ideal production system might be described by the following:

(i) Only one type of product is produced.,

(ii) Demand for the product is constant at the rate of one unit every 't' units of time.

(iii) Customers purchase the product at the production facility.

(iv) All resources needed to produce the product (materials and labour) are available at the production site.

(v) All materials are without defect and will be delivered exactly when needed and only the amount needed will be provided (every 't' units of time, the materials to make one unit of product are delivered).

(vi) The amount of processing time required to make one unit of the product is "Nt" where N is a positive integer.

(vii) There is no randomness in processing times.

(viii) No defects are produced.

(ix) Machines never wear out or break down.

(x) Employees always show up for work and never make mistakes.

In the ideal production system, there are no raw materials, in-process or final product inventories, except the product actually being processed at the workstations. There is no need for safety stocks of any kind because it is known when demand will occur and there are no unexpected production shortages due to quality defects, machine break-downs or employee absences. Because only one product is made, ho time is lost on changing over or setting up machines and no scheduling or coordinating of different products or jobs is necessary. Such a system would be easy to manage.

Unfortunately, in the real life, the situation is not like the ideal production system. Most firms produce a variety of products that share equipment and personnel in their production, demand is not uniform and totally predictable, final products must be transported to spatially dispersed customers, resources must be collected from various locations, deliveries are not always reliable and there are economies of scale in acquisition. The tasks performed in the production process are often lumpy (not totally decomposable) in terms of their processing times, processing times are variable, mistakes are committed, defects occur, machines breakdown and employees are absent. Firms normally accommodate these deviations from the ideal environment by changing the design and operation of the system in ways that result in higher cost, lower quality and less timely product delivery than occurring in the ideal system.

The one consistent system of deviation from the ideal production system is excessive inventories, in addition, excessive amounts of materials and products have to be scrapped due to poor quality and due to overproduction in anticipation of demand that does not materialise. Inspite of carrying large inventories and overproducing, firms may still suffer from poor product quality and late deliveries to customers.

The JIT philosophy and JIT system has been successful not simply because it reduces inventories and scrap but, more important, because it recognises that excessive inventories are symptomatic of more fundamental problems. Big JIT philosophy focuses on eliminating problems of demand variations, unreliable deliveries of raw materials, processing time variations and excessive set-up times. Reduction of inventories is then a natural consequence of the improvements in the production system.

Characteristics of Just-in-Time System

JIT systems focus on reducing inefficiency and unproductive time in the production process to improve continuously the process and quality of the product or service. Employee involvement and inventory reductions are essential to JIT operations. An outline of the salient characteristics of JIT are:

(i) pull method of material flow

(ii) constantly high quality

(iii) small lot sizes

(iv) uniform workstation loads

(v) standardised components and work methods

(vi) close supplier ties

(vii) flexible workforce

(viii) line flow strategy

(ix) automated production and

(x) preventive maintenance.

JIT Manufacturing Versus JIT Purchasing

Just-in-time manufacturing is an organisation-wide quest to produce output within the minimum possible lead time and at the lowest possible total cost by continuously identifying and eliminating all forms of waste and variance. Just-in-Time purchasing has the same pull type approach used in JIT manufacturing (or JIT production) applied to purchasing shipments of parts from suppliers. The essentials of JIT purchasing are:

(i) Supplier development and supplier relation undergo fundamental changes. The supplier and customer have co-operative relationship which is also known as subcontractor network and suppliers are referred to as co-producers. Sensitive information, assistance in reducing costs and improving quality and even financing are often shared by customers and suppliers.

(ii) Purchasing departments develop long term relationships with few suppliers rather-than a short term relationship with many suppliers.

(iii) Although price is important, delivery schedules, product quality and mutual trust and co-operation become the primary basis for the selection of suppliers.

(iv) Suppliers are encouraged to extend JIT methods to their own suppliers.

(v) Suppliers are ordinarily located near the buying firm's factory or clustered together at some distance which will keep the lead times shorter and more reliable.

(vi) Shipments are delivered directly to the customer's production line usually through transportation vehicles owned by suppliers.

(vii) Parts are delivered in small, standard size containers with a minimum of paperwork and in exact quantities.

(viii) Delivered material is of near-perfect quality.

Pre-requisites for JIT Manufacturing

JIT production drastically reduces WIP inventories throughout the production system and thereby reduces the manufacturing lead times. The result is a smooth, uninterrupted flow of small lots of products throughout production. Most successful JIT applications have been in repetitive manufacturing operations where batches of standard products are produced at high speeds and high volumes with materials moving in a continuous flow.

Before implementing the JIT system, certain changes to the factory and the way it is managed must occur before the benefits of JIT can be realised. These changes are:

(i) Stabilise production schedules.

(ii) Make the factories focussed.

(iii) Increase production characteristics of manufacturing work centres.

(iv) Improve product quality.

(v) Cross-train workers so that they are multi-skilled and competent in several jobs.

(vi) Reduce equipment break downs through preventive maintenance.

(vii) Develop long-term supplier relationships that avoid interruptions in material flows.

Elements of a JIT Manufacturing System

The important elements or components of a JIT manufacturing system are:

(i) Eliminating waste

(ii) Enforced problem solving

(iii) Continuous improvement

(iv) Involvement of people

(v) Total quality management and

(vi) Parallel processing.

Replacement of Machine and Other Relevant Concept

Replacement of Machines and Equipment:

Machines are purchased and replacement of old machines are made mainly for two reasons:

1. To increase the productive capacity and
2. To reduce cost of production.

Various other reasons for replacement are the following:

(i) To get rid of worn out, broken down or obsolete machines,

(ii) To accommodate larger sizes of work and increase the machine capacity,

(iii) To reduce labour cost by introducing semi-automatic machines or machines more than one of which can be operated by a single operator,

(iV) To simplify operations by using automatic machines which are capable of performing variety of work usually performed by a number of different machines,

(v) To minimise repair cost and reduce idle time.

An analysis of the above six reasons will lead to either increase in capacity or reduction in cost or both.

Factors on which Equipment is Replaced: The replacement plan depends on evaluation of present and replacement machines from the point of view of technical suitability and cost saving features.

The points to check for replacement studies vary from industry, to industry on management conditions and management policies. But some factors are common to practically all cases. These are:

Technical Factors:

(i) Inadequacy from the stand paint of range, speed, accuracy, strength, rigidity, output and capacity,

(ii) Obsolescence and equipment worn out condition,

(iii) Special advantage of the new machine as to easiness of set ups convenience of operation, safety, reliability performance, control panels and special features,

(iv) Flexibility and versatility of the machine.

Cost Factors:

(i) High repair cost of existing machine,

(ii) High remodelling cost of existing machine,

(iii) Less chance of spoilage and rejection work causing: saving in cost,

(iv) Faster rate of production causes lower cost,

(v) Replacement of skilled -workers by semi-skilled and: unskilled workers leading to lesser labour cost,

(vi) Compactness of the machine leading to a saving in-space which means saving of overhead costs,

(vii) Machine pay back period i.e. how soon the cost of the equipment is recovered,

(viii) Life of the new machine giving effective service,

(ix) Flexibility and versatility of the machine tending to reduce idle time cost with changes in methods of production-which might occur in future,

(x) Availability of funds for the acquisition of the equipment or possibility of special arrangement like hire-purchase or government loans or other accommodations.

Replacement Programmes: It is prudent to have phased policies of machine replacement plans than to wait until breakdowns occur causing production hold ups. There are different forms of the programme.

1. A definite amount of money or a certain percentage of earning of the company is used each year to replace existing machines which are either superseded by improved models or are not in tip top condition or are having insufficient capacity.
2. Replacement is made of the oldest or most inadequate machine each year by upto date machines of greater accuracy or higher capacity. Some times automatic machines are gradually introduced in this way which is capable of doing several operations with lesser number of operators.
3. The economy of working on various machines are studied .and replacement of machines are made only to have a definite cost reduction.

Whatever may be the programme, replacement question is to be carefully considered in prosperous and normal years only. In slum or dull periods, replacement should not be done unless it is unavoidable.

The basic concept of 'Replacement Theory' is to take decision about the time when an item of 'Capital Asset' should be replaced by another of the same type or by a different one. In other words 'Replacement Theory' concerns about 'optimum period of replacement'.

For the purpose of 'Replacement Theory' Capital equipment are basically divided under two broad categories:

1. Replacement policy for Equipment which detoriates with time gradually;

2. Items which fail suddenly and cannot be made workable by incurring repairing costs.

Again, replacement of Capital equipment which gradually detoriates with time, can be worked-out under two different ways:

Ignoring the concept of time value of money and considering the time value of money.

(i) When time value of money is not considered: Determination of optimum period of 'Replacement' Let us, consider the following formula:

$$T(r) = C - S + \sum_{t=1}^{r} Mt$$

where, T(r) denotes owning and maintaining cost of keeping an equipment for 'r years'

C = Capital cost of the equipment

S = Salvage value of the equipment at the end of 'r years'

Mt = Cost of maintenance in year t

Accordingly, the average cost, A(r) can be calculated as under:

$$A(r) = \frac{1}{r}\left[C - S + \sum_{T=1}^{r} Mt\right]$$

Decision: When to replace? The optimal replacement period would be the year, in which A(r) = Average cost is minimum.

(ii) When time value of money is considered: In this case the concept of present value of money is considered. Considering the interest rate, which is also termed as discounting factor or discounting rate with that the present values of maintenance costs are to be evaluated for each year and final annualised cost, for different years are also evaluated. Decision: When to replace? The decision will be taken by considering the following rules:

A. Replacement will not be made if annualised cost > next period's cost.

B. Replacement will be made in that year only, when annualised cost < next period's cost. In other words, replacement will be made every r years.

when A(r) = the annualized cost of replacing every r years is the minimum.

Important Assumptions

(a) Salvage/scrap value of the equipment to be replaced should be considered as 'nil'.

(b) The maintenance costs are assumed to be incurred at the beginning of the year.

Replacement of items which fail suddenly

Sometimes, the failure of an item may cause a complete breakdown of the system. The costs of failure, in such a case will be quite higher than the cost of the item itself. So, it is important to know in advance as to when the failure is likely to take place so that item can be replaced before it actually fails and the time of failure can be predicted from the probability distribution of failure time obtained from past experience and then, to find the optimal value of time t which minimises the total cost involved in the system. Mainly two types of replacement policies are there:

(1) Individual replacement policy in which an item is replaced immediately after it fails.

(2) Group replacement policy in which all items are replaced, irrespective of whether they have failed or not, with a provision that if any item fails before the optimal time, it may be individually replaced.

Let us, explain through example how 'Replacement of items which fail suddenly' is considered:

Illustration 29:

Following failure rates have been observed for a certain type of light bulbs:

Week	1	2	3	4	5
Per cent failing by the end of week:	10	25	50	80	100

There are 1,000 bulbs in use, and it costs ₹ 2 to replace an individual bulb which has burnt out. If all bulbs were replaced simultaneously it would cost ₹ 50 paisa per bulb. It is proposed to replace all bulbs at fixed intervals of time, whether or not they have burnt out, and to continue replacing burnt out bulbs as and when they fail. At what intervals all the bulbs should be replaced? At what group replacement price per bulb would a policy of strictly individual replacement become preferable to the adopted policy?

Solution:

Let, P_i be the probability that a light bulb, which was new when placed in position for use, fails during the ith week of its life.

Thus, following frequency distribution is obtained assuming to replace burnt out bulbs as and when they fail,

P_1 = the prob. of failure in Ist week = (10/100)	= 0.10
P_2 = the prob. of failure in IInd week = (25 - 10 /100	= 0.15
P_3 = the prob. of failure in IIIrd week = (50 - 25)/l00	= 0.25
P_4 = the prob. of failure in IVth week = (80 - 50)/100	= 0.30
P_5 = the prob. of failure in Vth week = (100 - 80)/100	= 0.20
Total	= 1.00

Since the sum of all probabilities can never be greater than unity, therefore all further probabilities P_6, P_7 and P_8 so on, will be zero. Thus, a bulb that has already lasted four weeks is sure to fail during the fifth week. Furthermore, assume that

(i) Bulbs that fail during a week are replaced just before the end of that week, and

(ii) The actual percentage of failures during a week for a subpopulation of bulbs with the same age is the same as the expected percentage of failures during the week for that subpopulation.

Let N_i be the number of replacements made at the end of the ith week, if all 1000 bulbs are new initially. Thus,

$N_0 = N_0$ = 1,000

$N_1 = N_0 p_1 = 1{,}000 \times 0.10$ = 100

$N_2 = N_0 p_2 + N_1 p_1 = 1{,}000\times0.15 + 100\times0.10$ = 160

$N_3 = N_0 P_3 + N_1 p_2 + N_2 p_1 = 1{,}000\times0.25 + 100\times0.15 + 160\times0.10$ = 281

$N_4 = N_0 p_4 + N_1 p_3 + N_2 P_2 + N_3 p_1$ = 377

$N_5 = N_0 p_5 + N_1 p_4 + N_2 P_3 + N_3 p_2 + N_4 p_1$ = 350

$N_6 = 0 + N_1 p_5 + N_2 p_4 + N_3 p_3 + N_4 p_2 + N_5 p_1$ = 230

$N_7 = 0 + 0 + N_2 p_5 + N_3 p_4 + N_4 p_3 + N_5 p_2 + N_6 p_1$ = 286

and so on.

It has been observed that the expected number of bulbs burnt out in each week increases until 4th week and then decreases until 6th week and again starts increasing. Thus, the number will continue to oscillate and ultimately the system settles down to a steady state in which the proportion of bulbs failing in each week is the reciprocal of their average life.

Since the mean age of bulbs

$= 1 \times p_1 + 2 \times p_2 + 3 \times p_3 + 4 \times p_4 + 5 \times p_5$

$= 1 \times 0.10 + 2 \times 0.15 + 3 \times 0.25 + 4 \times 0.30 + 5 \times 0.20 = 3.35$ weeks.

the number of failures in each week in steady state becomes

= 1,000/3.35 = 299 and the cost of replacing bulbs only on failure = 2 × 299 (at the rate of ₹ 2 per bulb) = ₹ 598.

Since the replacement of all 1,000 bulbs simultaneously costs 50 paise per bulb and replacement of an individual bulb on failure costs ₹ 2, therefore cost of replacement of all bulbs simultaneously is as given in the following table:

End of week	Cost of individual replacement	Total cost of group replacement	Average cost per week
1	100 × 2 = 200	1,000 × 0.50 +100×2 = ₹ 700	₹ 700.00
2	160× 2 = 320	700 + 160×2 = ₹ 1,020	₹ 510.00
3	281 ×2 = 562	1,020 + 281 ×2 = ₹ 1,582	₹ 527.33

The cost of individual replacement in the third week exceeds the average cost for two weeks.

Thus it would be optimal to replace all the bulbs after every two weeks; otherwise the average cost will start increasing.

Further, since the group replacement after one week costs ₹ 700 and the individual replacement after one week costs ₹ 598, the individual replacement will be preferable.

Replacement—Staffing Problem

Illustration 30:

Problems concerning recruitment and promotion of staff can sometimes be analysed in a manner similar to that used in replacement problems in industry.

A faculty in a college is planned to rise to strength of 50 staff members and then to remain at that level. The wastage of recruits depends upon their length of service and is as follows:

Year	1	2	3	4	5	6	7	8	9	10
Total % who left up to:	5	35	56	65	70	76	80	86	95	100

the end of year

(i) Find the number of staff members to be recruited every year.

(ii) If there are seven posts of Head of Deptt. for which length of service is the only creterion of promotion, what will be average length of service after which a new entrant should expect promotion?

Solution:

Let us assume that the recruitment per year is 100. From above it is clear that the 100 who join in the first year will become zero in 10th year, the 100 who join in the 2nd year will (serve for 9 years and) become 5 at the end of the 10th year and the 100 who join in the 3rd year will (serve or 8 years and) become 14 at the end of the 10th year and so on. Thus, when the equilibrium is attained, the distribution length of service of staff members will be as under:

Year	No. of staff members
0	100
1	95
2	65
3	44
4	35
5	30
6	24
7	20
8	14
9	5
10	0
Total	432

(i) Thus if 100 staff members are recruited every year, the total number of staff members after 10 years of service = 432

100 to maintain a strength of 50, the number to be recruited every year = $\frac{100}{432} \times 50 = 11.6$

It is assumed that those staff members who completed x years' service but left before x + 1 years' service, actually left immediately before completing x + 1 years.

If it is assumed that they left immediately after completing x years' service, the total number will become 432 - 100 = 332 and 100 the required intake will be $50 \times \frac{100}{332} = 15$

In actual practice they may leave at any time in the year so that reasonable number of recruitments $\frac{11.6 + 15}{2} = 13$ (approx)

(ii) If we recruit 13 persons every year then we want 7 seniors. Hence if we recruit 100 every year, we shall require $\frac{7}{13} \times 100 = 54$ (appox) seniors.

It can be seen that 54 seniors will be available if we promote them during 6th year of their service ($\because$ 0 + 5 + 14 + 20 + 24 = 63 > 54).

$\therefore$ The promotion of a newly recruited staff member will be due after completing 5 years and before putting in 6 years of service.

Illustration 31:

The following table gives the running costs per year and resale values of a certain equipment whose purchase price is ₹ 6,500. At what year is the replacement due optimally.

Year	1	2	3	4	5	6	7	8
Running Cost (₹)	1,400	1,500	1,700	2,000	2,400	2,800	3,300	3,900
Resale Value (₹)	4,000	3,000	2,200	1,700	1,300	1,000	1,000	1,000

Solution:

Let Purchase price = C & Resale value = S.

Chart showing optimal Replacement period

Year	Net capital cost (₹) (C -S)	Running Cost (₹)	Cumulative running Cost (₹)	Total cost ₹. (2) + (4)	Average Annual cost (₹) (5)÷(1)
(1)	(2)	(3)	(4)	(5)	(6)
1	2,500	1,400	1,400	3,900	3,900
2	3,500	1,500	2,900	6,400	3,200
3	4,300	1,700	4,600	8,900	2,267
4	4,800	2,000	6,600	11,400	2,850
5	5,200	2,400	9,000	14,200	2,840
6	5,500	2,800	11,800	17,300	2,882

∴ Optimal replacement period at the end of 5^{th} year.

Illustration 32:

A truck-owner finds from his past experience that the maintenance costs are ₹200 for the first year and then increase by ₹2,000 every year. The cost of the Truck Type A is ₹9,000. Determine the best age at which to replace, i.e. truck. If the optimum replacement is followed what will be the average yearly cost of owing and operating the Truck? Truck Type B cost ₹10,000. Annual operating costs are ₹400 for the first year and then increase by ₹800 every year. The Truck owner have now the Truck Type A which is one year old. Should it be replaced with B type, and if so, when?

Solution:

Truck A Chart Showing Optimal Replacement Period

Year	Capital cost (₹)	Maintence Cost (₹)	Cumulative running Cost (₹)	Total cost (₹) (5) (2) + (4)	Average Annual cost (₹) (6) (5) ÷ (1)
(1)	(2)	(3)	(4)		
1	9,000	200	200	9,200	9,200
2	9,000	2,200	2,400	11,400	5,700
3	9,000	4,200	6,600	15,600	5,200
4	9,000	6,200	12,800	21,800	5,450

∴ Optimal replacement period end of 3rd year.

Truck B Chart Showing Optimal Replacement Period

Year	Capital cost (₹)	Maintence Cost (₹)	Cumulative running Cost (₹)	Total cost (₹) (5) (2) + (4)	Average Annual cost (₹) (6) (5) ÷ (1)
(1)	(2)	(3)	(4)	(2) + (4)	(5) ÷ (1)
1	10,000	400	400	10,400	10,400
2	10,000	1,200	1,600	11,600	5,800
3	10,000	2,000	3,600	13,600	4,533
4	10,000	2,800	6,400	16,400	4,100
5	10,000	3,600	10,000	20,000	4,000
6	10,000	4,400	14,400	24,400	4,067

Comparing the average cost of Trucks A and B when the current truck A is one year old.

Average Annual Maintenance Cost

Year	A	B
1	5,700	10,400
2	5,200	5,800
3	5,450	4,533

At the year third, the Truck A can be replaced by Truck B and subsequently it can be replaced at the end of 5 years of its use.

Illustration 33:

A Plant Manager is considering replacement policy to a new machine. He estimates the following costs:

Year	1	2	3	4	5	6
Replacement cost at the beginning of the year	100	110	125	140	160	190
Salvage value at the end of the year	60	50	40	25	10	0
Operating costs	25	30	40	50	65	80

Find the year when replacement is to be made.

Solution:

Chart Showing Optimal Replacement Period

Year (1)	Net capital cost (₹) (Cost - Scrap)(2)	Operation cost (₹) (3)	Cumulative operation cost (₹)(4)	Total cost (₹.) 5 = (2+4)	Average annual Cost ₹)(6= 5+1)
1	40	25	25	65	65
2	60	30	55	115	57.5*
3	85	40	95	180	60
4	115	50	145	260	65
5	150	65	210	360	72
6	190	80	290	480	80

The asset should be replaced by the end of 2nd year where the average annual cost is lowest.

Illustration 34:

A fleet owner finds from his past records that the costs per year of running a vehicle whose purchase price is ₹ 50,000 are as under:

Year	1	2	3	4	5	6	7
Running Cost (₹)	5,000	6,000	7,000	9,000	11,500	16,000	18,000
Resale Value (₹)	30,000	15,000	7,500	3,750	2,000	2,000	2,000

Thereafter, running cost increases by ₹ 2,000, but resale value remains constant at ₹ 2,000. At what age is a replacement due?

Solution:

Chart Showing Optimal Replacement Period

Year (1)	Net capital (2)	Annual maintenance cost (₹) (3)	Cumulative operation costs (₹) (4)	Total cost (₹) 5 = (2+4)	Average annual cost (₹) (6) (5) ÷ (1)
1	20,000	5,000	5,000	25,000	25,000
2	35,000	6,000	11,000	46,000	23,000
3	42,500	7,000	18,000	60,500	20,167
4	46,250	9,000	27,000	73,250	18,313
5	48,000	11,500	38,500	86,500	17,300
6	48,000	16,000	54,500	1,02,500	17,083*
7	48,000	18,000	72,500	1,20,500	17,214

Optimal replacement at the end of 6th year.

Illustration 35:

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

(i) 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.

(ii) 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 $1 \times 0.01 + 2 \times 0.02 + 3 \times 0.03 + 4 \times 0.05 + 5 \times 0.07 + 6 \times 0.12 + 7 \times 0.20 + 8 \times 0.3 + 9 \times 0.16 + 10 \times 0.04 = 7.05$

No. of poles to be replaced every year $= \frac{5,000}{7.05} = 709$

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	Cumulative cost	Total cost	Avg.annual cost
1	5,000 × 0.01 = 50	8,000	8,000	4,0800	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

Year	No. of poles to be replaced	Yearly cost	Cumulative cost	Total cost	Avg.annual cost
5	5,000 × 0.07 + 50 × 0.05 + 101 × 0.03 + 152 × 0.02 + 265 × 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 = 6,023	9,63,680	11,11,040	15,11,040	2,51,840

Optimal replacement at the end of the 5th year.

Illustration 36:

A manufacturer is offered two machines A and B. A is priced at ₹ 5,000 and running costs are estimated ₹ 800 for each of the first five years, increasing by ₹ 200 per year in the sixth and subsequent year. Machine B, which has the same capacity as A, costs ₹ 2,500 but will have running costs of ₹ 1,200 per year for six years, increasing by ₹ 200 per year thereafter.

If money is worth 10% per year, which machine should be purchased? (Assume that the machines will eventually be sold for scrap at a negotiable price).

Solution:

Machine A: Chart Showing Optimal Replacement Period

Year	Running cost (₹)	Discount factor	Discounted running Cost (₹)	Cumulative running Cost (₹)	Total cost (₹)	Cumulative discounted factor	Annualized cost (₹)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8) = (6) ÷7
1	800	1.00	800	800	5,800	1.00	5,800
2	800	0.9091	727	1,527	6,527	1.9091	3,419
3	800	0.8264	661	2,188	7,188	2.7355	2,628
4	800	0.7513	601	2,789	7,789	3.4868	2,234
5	800	0.6830	546	3,335	8,335	4.1698	1,999
6	1,000	0.6209	621	3,956	8,956	4.7907	1,869
7	1,200	0.5645	677	4,633	9,633	5.3552	1,799
8	1,400	0.5132	718	5,351	10,351	5.8684	1,764
9	1,600	0.4665	746	6,097	11,097	6.3349	1,752
10	1,800	0.4241	763	6,860	11,860	6.7590	1,755

Machine B:

CHART SHOWING OPTIMAL REPLACEMENT PERIOD

Year	Running Cost (₹)	Discount factor	Discounted running Cost (₹)	Cumulative running Cost (₹)	Total cost	Cumulative discounted	Annualized cost (₹)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)=6÷7
1	1,200	1.00	1,200	1,200	3,700	1.0000	3,700
2	1,200	0.9091	1,091	2,291	4,791	1.9091	2,510
3	1,200	0.8264	992	3,283	5,783	2.7353	2,114
4	1,200	0.7513	902	4,184	6,684	3.4868	1,917
5	1,200	0.6830	820	5,004	7,504	4.1698	1,800
6	1,200	0.6209	745	5,750	8,250	4.7907	1,722
7	1,400	0.5645	790	6,540	9,040	5.3552	1,688
8	1,600	0.5132	821	7,361	9,861	5.8684	1,680
9	1,800	0,4665	840	8,201	10,701	6.3349	1,689

Machine B should be purchased as its annual cost is lowest i.e. ₹ 1,680.

Illustration 37:

Suppose that a special purpose type of light bulb never lasts longer than 2 weeks. There is a chance of 0.3 that a bulb will fail at the end of the first week. There are 100 new bulbs initially. The cost per bulb for individual replacement is ₹ 1 and the cost per bulb for a group replacement is ₹ 0.50. It is cheapest to replace all bulbs: (i) individually, (ii) every week, (iii) every second week, (iv) every third week?

Solution:

Chart Showing Optimal Replacement Period

Probability 0.3; 0.7

Individual replacement: Average life of bulb = $1 \times 0.3 + 2 \times 0.7 = 1.7$

Weekly replacement = $\frac{100}{1.7} = 59$

Group replacement: $100 \times 0.5 = 50$

Week	Items to be replaced	Weekly	Cumulative	Total cost	Avg. weekly cost
1	100 × 0.3 = 30	30	30	80	80
2	100 × 0.7 + 30 × 0.3 = 79	79	109	159	79.50

It should be replaced by the end of second week. It cannot be replaced every third week as the life of the bulb is only 2 weeks.

Study Note - 3

PRODUCTIVITY MANGEMENT AND TOTAL QUALITY MANAGEMENT

This Study Note includes

3.1 PRODUCTIVITY

The term "productivity" conjures up different images and different interpretations to different people and even segments of society. According to Soloman Fabricant "Productivity" is a subject surrounded by considerable confusion.

The I.L.O. publication, "Higher Productivity in Manufacturing Industries" has defined productivity as the ratio between output of wealth and the input of resources used in the process of production.

The organised labour has tried to interpret productivity as the value of all output divided by man-hours of work. This assumption is based on the promise that labour is more productive, where the ratio of the time required to time spent in producing a unit of output is higher than in a situation where this ratio is lower.

The European Productivity Agency (EPA) has defined productivity as follows :

"Productivity is an attitude of mind. It is a mentality of progress of the constant improvement of that which exists. It is the certainty of being able to do better today than yesterday, and continuously. It is the constant adaptation of economic and social life to changing conditions, it is a continual effort to apply new techniques and methods, it is the faith in human progress."

Even though productivity in a general connotation is referred as the 'output to input' ratio, in essence it is the process of harnessing the capacity to increase productivity by ensuring proper and efficient use of all types of resources in employment using them to produce as many goods and services as possible, of the kind and quality most wanted by the consumers at lower costs.

Definition

The term productivity can be defined in two ways. In simple terms, productivity is defined as a ratio between the output and input.

$$\text{Productivity} = \frac{\text{Output obtained}}{\text{Inputs consumed}}$$

In a broader sense, productivity is defined as a measure of how well resources are brought together in organizations and utilized for accomplishing a set of results.

$$\text{Productivity} = \frac{\text{Performance achieved}}{\text{Resources consumed}} = \frac{\text{Effectiveness}}{\text{Efficiency}}$$

Productivity is achieving the highest results possible while consuming the least amount of resources. Accordingly performance refers to the "effectiveness" in reaching in mission or planned achievement or a needed value without serious regard to the costs incurred in the process. Efficiency refers to how well these resources are brought together for achieving results with minimum costs. It implies the attainment of a level or range of result that is acceptable but not necessarily desirable. An action may be cost efficient, but not effective, in case the required result is not achieved.

$$\text{Effectiveness} = \frac{\text{Target achieved}}{\text{Target achievable}}$$

Organizational effectiveness means the degree or the extent to which the targets of an organization are achieved. The term organization in behavioural sciences denotes a body corporate or a firm as in Economics. The term "efficiency" seems to have been borrowed from Energy Engineering wherein the fuel efficiency, for example, means economy in the use of resources.

The efficient use of resources does not involve cost. It is measured in physical units. It can be defined as

$$\text{Input efficiency} = \frac{\text{Actual consumption}}{\text{Desired or standard consumption}}$$

The term optimal has the same connotation as in Economics. The optimal speed, for example, means the speed at which fuel consumption of the vehicle is minimum. But all these are measures in physical units.

Need of a Standard Definition

The common use of the term productivity in different sciences – physical, economic, and behavioural-alike has created a lot of confusion in its use. In the initial stages of inter-disciplinary uses, it is not unusual. It should be standardized in due course in order to be scientific. It would be better and would solve several problems if it is made clear that productivity is a physical phenomenon whereas efficiency is a monetary phenomenon. Keeping this criterion in mind, some concepts can be defined as follows:

$$\text{Productivity} = \frac{\text{Effectiveness}}{\text{Economy in consumption}}$$

$$= \frac{\text{Achieved target/Desired target}}{\text{Achieved consumption/Desired Consumption}}$$

$$= \frac{\text{Achieved target}}{\text{Desired target}} \cdot \frac{\text{Desired input consumption}}{\text{Achieved input consumption}}$$

$$\text{Production efficiency} = \frac{\text{Maximum effectiveness}}{\text{Minimum cost}}$$

$$\text{Organizational effectiveness} = \frac{\text{Achieved performance or target}}{\text{Desired performance or target}}$$

$$\text{Organizational or a firm's efficiency} = \frac{\text{Organizational effectiveness}}{\text{Cost effectiveness}}$$

$$= \frac{\text{Degree of targets achieved}}{\text{Minimum cost of achieving it}}$$

Thus, organizational effectiveness at the minimum cost may be called organizational efficiency. Efficiency enters into the picture only when monetary values (prices) are involved. In case the input and output data are available in value terms, not in physical units, productivity can be calculated after deflating them. Just like the estimation of production functions with deflated values, it will serve the purpose of estimating productivity in physical terms.

Another important variation in defining productivity arises on account of different definitions of the inputs and output. This aspect has already been explained in the context of production function analysis. There are several ways of defining an output such as gross output, net output, in physical units, in deflated monetary units, in terms of value added, value of service rendered, and so on. Defining and measuring the value of output, particularly that of the service sector, is a difficult task. Similar problems are faced in case of inputs. Besides the usual, routine problems of measurement and quality variance of inputs within the same price range is an important problem. Sometimes, the higher-priced input, particularly in the case of labour, happens to be inferior to the low-priced one.

This is more probable with the permanent system of employment.

Kinds of Productivity

Basically productivity is measured in two ways.

1. **Partial Productivity:** This measures productivity of one factor or input, keeping other factors or inputs constant or unchanged. Mathematically, this is a partial derivative of the output with respect to one input, keeping the other inputs constant. As seen in the case of the Cobb-Douglas production, which has two factors labour and capital, labour productivity can be estimated by $\partial Y / \partial L|K|$ assuming capital as constant and the capital productivity by $\partial Y / \partial K|L|$ assuming labour as constant. These measure the change in output with respect to labour and capital, one at a time respectively, keeping in other constant. Similarly, various productivity ratios can be calculated with respect to other inputs such as material, energy consumed, and so on.

2. **Total Productivity:** Here, productivity is calculated with respect to the total cost or the total finances committed, instead of one input, as given below:

$$\text{Productivity} = \frac{\text{Value added}}{\text{Total factor cost}} = \frac{\text{Value of gross output}}{\text{Total value of inputs.}}$$

   The total factor productivity (TFP) is a measure of the overall changes in production efficiency.

Measuring productivity

Bain suggests that a good productivity measure should possess the following properties. The more closely the measurement meets these criteria, the more useful it is for improving productivity.

1. **Validity:** it reflects accurately the changes in productivity.
2. **Completness:** It takes into consideration all components of both the output and the input for a given productivity ratio.
3. **Comparability:** It enables the accurate measurement of a productivity change between periods.
4. **Inclusiveness:** It takes into account and measures separately all activities.
5. **Timeliness:** It ensures that data is provided soon enough for managerial action to be taken when problems arise.
6. **Cost effectiveness:** It obtains measurement in a manner that will cause the least interruption possible to the ongoing productive efforts of the firm.

Models of Productivity Measurement –

These models can be classified into three. As pointed out earlier, their major differences arise from the type and coverage of the output and input variables.

(A) Ratio method

(B) Production Function method

(C) P-O-P method.

(A) Ratio Method: There are a good number of models in this category. Their differences stem from

(i) The definition of output;

(ii) One input partial productivity measure; and

(iii) Many input total productivity measure.

(i) Definition of output: Output has been defined in more than one way.

(a) Gross or total output

(b) Net output or value added

(c) Differences in type of output selected

(i) Gross/net deflated value of sales and operating revenue (Kendrick and Creamer);

(ii) Aggregate production weighted of selling price of the product (Craig and Harris);

(iii) Value added = Total cost – material cost, and profit (Ramsay); V.A. = (Sales + inventory + internally produced intermediates) – (total value of purchases and supplies, depreciation, rentals, etc.) (Taylor and Davis).

(ii) Partial productivity: These models consider only one input at a time such as labour, capital, and material.

(iii) Total productivity: Total factor productivity is measured by taking into consideration all input variables, at least the main variables like capital and labour.

$$\text{Total productivity} = \frac{\text{Gross output}}{\text{All variables}} = \frac{\text{Value added}}{\text{main variables (L, K)}}$$

In most of the studies, the aggregation of inputs is a simple linear combination of inputs. Taylor and Davis define it in a different way, that is, as the sum of wages, salaries, and benefits added to the total of working and fixed capitals adjusted for investor contribution and deflated for price changes.

Timbergen introduced the concept of total factor productivity as the ratio between the real product output and the real factor inputs together for an international comparison of productivity growth. Stigler developed the concept in 1947 and suggested measurement of the real total factor input by weighting the real capacity and real labour by their marginal products. These TFP measures differ from one another not only for their definitions of input and output but also in the underlying production function. Some of the most frequently used and popular models are reproduced here.

(a) Domar or Geometric Index

$$V_t = P_t L_t^{\alpha} K_t^{\beta}$$

Where P_t = Total factor productivity and V_t = Value added. The rate of TFP is given by the difference between the rate of change of output and the weighted sum of the rate of change of capital and labour.

$$\frac{\Delta P}{P} = \frac{\Delta V}{V} - \left(\alpha \frac{\Delta L}{L} + \beta \frac{\Delta K}{K}\right)$$

Assuming constant returns, that is, $\alpha + \beta = 1$ and the labour share in income "s", the capital's share would be (1-s), s varying over time.

$$\log P_t = \log V_t - S_t \log L_t - (1 - S_t) \log K_t$$
$$gP_t = gV_t - [S_t\, gL_t + (1 - S_t)\, gK_t]$$

(b) Solow's Index: It is based on the homogenous production function of degree one.

$$V = A_s^t \cdot F(K, L)$$
$$V/L = A_s^t \cdot F(K, L)$$

Where L = labour and K = capital. Assuming the Cobb-Douglas production function, the expression for TFP is.

$$\frac{\Delta A_s^t}{A_s^t} = \frac{\Delta V/L}{V/L} - \frac{\beta \Delta k/L}{K/L}$$

(c) Kendrick Measure (I_t): It is based on a linear production function $V = \alpha L + \beta K$

$$I_k^t = \frac{V_t}{\alpha_o L^t + \beta_o K^t}$$
$$= \frac{V_t / V_0}{S_0 (L^t / L^0) + (1 - S_0) K^t / L_0}$$

Where V_t = real value added or measure of real output, L_t = real labour input, K_t = real capital input, t = time, s = share of labour in income, and α_o, β_o = base year remuneration of the labour and capital.

The Kendrick measure assumes constant elasticity of substitution. All three measures assume neutral technical progress, perfect competition, and constant returns to scale.

(B) Shifts in Production Function Measure: This method has been adopted by Earnst, 1956; Solow, 1959; and several others. The most popular model used in the Cobb-Douglas but some studies (for example, Earnst and Maruo) consider a generalized production function that can accommodate input variables.

(C) Performance-Objective-Productivity (P-O-P) Approach: Sardana and Vrat (1984) have used the P-O-P approach. According to this

$$\text{Productivity Index} = \frac{\text{Performance in m activities over n functional sub-system}}{\text{performance objectives in m activities over n functional sub-system}}$$

This ratio is weighted with a job performance factor and a sub-system factor.

Need for Productivity Improvement

Productivity improvement is vital not simply for firms but also nations, which are facing international competition. At the firm level, it is one of the most important instruments to reduce costs, improve profitability, and enhance competitive strength of the firm in the market. At the national level, it is means not to improve the nation's competitive position in the international market but also to check inflationary pressures in the economy. In fact, it is the backbone of supply-side Economics. At both the micro and the macro levels, increased productivity implies economy in use of productive resources.

In business, improved productivity may lead to:

1. Better consumer service through lowering of prices;
2. Increased cash flows, improved return on assets, and greater profits;
3. Increased profits that would enhance stock price substantially;
4. Increased profits that would lead to expansion of capacity and creation of new jobs;
5. Greater investment in R/D and development of new products; and
6. Better living standards. "Economists do not agree on many things, but all agree that improved living standards are dependent absolutely on increasing productivity."

Improved Productivity and Unemployment

There is a general belief amongst workers that increased productivity would lead to unemployment. That greater productivity at the firm level might require less workers to produce a given level of output. But it is static analysis. Since increased productivity may reduce costs and price, and increase sales, the same number of persons may remain employed or more number may be required. Moreover, "A study of 20 peer group manufacturers showed that during the recession of 1976- 1981 (in USA) when sales volume had fallen 10 per cent in constant dollars, the administrative workforce had actually increased. In perhaps less dramatic fashion every business has experienced creeping growth in size of administrative and staff positions, a growth not justified by business volume or explainable by the increased technology of business." At the national level also, he is of the opinion that increased productivity ultimately means more jobs.

What is Special with Productivity Management Today?

Productivity management today faces an altogether changed environment and attitude of the worke` According to Paul Mali (1978), there are three main areas in which the difference between traditional and present productivity management can be clearly marked -1. human expectations, 2. changing technology, and 3. limited accountability.

1. **Human expectations:** Today, the labour force is completely different from what it used to be. Their needs, attitudes, personal goals, the type of work they want to do, the reasons for which they would work – all have changed. How far they would respond to organizational pressure and demands has changed too. In sum:
   (a) Workers have over-expectations;
   (b) They are placing a higher value on themselves than they formally did;
   (c) There is a strong interest in improvement in work climate; and
   (d) There is a desire for self-supervision, for participation in decision making, satisfaction, communication and trust, and so on.
2. **New and changing technology:** The change in technology has a disruptive impact on the established methods, procedures and processes. There has been a wide gap between the technological uses and innovations. There are some other factors too which have decreased the use of innovations. This decreased technological trust has been adversely affected productivity.
3. **Accountability:** Traditionally, productivity improvement has been considered as the management's responsibility. Now the situation has changed and any effective improvement programme has to bring together management, labour, government, education, and society in a mutuality of interests. He has identified 12 causes for productivity crisis in US business organizations. Some of them are relevant for the Indian economy too.

Illustration 1:

Compute the productivity per machine hour with the following data. Also draw your interpretation.

Month	No. of Machines Employed	Working Hours	Machine Hours	Production Unit
March	400	225	90,000	99,000
April	500	200	1,00,00	1,00,000
May	600	250	1,50,000	1,35,000

Solution:

We know, p = Productivity per machine hour,

= Number of units produced /Machine hours

For March p = 99,000/90,000 = 1.1

April p = 1,00,000/1,00,000 = 1

May p = 1,35,000/1,50,000 = 0.9

Interpretation:- Though the total production in number of units is increasing, the productivity is declining.

Productivity and Performance

Particularly with regard to the individual, confusion often exists in people's minds, between "productivity" and performance. As discussed above productivity is defined as the ratio of output to input while performance is the ratio, over any convenient period, between :

$$\frac{\text{Actual achievement in effective work done}}{\text{An ideal or basic standard target of achievement}} \times 100$$

It is convenient to express this as a percentage of standard target.

This index is of particular and increasing importance to management when it is evaluated on a basis of modern work measurement to 'shop floor' or 'office desk' production of any type.

Production

Production directly refers to the rate of units produced in terms of machine, labour, material or any other effective basis.

Utility of Increasing Productivity

Constant endeavours should be made to increase the productivity. Higher productivity has manifold advantages.

(a) To the Individual Concern

(i) Higher productivity means more wages directly to the piece-workers and more production bonus to all workers. It means satisfied staff and harmonious staff relations.

(ii) The factory earns more profit because of the reduction in costs.

(iii) Continuous higher productivity may induce the management to reduce selling prices so that sales and production may increase.

(b) To the Industry

Higher productivity in some concerns will enable less efficient firms to follow them for their own survival.

(c) To the Government

(i) Higher profits earned by factories will bring more revenue to the government by taxation.

(ii) Export trades may develop bringing more foreign exchange to the nation.

(iii) Overall higher productivity will raise an all round standard of labour.

Human Relations Approach to Productivity

The well known Hawthorne experiments gave birth to what is known as the human relations approach to the study of organisation.

This approach in part, was a reaction against the mechanistic and rational considerations emphasized by Taylor and Fayol. The experiments and many subsequent studies produced a strong trend towards social and interpersonal considerations, and the importance of economic and technical factors was often ignored. These researches concentrated on such aspects as styles of supervision, interpersonal relations and informal organisation, and in demonstrating the importance of informal interactions, sentiment, and satisfaction in determining the productivity of work group behaviour.

However, a review of several research findings during the last decade in this area has shown that the results are increasingly inconsistent, contradictory and confusing.

Modern Approach to Productivity

The modern approach to study of organisation and productivity attempts to provide an integrated framework which combines both the classical and the neoclassical elements. It treats organisation as a system of mutually dependent variables. The studies undertaken by the Tavistock Institute of Human Relations illustrated the usefulness of viewing organisations as socio-technical systems.

The analysis of socio-technical system is important for the determination of optimum solutions for process, design. The task of process specifications that will produce the output most economi-cally. Process design is concerned with selecting the work stations needed to perform the operations and effect flow of work between different stations (Timms, 1966). In selecting the work situations. In an assembly line, work is divided into individual tasks and assigned to consecutive operators on the line. The manager should give considerations to the need for designing work situations so as to create favourable interpersonal relationship in addition to meeting the technological specifications. In industries where work groups operate under conditions of pooled interdependence the manager should give consideration to the creation of sequential work groups that generate social motivation and promote productivity.

Total Productivity

The ratio of all output to a composite of all inputs. It is called 'total' (as distinct from 'partial') productivity because it is not merely output per unit of labour alone, or any one input alone. It is the productivity of all 'factors' (i.e., inputs) taken together.

Total Productivity = Total Outputs/Total Inputs

Partial Productivity

The ratio of Total output to the partial measure of input is called partial productivity. Partial Productivity of Labour = Total Outputs/Labour Hours

Firm uses ₹ 50,00,000 in capital and 50,000 labour hours per year to produce ₹ 5,00,00,000 in product. What is the Partial Productivity of labour and partial productivity of capital ?

1. Partial Productivity of labour = ₹ 5,00,00,000/50,000 = ₹ 1,000
2. Partial Productivity of capital = ₹ 5,00,00,000/ ₹ 50,00,000 = 10

Causes of Low Productivity

For evolving specific measures for improving productivity it will help the management to analyse on continuing basis, the causes of low productivity and, at the same time to keep abreast with the latest management and productivity techniques.

In the Indian context, the causes of low productivity have their origin in two distinct sources. The first category consists of the exogenous or external factors like shortages of essential inputs-power, raw materials, transport facilities etc. — over which the management of an enterprise has little or no control. The second basket contains the endogenous of internal factors mainly in the form of system deficiencies preventing the optimum utilisation of resources.

Since the management can do practically nothing to control the external factors and their adverse effect on productivity, it will be fruitless to discuss them here. The challenge before the Indian managers lies in overcoming the internal causes of low productivity.

It is towards helping the management and workers in identifying these internal factors in this regard effort has been made as shown in figure 3.2 and 3.3 to list down the causes of low productivity together with their consequences. The figures and the narrations therein are self explanatory.

Management and Productivity Techniques

Fortunately considerable human ingenuity has-already gone into finding out the ways and means of overcoming the internal causes of low productivity, thanks to the continuing research in management science. For the ready reference of the management, some of the important techniques have been listed out in Figure 3.4 to 3.6 along with the necessary narrations. Finally a ‘Productivity Equation’ has been given in Figure 3.7 underlining the pre-requisites for achieving the highest level of productivity.

<table>
<tr><td></td><td>Each activity in an organisation has a basic work content which is neither more nor less to meet the organisation objectives</td><td>=</td><td>Like-wise for Completing each activity in an organisation some basic resources are required that should neither be more nor less than the work content</td></tr>
<tr><td></td><td>Unproductive work and ineffective time being added due to</td><td></td><td>More resources are consumed due to</td></tr>
<tr><td>A</td><td>Defects in design or specifications of product</td><td></td><td rowspan="4">Unproductive work content and ineffective time being added to the basic work content as a result of inefficiencies</td></tr>
<tr><td>B</td><td>Inefficient methods of manufacture or operation</td><td></td></tr>
<tr><td>C</td><td>Managerial inefficiencies</td><td></td></tr>
<tr><td>D</td><td>Workers’ inefficiencies</td><td></td></tr>
</table>

Fig. 3.1: Causes and Consequences of Low Productivity

Cause	Consequences
Unproductive work contents added by defects in design or specification of the product	A-1 Bad design of product prevents use of most economic process. A-2 Lack of standardization prevents use of high-production process. A-3 Incorrent Quality Standard causes unnecessary work. A-4 Design demands removal of Excess Material.
Unproductive work content added by inefficient methods of manufacture or operation	B-1 Wrong Machine used. B-2 Process Not Operative or in bad condition. B-3 Wrong tools used. B-4 Bad Layout causing wasted movement. B-5 Operative's Bad Working methods.
Ineffective time due to shortcomings of the management	C-1 Excessive Products variety adds idle time due to short runs. C-2 Lack of Standardisation adds idle time due to short runs. C-3 Design Changes add ineffective time due to stoppages and rework. C-4 Bad Planning of work and orders add idle time of men and machines. C-5 Lack of Raw materials due to bad planning adds idle time of men and machines. C-6 Plant Breakdowns add idle time of men and machines. C-7 Plant in bad condition adds ineffective time. C-8 Bad working condition add ineffective time through forcing workers to rest. C-9 Accidents add ineffective' time through stoppages and rework. C-10 Bad Industrial Relations resulting in strikes/lockout.
Ineffective time due to shortcoming of workers	D-1 Absence. Lateness and Idleness add ineffective time. D-2 Careless workmanship adds ineffective time due to scrap and rework. D-3 Accidents add ineffective time through stoppages and absence. D-4 Bad Industrial Relation resulting in strikes/lockout.

Fig. 3.2: Causes and Consequences of Unproductive Work & Ineffective

TOTAL WORK CONTEN	=	BASIC WORK CONTENT	Provided there is no unproductive elements of work content

Productivity Techniques require to ensure the following :

A-1 Product Development and Value Analysis reduces excess work content due to design defects;

A-2 Specialisation and Standardisation enable high-production processes to be used ;

A-3 Market, Consumers & Product Research ensure quality standards;

A-4 Product Development & Value Analysis reduces work content due to excess material;

B-l Process Planning ensures selection of correct machines;

B-2 Process Planning and Research ensure correct operation of processes;

B-3 Process Planning and Method Study ensure selection of correct tools;

B-4 Method Study reduces work content due to bad layout;

B-5 Method Study and Operator Training reduce work content due to bad working methods;

Fig. 3.3: Productivity Techniques for Eliminating Unproductive Work Content.

TOTAL TIME REQUIRED	=	TOTAL WORK CONTENT	Provided if there is no unproductive time

Productivity Techniques require to ensure the following :

C-1 Marketing and Specialisation reduce idle time due to product variety;

C-2 Standardisation reduces idle time due to short runs;

C-3 Product Development reduces ineffective time due to changes in design;

C-4 Production Control based on Work Measurement reduces idle time due to bad planning;

C-5 Materials Control reduces idle time due to lack of raw materials;

C-6 Maintenance reduces ineffective time due to plant in bad condition;

C-7 Maintenance reduces idle time of men and machine due to breakdowns;

C-8 Improved Working Conditions enable workers to work steadily;

C-9 Safety measures reduce ineffective time due to accidents;

C-10 Clear organisation objectives and polices of employer and employees help improve industrial relations;

D-1 Sound Personnel Policy and Incentives reduce ineffective time due to absence etc;

D-2 Personnel Policy and Operator Training reduce ineffective time due to carelessness;

D-3 Safety Training reduces ineffective time due to accidents;

D-4 Industrial Relations Audit;

Fig. 3.4: Productivity Techniques for Eliminating Ineffective Time.

TOTAL RESOURCES UTILISED = TOTAL RESOURCES REQUIRED = TOTAL WORK CONTENT

Productivity Techniques ensuring this :

Manpower:
* Systematic assessment of manpower requirements in relation to basic work content in order to eliminate redundant employment;
* Job Evaluation and Job Specification for ensuring right man for right work;
* Fair and firm Personnel and Industrial Relations Policy for erecting harmonious industrial relations;

Machines :
* Preventive Maintenance and condition' monitoring;
* Tribology;
* Plant Engineering;
* Production Planning & Control;

Materials :
* Materials Management & Planning;
* Inventory Management;
* Value Engineering;
* Fuel Efficiency and Energy Conservation Techniques.

Fig. 3.5: Productivity Techniques for Eliminating the Wasteful use of Resources

1 where	Total work content	=	Basic work content	
		AND		
2 where	Total Time required	=	Total work content	Productivity is at the highest level
		AND		
3 where	Total Resources required	=	Total work content	

→ Indicative of the situation where an organisation has been able to eliminate
* Unproductive use of Manpower
* Unproductive use of Machine
* Unproductive use of Materials
* Unproductive use of Time.

Fig. 3.6: Productivity Equation.

Work Study and Productivity

Upto some twenty to thirty years ago, the techniques for the analysis and evaluation of work done, were very limited in scope and application. Since then they have developed rapidly in quality and effectiveness and particularly in the range of work to which they can be applied. Work study is the most important concept in the process of increasing productivity. The growing complexity of new processes and equipment are quite apart from rising prices, means that now-a-days it is frequently necessary to make a considerable capacity investment for each new plant employee. A modern trend, therefore, is for all technical staff to be given some training in the principles of work study and for the design and layout of new plants and better processes to proceed with these principles in mind as well as purely technical considerations. In the case of product standardisation and simplification, work study can be used to assess the economies of various alternatives.

Work Study is a management service based on those techniques, particularly method study and work measurement, which are used in the examination of human work in all its contexts, and which lead to the systematic investigation of all the resources and factors which affect the efficiency and economy of the situation being reviewed, in order to effect improvement.

Method Study is the examination of the ways of doing work;

Work Measurement is the assessment of the time which a job should take.

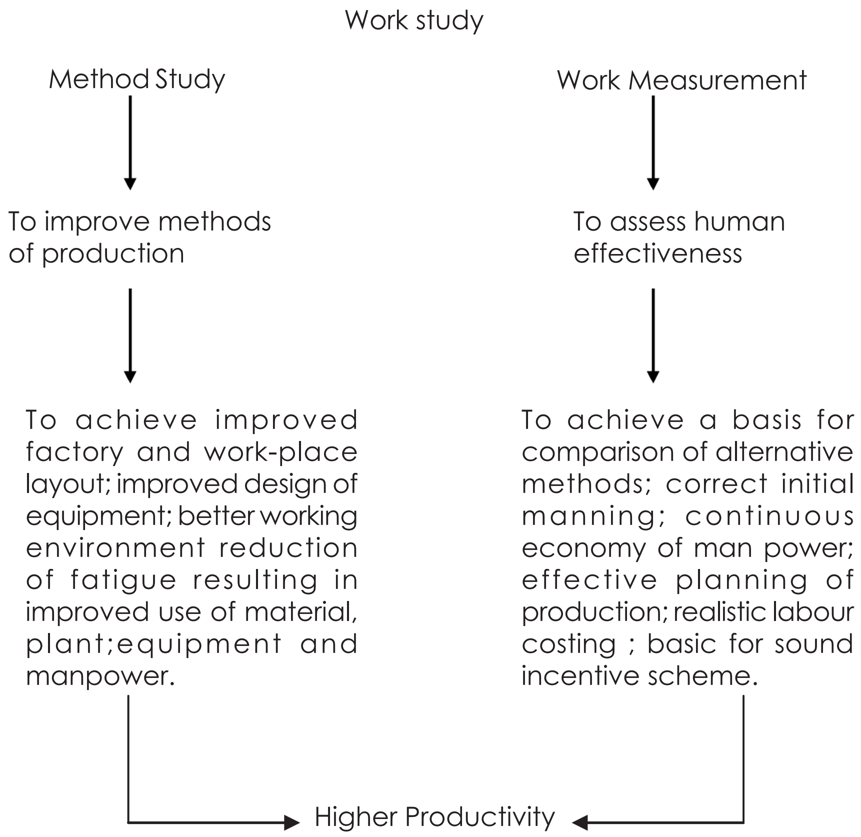


Fig. 3.7: The diagram shows how the work study helps in increasing productivity.

Factors Affecting Productivity

The factors affecting productive efficiency are listed below along with corresponding productivity tools.

Plant/Organisation	
Productivity factors	**Productivity tools**
Top management planning	Plant policy
Management and supervision	Organisation chart
Co-ordination and cooperation	Organisation manual
Internal communications	Human relations studies
	Joint consultation
	Mutual trust and co-operation
Internal communications	Management reports, Management audit.
Products	
Product selection	Operation research
Product quality	Product planning
	Statistical quality control
Product programme	Product research
Product design	Specialisation
Product packaging	Standardisation
	Simplification
Physical Facilities	
Plant capacity	Plant labour techniques
Plant location	Mechanisation
Plant building	Automation
Plant equipment	Human engineering
Plant installation	Preventive maintenance
Personnel	
Selection	Job analysis
Employment	Job evaluation
Training	Merit rating
Safety	Accelerated training
Wage payment	Works measurement

Production	
Manufacturing	Budgeting
Assembly	Production-engineering
Sales	Production planning
Distribution	Predetermined Motion Standard
	Materials control
	Materials handling
	Work simplification
	Activity sampling
	Cost control
	Statistical methods of quality control
	Market analysis

Role of Factory Executives and Workers In -Raising -Productivity

A. Engineers : The scope of Industrial Engineers on this subject of increasing productivity is enormous.

Industrial Engineers can make valuable contribution to raise productivity. The object of Industrial Engineering is to apply scientific and engineering knowledge and techniques to increase the efficiency of industrial activities. It is concerned with product design, standardisation, plant layout, efficient machine operation, materials handling, tool designs, maintenance of plant, time and motion study, incentive methods and industrial relations, value analysis and value engineering etc.

B. Sales Manager: Sales managers should be interested not only in delivering the goods by due dates in proper quality but also raising the productivity of factory for increasing the sales. They may help the production people by (a) Supplying data about efficient production arrangement of other competitors, (b) Relaxing rigidity in inspection provided quality does not suffer and (c) Accepting orders enabling standardisation and simplification.

C. Personnel Manager : Responsibility of personnel manager is

(i) to ensure cordial labour relations

(ii) to settle labour problems

(iii) to look after the amenities of the workers. On behalf of the management the personnel manager looks after better human relations which will motivate all employees to work co-operatively and to achieve required work level.

He should also be responsible to recruit right persons and place them in the right jobs. A man's productivity depends to a considerable extent on his job being suited to his abilities and his attitude towards that job.

He should properly educate the workmen as to how they may contribute to increase the national wealth, and standard of living. He should check the absenteeism, lack of co-operation the some workers and tactfully eliminate bad elements causing dishormony among other-workers.

D. Finance Manager

The finance manager can make some vital contribution towards higher productivity by setting up proper standard of costing system and by supply periodical reports to the management for visualising the trend in the activity of their performance.

The finance manager will remain a constant companion in all activities of the management, say setting norms of standards, work study, fixing production bonus, or piece rates of wages, job evaluation cost estimation, cost concepts in various natures of activities and so on.

E. **Managers and Workers (Through KAIZEN):** KAIZEN is Japanese word made up of KAI and ZEN. KAI means change and ZEN means better. Thus KAIZEN means change for the better. It implies continuous improvement done consistently. KAIZEN diagnoses the major root causes of inefficient working in the organisation and offers a systematic approach to change the attitudes of people for increasing productivity, improving quality and thus leading to miraculous organizational change. The essence of KAIZEN is simple and straight forward, i.e. "on going improvement involving everyone including both managers and workers". KAIZEN signifies productivity improvement made in the status-quo as a result of on-going efforts.

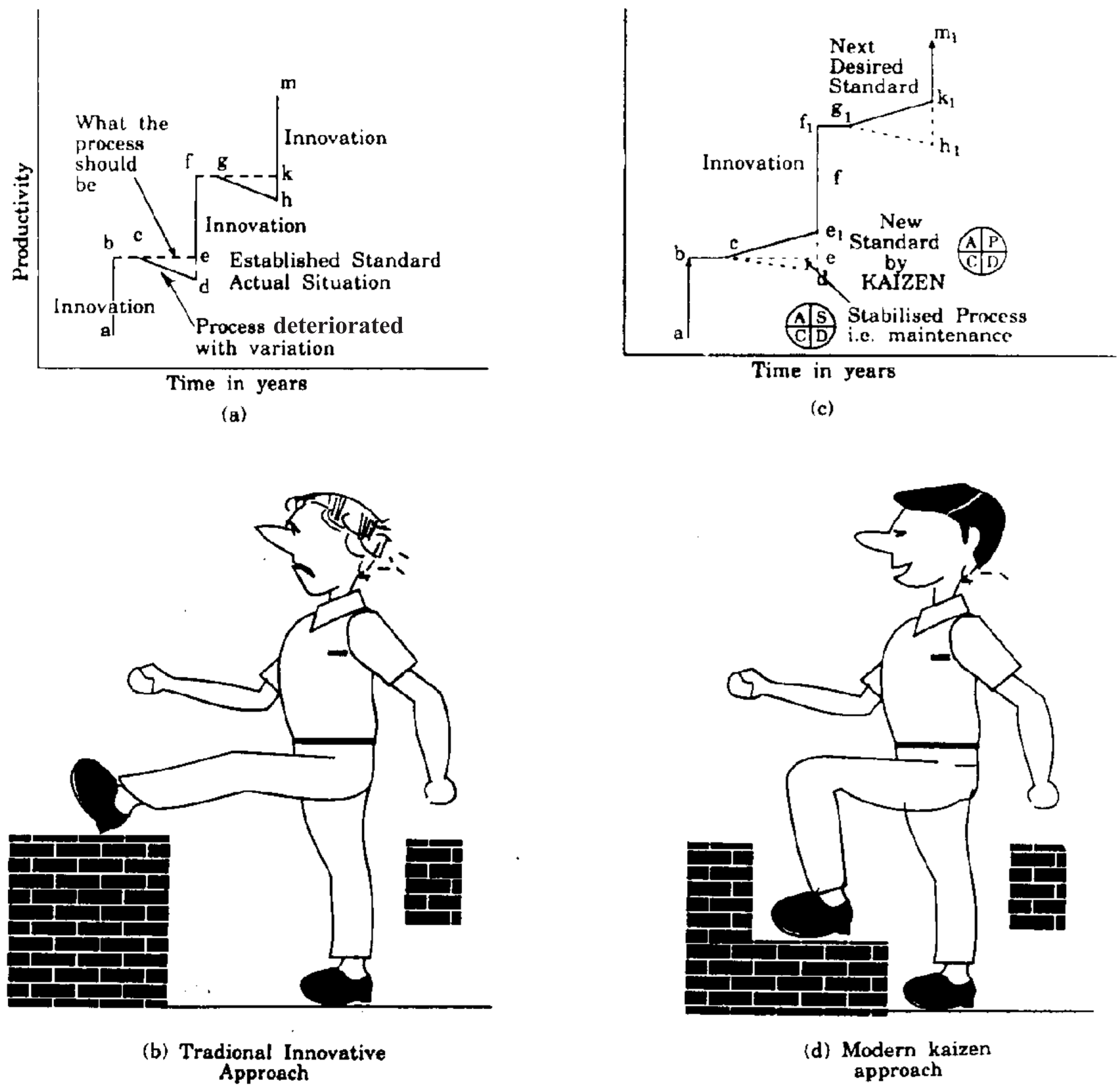


Fig. 3.8 (a, b, c, d): Productivity Enhancement Through Traditional and Modern KAIZEN Approaches.

Fig. 3.8 (a) shows the productivity pattern followed by an organisation if innovations are used in isolation of KAIZEN. Most hi-tech innovative machines, if not properly operated, maintained and improved by continuous efforts, tend to deteriorate **(see Fig. 3.8 (a)).** The causes of process variation and productivity enhancement are demostrated through cartoons where in innovations means climbing up a height in one step while KAIZEN approach **(see Fig. 3.8 (d))** means climbing up a height in small-small steps. Don't we recall the fate of hi-tech machines, initially, resulting in sudden improvement in status-quo, characterised by, (a, b) **(Fig. 3.8 (a))** on shop floor, becoming useless over a period of time. To compensate for such a drop in productivity, we undertake world tours to find another hi-tech innovation (d-f) for another improvement and the process continues for even a higher technology jump such as (h-m) etc. KAIZEN, on the other hand **(see fig. 3.8 (b))** works within the confines of current technology and meant a constant effort not only to maintain (c-e) **(see Fig. 3.8 (c))** but also upgrade the working standard of (c-e).

In general there is little appreciation, for small productivity improvement i.e. for the KAIZEN concept, particularly in Indian context, we normally tend to get excited and appreciate innovations which not everyone is capable of making. Whereas such innovations need major break throughs in process capability and are restricted mainly to chronic problems. Whereas, by the very nature, KAIZEN technique which can be applied for increasing productivity by anyone and anywhere, involving everyone.

KAIZEN and Productivity

No matter what the definition of the productivity be (quality based or cost based) either side of this is KAIZEN. It becomes much easier to remove the differing perception of management and labour since no one can dispute the value of improvements. The KAIZEN simply means improvements, on-going improvements involving every one in the organisation from door-man to the chairman. One should have a religious feel in promoting the KAIZEN strategy. KAIZEN is a religion in order to lay a long term foundation for a sustained business activity as against a short-term approach for immediate pay off. Whenever you need to manage people, then you need to manage them from the heart, not with your head. If everyone starts changing with, team spirit, cooperation, support self commitment comes automatically. This thinking requires 'Change of Heart' on the part of the chief executive first, it is then followed by 'Change of Heart' of the emoployees and even the labour-unions too.

Motivational implications of KAIZEN Technique Implimentation

The KAIZEN gives freedom to the employees. It does not specify what changes are to be made or how many of them are to be made. Improvements can be in any discipline and in any field of human activity related to the productivity. These decisions are left to the individuals. This leads to obvious advantages as follows :

(a) The first and foremost benefit of KAIZEN is that it brings about changes in attitude among employees towards improvements of their routine work. Hence it increase the productivity and a new work culture is created in the organisation.

(b) Once the culture is transformed, the way gets cleared for introducing other productivity improvement systems like JIT, KANBAN etc. obviously leading to productivity improvement.

(c) KAIZEN system reduces resistance to change.

(d) Ownership of work improves in KAIZEN environment. It is the inner voice of the employees that drives them to make the improvements, rather than the orders given down through the hierarchy.

3.2 TECHNOLOGICAL INNOVATION AND PRODUCTIVITY IMPROVEMENT

Technology and Economics

There are many ways in which technology and Economics interact. Two of them are of direct relevance in the present context.

(a) First, the popular and common understanding that all technological efforts not only have economic motives as their ultimate ends but they also need the economic evaluation.

(b) Secondly, technology is the last resort for improving the competitive strength of firms as well as nations in the market.

The former may be termed as the role of Economics in technological efforts, that is, R & D. This has three important aspects (i) objectives of R & D, that is, the commercial exploitation of inventions; (ii) Economics of R & D, that is, the costs and benefits of R & D efforts; and (iii) R & D as an investment decision.

The second way of interaction between technology and economics emphasizes the role of technology in economic decision making, which is done at two levels—the firm and the economy as a whole. At the macro level, growth models have very well assimilated the role of technology. At the micro or the firm level, the role of technology in improving factor productivity is evaluated by empirical production functions. Some efforts are also made to measure its pure effect by segregating it from that of the technology imbibed in capital equipment.

Technology

Scientists have not given much importance to the distinction between science, engineering, and technology. Unlike some economists, who wanted to be neutral to the political dogmas and liked to be called positive scientists in economic analysis, physical scientists did not seem to attach any such euphoria to this phenomenon. Economics classifies sciences into three groups: (i) a ''Positive" science which simply establishes a causal relationship in a phenomenon and tells "what it is'': (ii) a normative science which suggests a course of action, that is, "what ought to be": and (iii) an applied science which prescribes a strategy to implement it, that is, "how to do". By these criteria, technology, as a branch of knowledge or study, unquestionably has to be classified under applied science.

Technology, as a way of doing things or as the nature of a capital equipment, has a different connotation. This, along with other factors of production, operates as a "through put" in the process of transformation of an input into output. It is a "black box" containing all information or the blueprint of specifications for a product or a process. A scientific theory or an invention has to reach the stage of a blueprint in order to be called a technology. A model, when produced on the basis of those specifications, should work. Technology is called a book of such specifications or blueprints.

Research & Development:

The term "Research and Development" (R & D) is somewhat different from pure scientific research. It goes beyond the simple, systematic, and intensive study of a phenomenon resulting into better knowledge and the establishment of causal relationship expressed in the form of generalizations, theories, models, or principles. R & D aims at the commercial exploitation of not the existing scientific knowledge by technological innovations, that is, product or process development. This is the systematic use of scientific, knowledge for the production of goods, devices, systems, or methods, and processes. Development is an activity, effort, or process leading to innovation. It is an act and innovation is the outcome. Since an innovation is the commercial exploitation of an invention, besides the design of a product or process, an assessment of its commercial viability is also an integral part of development. Innovation, thus, becomes the ultimate outcome of R & D activity. In short, the commercial exploitation of an invention is called innovation and it is the task of R & D to create an innovation.

Technique & Technology

The distinction between technique and technology has already been explained in the context of the production function analysis. A change in technique is related to a change in prices whereas a change in technology means a change in the book of blueprints. It is purely a physical phenomenon. Technological change is of two kinds:

(i) a process change when the "isoquant" shifts or its slope changes without any reference to the input or factor prices;

(ii) a product change when the "product transformation curve" shifts or its slope changes without any reference to the change in the product prices.

Technological change:

Technological change involves two stages:

(i) innovation and (ii) diffusion. Diffusion is relevant to both process and product change. Process diffusion takes place when the overtime use of the process is diffused to other firms. Product diffusion refers' primarily to the widespread use of the product among consumers rather than among firms. The rate of diffusion depends upon several factors and has many implications, particularly with respect to patents and monopoly.

Technological change is a time consuming process. Western experience suggests that there has been a gap of about thirteen years between an invention and an innovation, and about fifty years between an invention and diffusion. Secondly, technological change is a continuous process. Thirdly, past innovations determine the present ones and present ones lead to future innovations. There are cross-linkages between innovations. Lastly, there are international linkages and interdependence with regard to innovations where nations can be benefited without going through the stage of the "invention of wheel".

Role of Technology in Improving Business Performance

Technology is probably the most important force driving the increase in global competition. Companies that invest in and apply technologies tend to have stronger financial positions than companies that don't. For example, IBM and Sun Microsystem, Inc, believe that Java technology holds the key to new business opportunities.

As the investment in R & D for technology increases, so does profitability and new product introductions. A large number of manufacturers world wide have focused more on process technologies and demonstrated the strong link between financial performance and technological innovation.

At the same time, the relationship between technology and competitive advantage is often misunderstood. High technology and technological change for its own sake aren't always best. They might create a competitive advantage, be economically justifiable, fit with the desired profile of competitive priorities, or add to the firm's core competencies.

Role of Information Technology in Production/Operations Management

Information technology is crucial to operations everywhere along the supply chain and to every functional area. Computer based information technology, in particular, has greatly influenced how operations are managed and how offices work. It makes cross-functional coordination easier and links a firm's basic processes. In a manufacturing plant, information technologies can link people with the work centres, data bases and computers.

Components of Information Technology

Information technology is made up of four sub-technologies.

1. Hardware, 2. Software, 3. Database and 4. Telecommunications.

Hardware : A computer and the devices connected to it are called hardware. Improved hardware memory, processing capability and speed have, in large part, driven recent technological change.

Software : The computer programs written to make the hardware work and to carryout different application tasks are called software. Software is available for use with all most all the decision tools including statistical process control techniques, forecasting models, production and inventory control systems and scheduling techniques. Software is essential to many manufacturing capabilities such as computer-aided design and manufacturing, robots, automated material handling, computerised numerically controlled machines, automated guided vehicles and flexible manufacturing systems. Software also provides various executive support systems such as management information systems and decision support systems.

Databases : A data base is a collection of interrelated data or information stored on a data storage device such as a computer hard drive, a floppy disc or a tape. A data base can be a firm's inventory records, time standards for different kinds of processes, cost data or customer demand information.

Telecommunications : Fibre optics, telephones, modems, fax machines etc., make electronic networks possible. Such networks and the use of compatible software, allow computer users at one location to communicate directly with computer users at another location.

Creating and Applying Technology

Applying new technologies is an ongoing challenge for all organisations. Exhibit 3.1 illustrates the innovation process which is basic to the understanding of product and process technologies.

The innovation process focuses technological and scientific efforts on better ways of meeting market needs. There are various ways this can be done. One way for a firm to acquire new technology is the firm's own research and development (R & D) efforts which create new knowledge of materials and processes and then apply them to create and introduce new products and production processes.

The various stages of R & D projects include (i) Basic research stage, (ii) Applied research stage and (iii) Development stage.

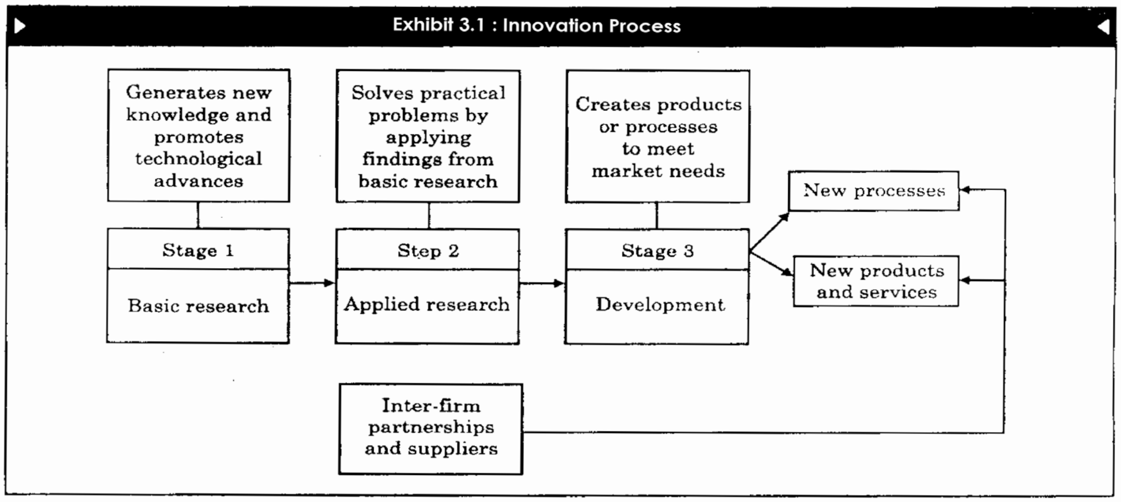
Basic research involves work that explores the potential of narrowly defined technological possibilities to generate new knowledge and technological advances. (Example - laser technology).

Applied research involves work geared toward solving practical problems and its results are more likely to lead to actual improvements in products, processes and services (Example - laser drilling, laser cutting and laser welding).

Development involves the activities that turn a specified set of technologies into detailed product designs and processes. Product and processes are developed taking into consideration ease of production and marketability.

Technology Fusion

Technology fusion refers to the process of combining several current technologies and scientific knowledge to create a **hybrid technology.** Adding one technology to another results in synergic effects. For example, in machine tool industry NC, CNC machines are the result of fusion of electronics and mechanical technologies.



Technology as a Competitive Advantage

A new technology should create some kind of competitive advantage. Competitive advantage is created by increasing the value of product to a customer or reducing the costs of bringing the product to the market. The most obvious cost-reduction strategy is that of reducing the **direct costs** of labour and materials.

On the other hand sales can increase, quality can improve by reduction of human errors, delivery times can become shorter due to reduced processing times, inventories can become smaller, the environment might improve - all owing to improved or new technologies.

Of course, new technology can also have its shortcomings. Investment in new technology can be forbidding. The investment also can be risky because of uncertainties in demand and profit per unit. Implementation of new technology may generate employee resistance, lower morale and increased turnover,

Technology Choice

The choice of technology should not only consider net present value of the investment made but also the effects on customers, employees and the environment. When technological alternatives are evaluated, they should be considered with respect to the do-nothing alternative.

To conclude, it may be said that investments should support a comprehensive technology strategy aimed at achieving or maintaining a competitive advantage.

Technology Integration

Today, cross-functional teams are responsible for implementation of new technology by an approach known as concurrent engineering to bridge the gap between R & D, product development and manufacturing. This approach is referred to as "technological integration".

The Human side : Technology determines how the jobs are done by people. When technology changes, jobs also will change. New technology may eliminate some jobs, add some jobs, upgrade or downgrade some other jobs. Employee training, education and involvement help a firm identify new technological possibilities and prepare employees for the new technologies.

Leadership : Manager's role in implementing new technologies is a crucial one. They must hold to tight budgets and schedules, plan implementation projects, continually monitor the program, assess the risks, costs and benefits of new technologies, have a technical vision, be committed to the project and have everyone focussed on implementation of new technologies. They should act as catalysts to bring-in technological advancements and implement them successfully.

Managing Technological Change

Some of the suggestions to production managers on how to manage changes in production technology and how to manage the implementation of major automation projects are given below:

(i) Have a master plan for automation.

(ii) Recognise the risks in going for automation.

(iii) Establish a new production technology or technology development department.

(iv) Allow plenty of time for the completion of automation projects.

(v) Do not try to automate everything at once.

(vi) People are the key to the successful implementation of automation projects.

(vii) Companies moving too slowly in adopting new production technology, may be left behind others.

Role of Technology in Economic Decisions

This section tries to answer why a firm or an economist lays so much emphasis on technology and technological change. The scope is limited to firm-level decisions only. The technological aspects of economic decisions may be classified as follows:

(i) production and productivity related aspects of technology; (ii) marketing and distribution technologies; and (iii) pricing related aspects of technology. Taken together, all of them determine a firm's competitive strength in the market. The role of technology in the production system and in improving productivity has been dealt with separately. As regards the second aspect of marketing and distribution, the scope of Economics is limited to the treatment of selling costs only. The pricing related aspects can be further classified into; (a) technical maturity of the product and pricing; and (b) technological monopolies and pricing.

Technical Maturity and Pricing

Besides the cost of production, the nature of 'the product is one of the most important considerations in fixing its price. In the context of competitive selling, it indicates the presence of close substitutes of the product in the market. In the initial stages till the patent right exists, a firm enjoys monopoly. After the expiry of the patent rights, the firm's control over the market loosens and close substitutes enter the market. A brand name also provides monopoly but only with regard to the price and output policy since there is keen competition with close substitutes available in the market.

The competitive degeneration of the product in the market depends upon three important factors (i) technical maturity, (ii) market maturity, and (iii) competitive maturity. Technical maturity is indicated by (a) the declining rate of product development, (b) the increasing standardization among brands, and (c) the stability of manufacturing processes and knowledge about them. Market maturity is indicated by consumers' acceptance of the basic service idea, reduction in brand loyalty, and the competence of consumers to compare brands. Competitive maturity is known by the stability of the market share.

If product diffusion reaches a stage where it is impossible to claim distinctiveness of the product, the firm is no more in a position to dictate or determine price. The larger the number of substitutes, the weaker the firm's position with respect to the price output policy. The only alternative left then is to introduce a new product through product innovation. Meanwhile, all efforts have to be made to promote the existing product through a larger investment in advertising. "Superfluous" product innovations as in simply adding some adjectives to the name of the product cannot hold for long given the present level of awareness of the consumers.

Competitive Markets and Technological Change

The desperate need for technological innovations to improve competitive strength is realized in almost all the market conditions including perfect competition. However, its intensity is the highest under oligopoly. A firm in an oligopoly has four alternative policies at its disposal for gaining a competitive edge over other firms. These are highlighted on the following broad parameters:

(i) price policy;
(ii) promotion (advertisement) policy;
(iii) cartels and market segmentation (collusive oligopoly); and
(iv) technological innovation—(a) process innovation and (b) product innovation

3.3 EVIDENCE ON MARKET STRUCTURE R & D

Economics of R & D

Any reference to the economics of a project, on first impression, leads to its cost-benefit analysis. In the case of R & D projects, there are several other dimensions of the phenomenon both at the micro and economy level. Some of them are as follows:

1. R & D as an investment decision;
2. Sources of finance for R & D;
3. Cost of R & D projects and its measurement;
4. Benefits of R & D and their measurement;
5. Relationship between the R & D input and output;
6. Technological change and economic performance; and
7. Technological development and international competitiveness.

R & D as an Investment Decision

A firm's retained earnings (net profit - dividends) are invested primarily under three heads:

(a) **Physical investment** in the plant, machinery, and equipment, which improves its supply side.

(b) **Market investment** for the promotion of its product/s such as advertisement expenditure, development of distribution channels, servicing facilities, and payment of commission and incentives, and so on. This affects the demand side of the firm.

(c) **R & D investment**, may be either for product innovation or process innovation. Here, the investment in product innovation will improve the demand for the firm's products, and that in process innovation will help in cost reduction, and improve the supply and competitive strength of the firm. Thus, contrary to the physical and the market investments, the R & D investment helps to improve both the revenue and the cost sides of the firm's operations.

Besides being one of the major heads of the firm's investment, the' R & D expenditure also, involves risk and uncertainty. In fact, it is one of the most risky investments where outcomes are always unknown and uncertain.

Source of R & D Finance

The profits earned, particularly the retained part of it, have been found to be the basic source of finance for R & D. This feature, combined with the high degree of risk and uncertainty, places larger corporations in a better position with regard to R & D investment. This contention is well supported by researches conducted on R & D expenditure in western economies, where more than 80 per cent investment has come from the top 100 large corporations. Another important observation is that profits and R & D have been found to have a direct relationship, that is, higher profits lead to higher R & D investment and vice versa.

Costs of R & D

It is more difficult to measure the cost of one innovation than the cost of the R & D for a firm, industry, and the economy as a whole. The latter can be estimated by taking into account the total expenditure on R & D inputs, such as on laboratory establishment, personnel, and scientists, during a period. There may be dozens of projects but only a few or only one successful innovation. The allocation of costs may create a problem, particularly when considering whether only an individual project costs, or the distributed total costs (including those on unsuccessful projects) should be taken into account. Since R & D investment is also competing with other alternative investments such as physical and market investments, the opportunity cost should also be estimated to arrive at the real costs of the firm on this count.

Benefits of R & D

The benefits of R&D are difficult to, identify as well as to measure. The result of R & D may not be abstracted but it is, certainly, not something, which can be quantified. Product innovation may change some of the-existing characteristics of the product, add a few new ones, or bring out an altogether new product. But the simple counting of these characteristics may not provide an evaluation of the innovation. This is the added market value of the product, which would theoretically be the correct measure. The segregation of the impact of innovation from that of other associated efforts may create problems because the exploitation of the innovation in the market depends not simply on its quality but also several other factors such as the firm's size, competitive strength, market network, and so on. Similarly, the exploitation of process innovation may also vary from one firm to another, from one industry to another, and from one economy to another.

Present Practice of Measurement of Output

The output of R & D is measured in terms of the patents registered. Researches in this regard show a number of deficiencies in patent statistics such as the following:

(1) Firms register patents of products more than processes, as it is easier to maintain secrecy of the process than the product. The firm has to sell (imbibed) technology along with the' product.

(2) In advanced countries, there has been a decline in registration of patents despite the phenomenal increase in the R & D investment.

(3) The propensity to patent varies from one firm to another and from one industry to another.

(4) Smaller firms register more than larger firms do, as they feel more insecure.

(5) Patents registered show only quantity not quality of innovations.

Relationship between R & D Inputs and Output

So much of research has been done on this aspect that it is not easy even to summarize them. A number of efforts have been made to estimate the production function models for R & D and peep into its black box. Some important variables determining R & D efforts and its success have been identified as follows:

(a) The size of the operation has been found to be positively related to the success of R & D.

(b) The presence of technological opportunities in the industry leads to better R & D efforts.

(c) The philosophy and genuine efforts of the management are necessary for successful R & D efforts.

(d) The contribution of individual researchers to R & D has been found to be quite substantial.

(e) R & D efforts are likely to be more effective where growth prospects are good and profits are likely to be high.

(f) Diversification is positively related to the R & D efforts, as there is scope of their utilization.

(g) A number of studies have suggested a strong relationship between R & D and the marketing opportunities for a new product. Market opportunities have been found to contribute three times more than technical opportunities as sources for innovations.

3.4 TECHNOLOGY AND COST MINIMISATION

Technology has a great impact on cost minimization. Improvement of technology leads to hi-tech production facility which helps in mass production, that results in economies of scale. Technology also improves the quality of input and it results in flawless production. It also reduces the cost of error detection and rectification to a large extent. Improved technology brings automation and reduces the requirement of excess manpower, hence results in low cost of production. Automation speeds up production and results in increase of scale of production in a given period. Updated and newer technology also helps an organization by minimising the supply and distribution expenses. On the other hand improved and unique technology helps in creation of core competency. A better technological approach thus supports in many ways to achieve cost minimization.

Technological Change and Productivity

This aspect has been dealt with in detail separately. The Cobb-Douglas production model is a common approach to measure the contribution of technology to industrial output. Here, the variations in error or residual term over a period of time, with independent variables remaining unchanged, is considered to be an indicator of the contribution of technology. Solow's study is pioneering in this respect. He estimated a 9 per cent contribution by technological change to American non-farm output during 1909-49 as compared to 10 per cent by capital-intensification (capital per man). This residual approach of measuring technology's contribution to the labour productivity has been questioned and efforts have been made to improve it first, by breaking up the residual factor into its different constituent parts and secondly, by considering technological change as a separate variable in the production function.

R & D expenditure is considered as one of the proxy variables for technological change, which may not necessarily be correct. This is because (i) the outputs of R & D expenditure may differ from one organization to another, (ii) a firm may import or purchase technology from another, and (iii) the production function approach is not suitable for a multiple-product firm. The measurement of the output variable with product mix requires aggregation, which may not reflect the impact of technological innovations on it. Moreover, the real impact of technological innovation is seen only when diffusion takes place, which is neither within the purview of R & D nor reflected in R & D expenditure. The 'number of patent rights registered may be a better variable in this context as it is closer to the state of diffusion.

As regards the relationship between R & D expenditure and productivity, the majority of studies suggests a positive relationship. Similarly, the extent of innovations has encouraged the export performance of nations as it helps to achieve a competitive edge in the international market. Some countries have, however, achieved a high export growth by adaptation and. diffusion of imported technologies than with the number of patents registered.

3.5 TECHNOLOGY POLICY OF GOVERNMENT OF INDIA

The main planks of the technology policy are as follows:

1. Self reliance, meaning the development of indigenous technology and efficient absorption and adaptation of imported technology appropriate to national priorities and resources.
2. Strengthening the technology base through indigenous R & D, so as to attain a major technological break-through in the shortest possible time together with science and technology education and training of a high order.
3. Reducing the independence on foreign inputs particularly in critical and vulnerable areas and in high value-added items in which the domestic base is strong, and enhancing traditional skills and capabilities using knowledge and skills generated by advances in modern science and technology.
4. Ensuring the correct mix between indigenous and imported technology and between mass production technologies and production by masses.
5. Ensuring maximum development with minimum capital outlay, identifying areas of technological obsolescence, and arranging for modernization of both equipment and technology so as to develop technologies, which are internationally competitive particularly those with export potential.

6. Awakening the science and technology community through a system of rewards and incentives to the spirit of innovation and invention which is the driving force behind all technology change.

7. Evolving a conscious, integrated approach covering technology assessment, development, acquisition, absorption, utilization and diffusion, and connected aspects of financing based on overall national interests, priorities, and attainment of the most challenging technological goals.

3.6 QUALITY CIRCLES

After Second World War, most of the countries in the world had to face the problem of industrial development.

Japan was worst hit and the industrial units in Japan were going from bad to worse and it was necessary for Japan to put their shattered economy back on the rails. To do so they had to wipe out their poor image of quality. Later with the help of American quality management experts Dr. Deming and Dr. Juran, the Japanese managers learnt the quality control techniques and different aspects of quality management.

It was at this point, Dr. K. Ishikawa of Mushashi Institute of Technology, Tokyo added a new dimension to this effort by involving task performers at the grass root levels to work towards the improvement of quality. He motivated the workmen to follow quality control technique in their shop floors by forming small groups and sought their help in solving the daily problems of the company. After all the persons who are actually doing the job knows the job best. This is the basic philosophy behind forming QUALITY CIRCLES.

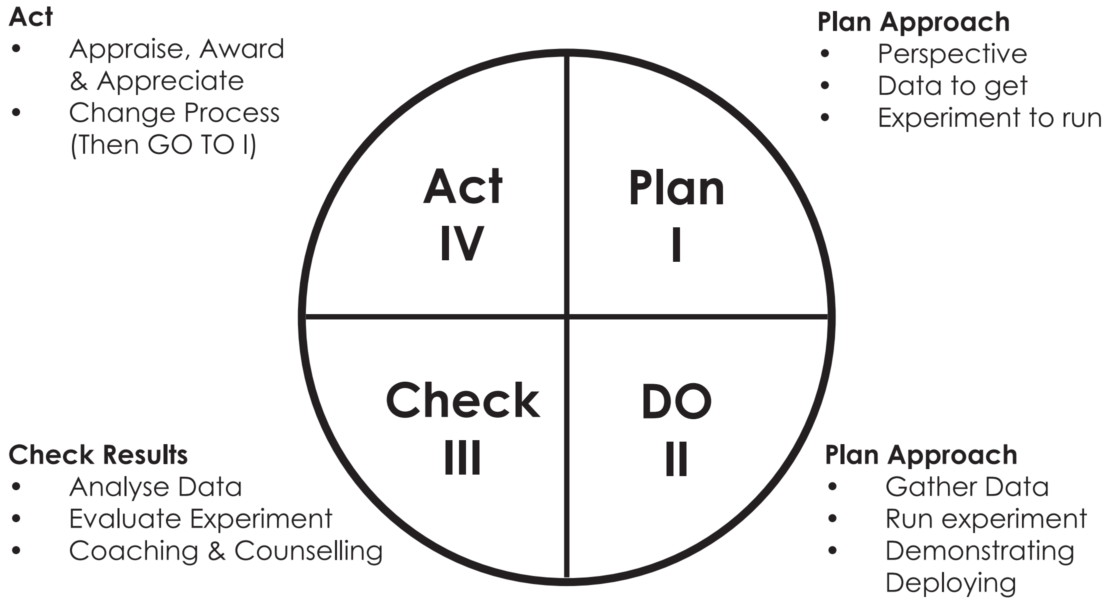


Fig. 3.9: The deming cycle.

Definition

According to the formal definition given by Union of Japanese Scientists and Engineers (JUSE) "Quality Circle is a small group formed to perform voluntarily QC activities leading to self development within the work place".

Quality circle is a small group of employees who voluntarily meet together regularly to identify, analyse and solve the work related problems (Quality, wastage, productivity, housekeeping, safety, communications etc.)

Quality Circle membership

QC members elect their leader and deputy leader and name their circle. They also decide about meeting place, time and day.

Quality circle then discuss the problems of their work area and arrive at some agreed upon solution. The management is then informed about the presentation. At the time presentation every member is given a chance.

If the recommendation of QC are accepted by the management, then it is the responsibility of the circles to implement and monitor it.

As a rule of thumb, the meeting takes place once a week and each meeting lasts for approximately one hour. It is preferable to conduct the meetings in a separate room in the same work area or very close to the work area. It is advisable to allow the members to conduct the meeting in company's time in order to get full participation in circle meeting.

Objectives

Quality circles adoption leads to benefits (A) Individual and (B) Organizational.

(A) Benefits for the Individual

(i) Personality Development. For doing a job, everyone needs some kind of help from others, during such help exchange of ideas are involved. This leads to the personality development of an individual as he is sure to receive good ideas of others.

(ii) Mutual Development. Quality circle is a group activity, as such in a group every individual, besides, developing self also help in the development of others, this leads to development of the whole group which in turn leads to the development of society and nation.

(iii) Job Satisfaction. It is a well-known fact that an individual or a group feels satisfied if the ideas given by them are implemented.

This is also a human tendency that once encouraged every person tries to do more and more constructive work in future. This gives job satisfaction. Moreover a stage comes when salary, allowances post, facility do not encourage an individual if his ideas are not given due importance.

(iv) Problem Solving Capability. In the absence of QC, every problem has to be solved by management. It is quite possible that top management may not completely understand the problems of a particular work area.

QC member are well in touch with the problems of their work area and hence can find best solution of such problems earlier.

This way the management can look into other work and problem solving capability in QC member are enhanced.

(v) Togetherness. QC is a group activity and this way it creates an atmosphere where an individual starts thinking about we rather than I, this reduces and eliminates the enemity between workers and then the problems can be solved easily.

(vi) Better Human Relationship. QC leads to better relationship because if we work together, we are sure to develop better relationship with others.

(vii) Exchange of Good Thoughts. When the better human relations are established we can exchange our thoughts in a better manner and without any hesitation.

(viii) Orating Capability (Stage openings). Many times an individual may not explain his ideas due to hesitation or shyness, after working in QC, a member can get rid off such problems and can express themselves in a better manner.

(B) Benefits for an Organization

(i) Improves Productivity.

(ii) Improves Quality of Product.

(iii) Reduces Wastage.

(iv) Increases Employee Motivation.

(v) Inspires more Effective Team Work.

(vi) Develops harmonious Superior-Subordinate Relationship.

(vii) Improves communication within Organizations.

(viii) Develops a complete coherent problem Solving Environment.

Structure

Structure involved in the process of QC - An Overview

The success of a QC mainly depends upon the structure and the main feature of a QC principle lies in that form top management to a small worker are tied up. The following basic elements constitute the structure of a QC :

(i) Top Management.

(ii) Steering Committee.

(iii) Co-ordinating Agency;

(iv) Facilitates;

(v) Leaders/Deputy Leaders;

(vi) Members.

Quality Circle Technique

It is necessary for QC to adopt following technique in order to smooth working of QC.

(i) Team is necessary for QC to adopt following technique in order to smooth working of QC.

(ii) Pareto Principle

(iii) Collection of Data

(iv) Analysis of Problem

(v) Problem Selection and Solution

(vi) Presentation to Management

(vii) Code of Conduct.

Team Work

Team Work does not mean that only QC members should work in a team spirit but includes management also there are four major points which effect the group activity.

(a) Sitting Arrangement; (b) Listening to Other;

(c) Attitude Towards Suggestions; (d) Decision Making Ways.

One of the main aspect of quality circle is to think about a problem again and again and then you will find an optimum solutions. There are two important types of field of ideas

1. Analytical ideas
2. Constructive ideas

Pareto Principle

Italian Sociologist Pareto's principle is found useful in QC at every level, Pareto proved, after studying the economic condition of Italy that 80% of the country's wealth is divided between 20% of the people. This is also known as 80—20 principle.

According to this principle if 80% of accidents are occurring in 20% of factory then 20% factories are having unsafe working procedures.

According to Pareto, the important cause are always quite less in number QC focuses it's attention on these less but important problems.

Data Collection

Any problem can be easily solved by collection of data, therefore it is an important aspects of QC Tachnique based on the dates QC which suggests new improvement or solution.

Problem Analysis

There are six important steps in analysis of problem:

(a) Write the result of the problem :
(b) Write the problems under main headings.
(c) Thinking by QC.
(d) Discussion on results of problem suggestions.
(e) Suggestions.
(f) To find main reasons of the problem by Pareto principle.

Problem Selection and Solution

There are five steps involved :

(a) First step : know and write about the problems encountered.
(b) Second step : Take the most important problem which is to be solved on priority basis.
(c) Use of Pareto principle/cause effect diagram.
(d) Data Collection.
(e) Solution.

Presentation to Management

Management presentation is a meeting in which the leader and his circle members explain to the steering committee the problem tackled, the methodology used and solution arrived at in this work area. The participants make the presentation with the help of charts, graph etc. prepared by them. A Management Presentation is important for following purposes.

(i) To show achievement in terms of projects completed.
(ii) To make recommendations.
(iii) To provide status report on long-term projects.

Code of Conduct

To give "Code of Conduct" the status of technique shows that how much important is given to it.

The following are main points.

(i) Participation of every member.

(ii) Do not criticize other members.

(iii) Each one to learn everyone.

(iv) Everyone should express his views openly.

(v) Listening to others idea.

(vi) QC should work in a planned way.

(vii) To start and end the meeting in time.

3.7 TOTAL QUALITY MANAGEMENT

The Govt. of India has shown that human development is top on it's agenda by making a separate ministry for Human Resources Development. The aim of QC is also human development and best possible use of human resources.

Though the QC activities have just started in India and we have to go miles, this is a matter of great satisfaction to the person involved in QC activity that an international conference on Quality Circle was organized in India in 1989.

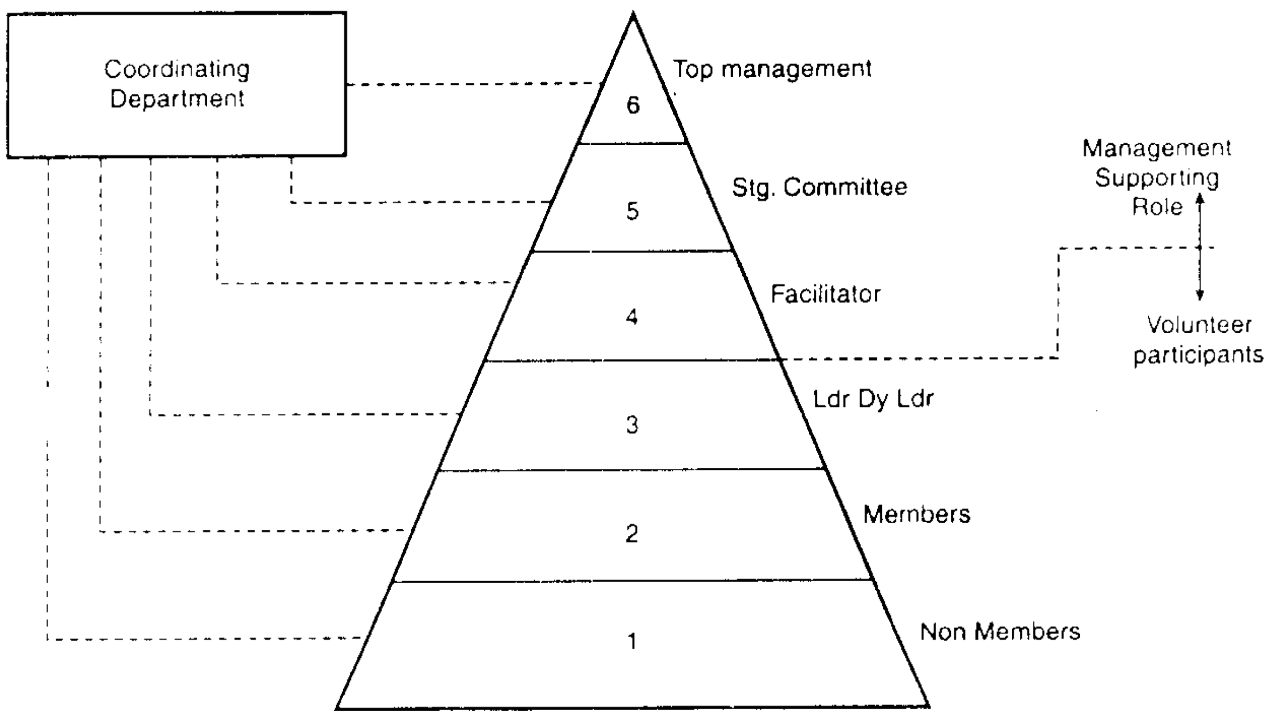


Fig. 3.10: Structure of quality circles.

Introduction

Quality is always an important issue. What is the concept of quality? How is quality described? What is the right quality? How to improve it? How to manage the quality? What is total quality management? These questions are debated at a great length. Yet the concept of Total Quality Management (TQM) is new to many and is yet to be understood properly.

In early days of industrialization, quality of a product was defined by its dimensions (length, width, height, weight, volume etc.) or by some physical and chemical characteristics."Subsequently it was argued that the right quality is related to the purpose for which the product or service is required. The concept of quality focused on the material of construction and design aspects of the product. Very soon it was realized that this understanding of the quality is limited in its scope. Today, quality is seen differently in different contexts. The concept of quality is very rapidly changing with emphasis on the systems and processes that govern the other aspects of quality. This new concept about quality has taken priority in many companies to retain their competitive position in the international market. This realization is not limited to the leaders in the competitive business environment of USA alone, but it has also become a major factor in business throughout Asia, Europe, Latin America and Middle East. New global customers, technology and business forces are changing their approach on quality and are reaping the benefits. Changing concepts of quality could be viewed as follows:

- Quality as an international business language;
- Quality for customer satisfaction;
- Quality for business effectiveness;
- Quality as a competitive connector;
- Quality in partnership;
- Quality in leadership;
- Quality in-modern managerial activity-based accounting;
- Quality in time management;

What is Quality?

Quality is:

- Conformance to specifications;
- Conformance to requirements;
- What the customer thinks it is;
- Measure of the conformance of the product/service to the customer's needs;
- Combination of aesthetics, features and design;
- Value for money;
- The ability of a product to meet customer's needs;
- Meeting or exceeding customer requirements now and in the future;
- Fitness for use of a product/service by the intended customer;
- A customer's perception of the degree to which the product/service meets his/her expectations;
- Totality of features and characteristics of a product/service that bears on its ability to satisfy a stated or implied need.

New Thinking About Quality

Old Quality is "small q"	New Quality is "Big Q"
About products	About organisations
Technical	Strategic
For inspectors	For everyone
Led by experts	Led by Management
High grade	The appropriate grade
About control	About improvement

Eight Dimensions of Product Quality

1. Performance 2. Features 3. Reliability 4. Serviceability 5. Aesthetics (appearance) 6. Durability 7. Customer service 8. Safety

Ten Dimensions of Service Quality

1. Reliability 2. Responsiveness 3. Competence 4. Access 5. Courtesy 6. Communication 7. Credibility 8. Understanding 9. Security/Safety 10. Tangibles.

Benefits of Quality

1. Gives positive company image.
2. Improves competitive ability.
3. Increases market share and net profits.
4. Reduces costs.
5. Reduces product liability problems.
6. Improves employee morale.
7. Improves productivity.

Customer-Driven Quality: Quality is meeting or exceeding customer expectations. The term "customer" includes both the "internal customer" and the "external customer" in the "customer chain".

1. Conformance to specifications (requirements).
2. Value for money
3. Fitness for use.
4. Support provided by seller (customer services)
5. Psychological impression (image, aesthetics)

Perceived Quality : "An assessment of quality based on the reputation of the firm." Customers base their assessment of quality on such factors as advertisements, media reports, reputations and past experience to indicate perceived quality.

Three Levels of Quality

1.	Organisation level	Meeting external customer requirements
2.	Process level	Meeting the needs of internal customers
3.	Performer level (job level or task design level)	Meeting the requirements of accuracy, completeness innovation, timeliness and cost.

Determinants of Quality

1. Quality of design, 2. Quality capability of process, 3. Quality of conformance, 4. Quality of customer service, 5. Organisation quality culture.

QUALITY IS	Q	–	Quest for excellence
	U	–	Understanding customer needs
	A	–	Action to achieve customer satisfaction
	L	–	Leadership - determination to be a leader
	I	–	Involvement of all people
	T	–	Team spirit to work for common goals
	Y	–	Yardstick to measure progress.

Quality Management ensures that an organization, product or service is consistent.

What is Quality Control?

1. Setting quality standards (objectives or targets)
2. Appraisal of conformance (quality measurement)
3. Taking corrective actions to reduce deviations
4. Planning for quality improvement

Quality control begins with product design and includes materials, bought-out items, manufacturing processes and finished goods at the hands of customers.

Quality control aims at prevention of defects rather than detection of defects (by inspection)

Objectives of quality control is to provide products/services which are dependable, satisfactory and economical.

Quality & Reliability : Reliability is the probability of performing without failure, a specified function under given conditions for a specified period of time.

Company-Wide Quality Control (CWQC) : System of activities that assume that quality products and services required by customers are economically designed, produced, and supplied involving all departments of an organisation

Quality Assurance : All activities required to ensure that the product performs to the customers' satisfaction.

Quality Improvement: Finding ways to do better than standard and breaking-through to unprecedented levels of performance. It is the responsibility of those who produce the products and not of inspectors, (i.e., quality at the source)

Concept of Total Quality : Systems approach to quality. Involves all employees (top to bottom) and extends backward to forward (i.e., supply chain & customer chain). Total quality stresses learning and adaptation to continual change as key to organisational success. It includes systems, methods and tools.

Principles of Total Quality

- Focus on the customer (Both internal & external)
- Participation and team work
- Employee involvement and empowerment
- Continuous improvement and learning.

What is Total Quality Control (TQC)?

It is an effective system for **integrating quality development, quality maintenance and quality improvement efforts of various groups in an organisations.**

Principles of Total Quality Control (TQC)

1. Top management policies - Zero defects, continuous improvement etc;
2. Quality control training for everyon;
3. Quality at product/service design stage;
4. Quality materials from suppliers;
5. Quality control in production (SQC);
6. Quality-control in distribution, installation and usg;

Modern Quality Management

Quality Gurus and their Philosophies

1. **W. Edwards Deming(USA)** U.S. statistician & consultant known as father of quality control
   (a) Higher quality means lower cost
   (b) Quality means continuous improvement
   (c) 14 points for quality management
   (d) Seven deadly diseases and sins
   (e) Deming wheel/cycle (P-D-C-A cycle)
   (f) Deming's triangle
   (g) Deming prize.

Deming's 14 Points for Quality Management

1. Create constancy of purpose for continual improvement of product/services.
2. Adopt the new policy for economic stability.
3. Cease dependency on inspection to achieve quality.
4. End the practice of awarding business on price tag alone.
5. Improve constantly and forever the system of production and service.
6. Institute training on the job.
7. Adopt and institute modern method of supervision and leadership.
8. Drive out fear. (Fear of failure, fear of change etc).
9. Breakdown barriers between departments and individuals.
10. Eliminate the use of slogans, posters and exhortations.
11. Eliminate work standards and numerical quotas.
12. Remove barriers that rob the hourly worker of the right to pride in workmanship.
13. Institute a vigorous program of education and retraining.
14. Define top management's permanent commitment to ever improving quality and productivity.

Deming's Seven Deadly Diseases and Sins

1. Lack of constancy of purpose (short-term quality programs)
2. Emphasis on short-term profits
3. Over reliance on performance appraisals
4. Mobility of management (Job hopping)
5. Over emphasis on visual figures
6. Excessive medical costs for employes healthcare
7. Excessive costs of warranty and legal costs.

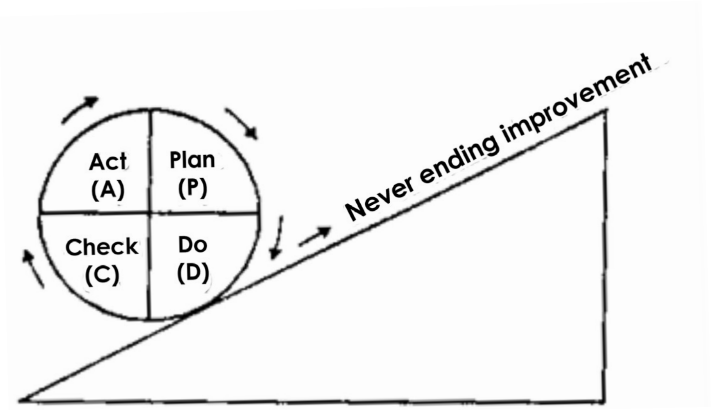
Deming Wheel/Deming Cycle/P-D-C-A Cycle

P - Plan (process) the improvement

D - Do Implement the plan

C - Check - Check how closely result meets goals

A - Act - Use the improved process as standard practice



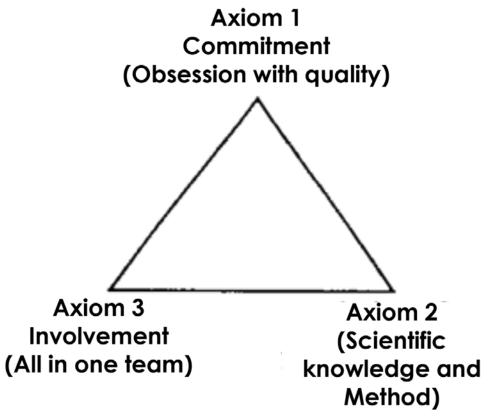
Deming's Triangle (3 Axioms)

Axiom 1 : Commitment (Obsession with quality)

Axiom 2 : (Scientific Knowledge & Method)

Axiom 3 : Involvement (All in one team)

Deming Prize : Awarded by the union of Japanese Scientists and Engineers (JUSE) to a firm or its division based on the distinctive performance improvements achieved through the application of Company Wide Quality Control (CWQC).



2. Joseph Juran (USA)

Professor and Quality consultant - wrote 12 books on quality including Quality Control Hand Book) Defined quality as "fitness for use".

Philosophy :

(a) Top management commitment, (b) Costs of quality, (c) Quality triology, (d) 10 steps for quality improvement, (e) Universal breakthrough sequence.

Costs of Quality

1. **Prevention costs :** Costs of quality planning, new product review, training, process planning, quality data and improvement projects.
2. **Appraisal costs :** Costs of incoming inspection, process inspection, finished goods inspection, quality laboratories and calibration of instruments.
3. **Internal failure costs :** Costs of scrap, rework, down grading (seconds quality products) retest, downtime.
4. **External failure costs :** Costs of warranty, returned goods, customer complaints, allowances to customers for substandard quality products.

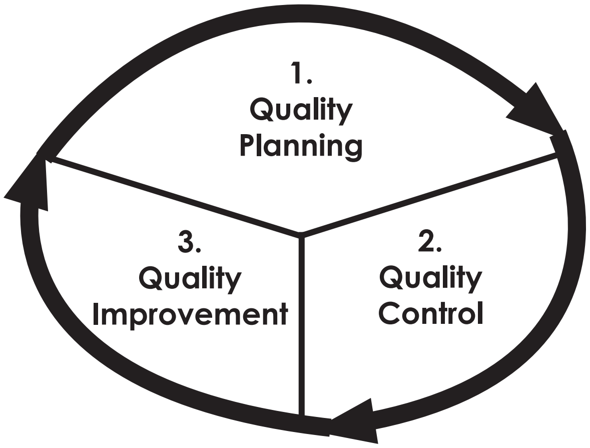
Costs of quality can be reduced by revising the production system including technology, management, attitudes and training.

Quality Triology

(i) Quality planning, (ii) Quality control and (iii) Quality improvement.

Quality Habit

1. Establish specific goals
2. Establish plans for achieving these goals
3. Assign clear responsibilities to employees
4. Base rewards on results.



Juran's 10 Steps for Quality Improvement

1. Build awareness for the need and opportunity for improvement 2. Set goals for improvement 3. Organise people to reach the goals 4. Provide training throughout the organisation 5. Carryout projects to solve problems 6. Report progress 7. Give recognition 8. Communicate results 9. Keep score 10. Maintain momentum by making annual improvement part of the regular system and processes of the company.

Universal Breakthrough Sequence

Break-through or major improvements follow the 7 steps given below:

1. Proof of need 2. Project identification 3. Organising for improvements 4. Diagnostic journey 5. Remedial action 6. Resistance to change 7. Holding on to gains.

3. Philip B Crosby (USA)

(Management consultant and director of Crosby's Quality College. Wrote a book titled "Quality is free" of which 1 million copies sold)

Philosophies

(a) Quality is free (b) Goal of zero defects (c) 6 'C's - Comprehension, Commitment, Competence, Correction, Communication, Continuance, (d) Four absolutes of Quality (e) 14 steps for quality improvement (f) Quality Vaccine/Crosby Triangle.

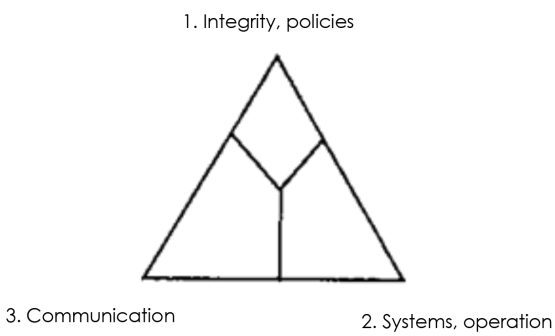
4. Absolute of Quality

1. Quality is defined as conformance to requirements, not goodness.
2. The system for achieving quality is prevention, not appraisal.
3. The performance standard is zero defects not that is close enough.
4. The measurement of quality is the price of non-conformances, not indexes.

Crosby's 14 Steps for Quality Management

(i). Management commitment (ii) Quality improvement team (iii) Quality measurement (iv) Cost of quality (v) Quality awareness (vi) Corrective action (vii) Zero defects planning (viii) Supervisor training (ix) Zero defects day (x) Goal setting (xi) Error cause removal (xii) Recognition (xiii) Quality councils (xiv) Do it all over again.

Crosby's Quality Vaccine or Crosby Triangle



5. Kaoru Ishikawa (Japan) (Japanese Quality Authority)

(i) Quality circles (ii) Ishikawa diagram for problem solving (Hi) Quality training (iv) Root cause elimination (v) Total employee involvement (vi) Customer focus (vii) Elimination of inspection (viii) C.W.Q.C. (ix) Japanese quality strategy.

Total Quality Management means:

- Top Management Commitment to quality
- Customer involvement and focus
- Employee involvement and focus
- Leadership and strategic planning for quality

- Company-wide quality culture
- Continuous improvement
- Customer satisfaction and delight

TQM improves productivity and competitive advantage.

Total Quality Management (TQM) consists of organization-wide efforts to install and make permanent a climate in which an organization continuously improves its ability to deliver high-quality products and services to customers. While there is no widely agreed-upon approach, TQM efforts typically draw heavily on the previously developed tools and techniques of quality control.

Definition

Total Quality Management (TQM) is an enhancement to the traditional way of doing business. It is a proven technique to guarantee survival in world-class competition. Only by changing the actions of management will the culture and actions of an entire organization be transformed. TQM is for the most part common sense. Analyzing these words.

Total — made up of the whole

Quality — Degree of Excellence a Product or Service provides

Management — Act, art or manner of handling, controlling, directing etc.

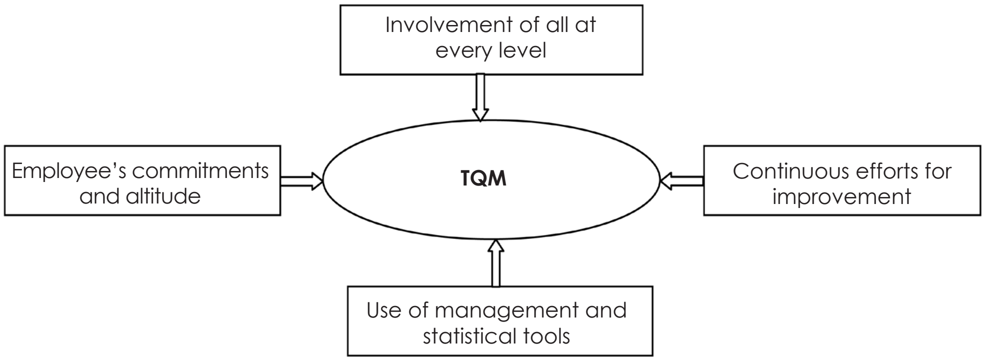


Fig. 3.11: Elements of Total Quality Management

TQM Concepts

The above principles are bandied freely around in the above discussion. Its worth dwelling with each for a moment.

Be customer-focused means everything you do will be done by placing the customer in the centre. The company should regularly check customer's attitudes. This will include the external and internal customer concept.

Do it right first time so that there is no rework. This essentially means cutting down on the amount of defective work.

Constantly improve, this allows the company gradually to get better. One of the axioms used by TQM people is 5% improvement in 100% of the areas is easier than a 100% improvement in 5% of the areas.

Quality is an attitude The attitude is what differentiates between excellence and mediocracy. Therefore it's very important to change the attitude of the entire workforce i.e., basically the way the company works i.e the company's work culture.

Telling the staff what is going on means keeping the entire workforce informed about he general direction the company is headed in typically this includes them briefings, one of the main elements to TQM.

Training and education of the workforce is a vital ingredient, as untrained staff tend to commit mistakes. Enlarging the skill base of the staff essentially makes them do a wider range of jobs and do them better. In the new system of working under TQM educating the staff is one of the principles.

Measurement of work allows the company to make decisions based on facts, it also helps them to maintain standards and keep processes with in the agreed tolerance levels.

The involvement of senior management is essential. The lack of which will cause the TQM program to fail.

Getting employees to make decision on the spot so that the customer does not face any inconvenience in empowering the employees.

Mailing it a good place to work. In many an organisation there exists a lot of fear in the staff. The fear of the boss, fear of mistakes of being sacked. TQM program is any company filled with fear cannot work, therefore fear has to be driven out of the company before starting of TQM program.

Introduce team working, its boosts employee morale. It also reduces conflict among the staff. It reduces the role of authority and responsibility, and it provides better more balanced solutions. In a lot of companies teamwork is discouraged, so TQM programs must encourage it.

Organise by process, not by function. This concentrates on getting the product to the customer by reducing the barriers between the different departments.

Present Trend

From maintenance of quality to continuous improvement of quality some important concepts.

1. **Product control Vs Process Control :** Process produces products. Product quality depends an process quality. Controlling the process is easier and cheaper than controlling the product. Controlling process needs knowledge tools and techniques.

2. **Upstream Vs Downstream :** Upstream is the starting area of a business process. Downstream is the tail end of the business process. Corrective action at upstream is very must cost effective. Cost goes up as and when the stream goes down. It will be in geometric proportions. Better planning is required to reduce downstream costs. It's worth spending more time for planning to reduce expensive execution time. This needs cross-functional organisation and knowledge of quality function deployment.

Basic Approach

TQM requires six basic concepts :

1. A committed and involved management to provide long-term top-to-bottom organizational support.
2. An unwavering focus on the customer, both internally and externally.
3. Effective involvement and utilization of the entire work force.
4. Continuous improvement of the business and production process.
5. Treating suppliers as partners.
6. Establish performance measures for the processes.

There concepts outline an excellent way to run an organization. A brief paragraph on each of them is given here:

1. Management must participate in the quality program. A quality council must be established to develop a clear vision, set long-term goals and direct the program. Managers participate on quality improvement teams and also as coaches to other teams. TQM is a continual activity that must be entrenched in the culture it is not just a one-shot program. TQM must be communicated to all people.

2. The key to an effective TQM program is its focus on the customer. An excellent place to start is by satisfying internal customers. We must listen to the "Voice of the customer" and emphasize design quality and defect prevention.
3. TQM is an organization-wide challenge that is everyone's responsibility. All personnel must be trained in TQM, statistical process control (SPC) and other appropriate quality improvement skills so they can effectively participate on project teams.

   People must come to work not only to do their jobs, but also to think about how to improve their jobs, people must be empowered at the lowest possible level to perform processes in an optimum manner.
4. There must be a continue striving to improve all business and production processes. Quality improvement projects, such as on-time delivery, order-entry efficiency, billing error rate, customer satisfaction, cycle time, scrap reduction and supplier management are good places to begin.
5. On the average 40% of the sales is purchased product or service, therefore, the supplier quality must be outstanding. The focus should be on quality and life cycle costs rather than price. Suppliers should be few in number so that true partnering can occur.
6. Performance measures such as uptime, percent non-conforming, absenteeism and customer satisfaction should be determined for each functional area.

   Quantitative data are necessary to measure the continuous quality improvement activity.

THE FIVE PRINCIPLES OF TQM

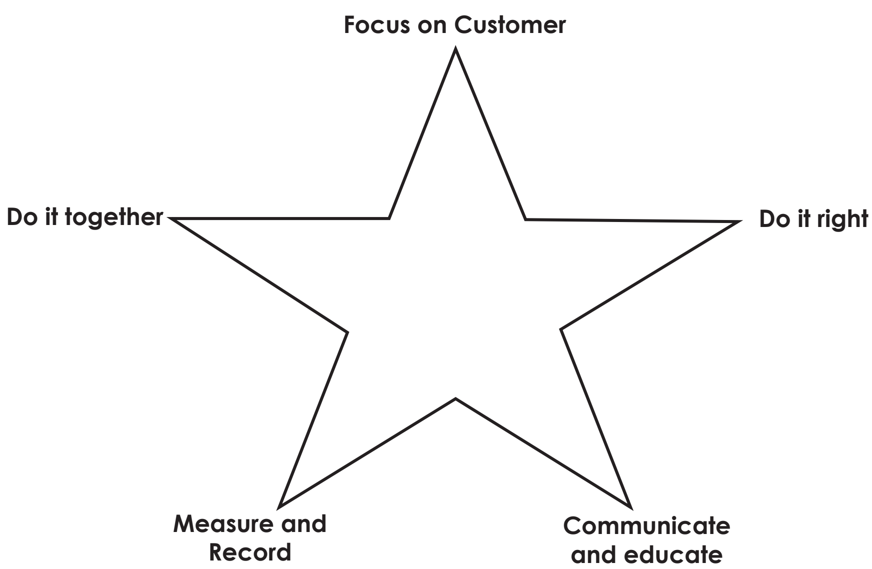


Fig. 3.12: Principles of Total Quality Management

1. Concentrate on the customer

   Be customer focused
2. Do it right

   Do it right first time

   Constantly improve

   Quality is an attitude not a inspection process
3. Communication and educate

   Tell staff what is going on

   Educate and train

4. Measure and record

   Measure work

5. Do it together

   Top management must be invovled

   Empower the staff

   Make the business a good place to work

   Organise by process not function

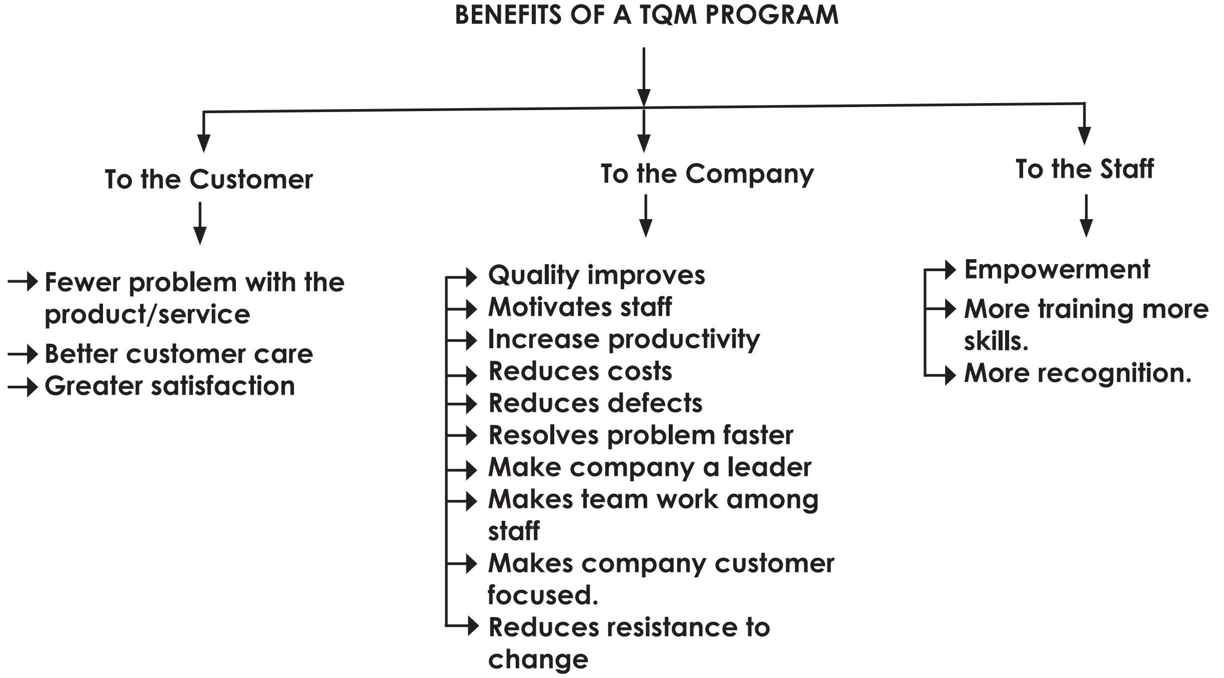


Fig. 3.13: Benefits of Total Quality Management

Involvement of Management in TQM

The involvement of management is very much necessary to make TQM a success in any organisation. Certain steps can be taken by senior managers to facilitate TQM. They are :

- Decide the purpose of introducing TQM management must know its goal.
  - ✓ What do you want to achieve out of this TQM program must be determined, otherwise the program will lack direction.
  - ✓ Empowerment of staff, reduction of defects, improving customer loyalty etc.
- Devote necessary time for the program. TQM programs take away substantial part of the manager's time and if they are not ready to spare it the program will never take off.
- Employee participation in every level should be encouraged. The involvement of the people in the organisation will ensure the success of TQM program.
- Train people. Making sure the managers are well trained in TQM, by personal checking and even conducting key quality training courses.
- The organisation must give some time for it to work. Managers might spend weeks in training, but results might not be visible immediately. It takes a long time for organisation to change their culture

and attitudes, this essentially means that results will take several years to show up their face. This time lag involved between the amount of efforts put in and the results to surface, puts many managers to loose interest in TQM.

- Maintain close contact with customer. And if needed, represent the customer interest in solving problems. Recognise efforts, get personally involved in quality awards.
- Be prepared for resistance. People fear change, because it could lead to redundancy, which means that staff will be apprehensive and sceptical about the TQM program. Many a time the staff simply wants to maintain their status quo, because they are familiar with it.
- Introduce new employees to quality values. Conduct orientation programs to show them the organisation level of commitment.
- Visiting other organisation who have implemented TQM will give a view of the benefits of TQM and you can learn how it should be applied. Often a group of your employees can make a visit to a non-competing company where the TQM manager will be pleased to show you around.
- Communication of quality to all the levels of the organisation. This is done by a monthly video film on quality, which will be viewed by all employees.
- The organisation has to commit a lot of money towards TQM program is the form of salary to a full-time TQM co-ordinator in case of an in-house program, payments for training courses. In addition, a lot of senior managers of visiting other companies. The organisation may also spend on give-away like printed is using a consultancy for this purpose, it will have to pay its fees.
- Emphasize continuous improvement encourage everyone to do better.
- Investments must be managed. TQM efforts will bring in solution and if these solution are not implemented the staff be disillusioned.
- Break down barriers to cross-functional co-operation.

Nominate a TQM facilitator, a TQM director, and set up a quality council. The quality facilitator will have day to day responsibility for TQM, he will remind advice and encourage staff about TQM.

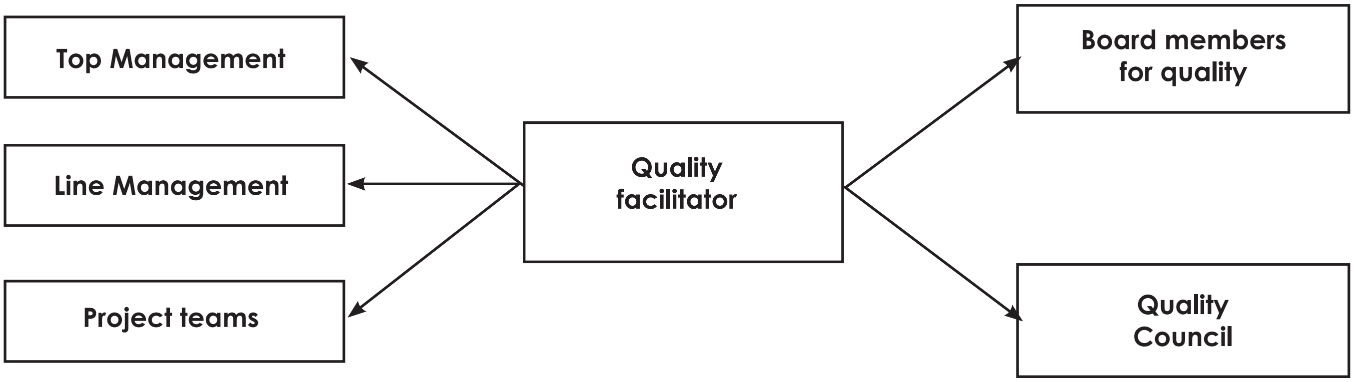


Fig. 3.14: Structure for TQM.

If the organisation is large, the TQM faciliator will report, to a board member, otherwise to the chief executive. The quality council or the TQM steering committee is constituted of top managers and it's the deciding authority on TQM matters. The quality council should comprise the quality manager, TQM facilitator senior line management and atleast one member of the board.

- Get rid of unnecessary distinctions. Some companies have abolished some management titles and eliminated perquisites.
- Set mission and values and make sure they are communicated to every employee.

Preparing Managers for TQM

While preparing managers for TQM the following three factors have to be considered.

1. **Managers must be empowered.** They are expected to further delegate this and if they don't have power and resources at their disposal, how will they delegate it.

2. **Manager must evaluate their style.** They will have to consider the way they are doing their jobs currently and how they will have to change as TQM is introduced.

3. **Management training at TQM has to be given careful attention.** This will aquaint managers with TQM, dispose them favourably towards TQM, show them ways of gradually introducing TQM ideas, and convince them of TQM's benefits and gains.

3.8 HISTORY OF QUALITY CONTROL IN INDIA

The history of quality control or statistical quality control in India can be traced thus.

1928 - Prof. P.C. Mahalonobis initiated statistical studies and resources in their statistical laboratory, setup in the presidency college. Calcutta.

1931 - The Indian Statistical Institute was found by Prof. P.C. Mahalonobis.

1932 - The Indian Statistical Institute got recognition in the form of a learned society under the societies Registration Act.

1948 - Dr. W.A. Shewart visited the industrial centers in India.

1952 - A team of UN experts visited India to train personel in the routine use of quality control.

1959 - The parliament of India enacted the India Statistical Institute Act declaring the institute to be of national important and empowering it to award Degrees and Diplomas.

Dr. W.E. Deming, Dr. J.M. Juran, Prof. Genichi Taguchi and Dr. Kabnu Ishikawa visited India. It's of interest to note that seeds of statistical studies and researchers were sown to India in 1928 and compared to January 1949 in Japan. Dr. Deming and Dr. Juran visited India and Japan almost during the same decade. But the massive investment made by Japan in education and training the implementation of these techniques with a sense of mission and commitment has made all the difference.

3.9 SIX SIGMA

Sigma(σ) is a letter in the Greek alphabet that has become the statistical symbol and metric of process variation. The sigma scale of measure is perfectly correlated to such characteristics as defects-per-unit, parts-per-million defectives, and the probability of a failure.

Six Sigma was launched by Motorola in 1987.

In the wake of successes at Motorola, some leading electronic companies such as IBM, DEC, and Texas Instruments launched Six Sigma initiatives in early 1990s.

Six Sigma is viewed as a systematic, scientific, statistical and smarter (4S) approach for management innovation which is quite suitable for use in a knowledge-based information society. The essence of Six Sigma is the integration of four elements (customer, process, manpower and strategy) to provide management innovation.

- Six Sigma provides a scientific and statistical basis for quality assessment for all processes through measurement of quality levels. The Six Sigma method allows us to draw comparisons among all processes, and tells how good a process is. Through this information, top-level management learns what path to follow to achieve process innovation and customer satisfaction.

- Six Sigma provides efficient manpower cultivation and utilization. It employs a "belt system" in which the levels of mastery are classified as green belt, black belt, master black belt and champion. As a person in a company obtains certain training, he acquires a belt. Usually, a black belt is the leader of a project team and several green belts work together for the project team.
- There are many success stories of Six Sigma application in well known world-class companies. As mentioned earlier, Six Sigma was pioneered by Motorola and launched as a strategic initiative in 1987. Since then, and particularly from 1995, an exponentially growing number of prestigious global firms have launched a Six Sigma program. It has been noted that many globally leading companies run Six Sigma programs, and it has been well known that Motorola, GE, Allied Signal, IBM, DEC, Texas Instruments, Sony, Kodak, Nokia, and Philips Electronics among others have been quite successful in Six Sigma. In Korea, the Samsung, LG, Hyundai groups and Korea Heavy Industries & Construction Company have been quite successful with Six Sigma.
- Lastly, Six Sigma provides flexibility in the new millennium of 3Cs, which are:
  - ➢ Change: Changing society
  - ➢ Customer: Power is shifted to customer and customer demand is high
  - ➢ Competition: Competition in quality and productivity

The pace of change during the last decade has been unprecedented, and the speed of change in this new millennium is perhaps faster than ever before. Most notably, the power has shifted from producer to customer. The producer-oriented industrial society is over, and the customer-oriented information society has arrived. The customer has all the rights to order, select and buy goods and services. Especially, in e-business, the customer has all-mighty power. Competition in quality and productivity has been ever-increasing. Second-rate quality goods cannot survive anymore in the market. Six Sigma with its 4S (systematic, scientific, statistical and smarter) approaches provides flexibility in managing a business unit.

Key Concepts of Management

The core objective of Six Sigma is to improve the performance of processes. By improving processes, it attempts to achieve three things: the first is to reduce costs, the second is to improve customer satisfaction, and the third is to increase revenue, thereby, increasing profits.

Six Sigma was started by Motorola as a way of reducing defects in the manufacturing process. Six Sigma represents a statistical measurement of variation from a specific attribute or characteristic desired by the end-user. It is expressed over six exponential layers:

Sigma	Defects per million	Remarks
One Sigma	690,000 defects per million	
Two Sigma	308,000 defects per million	
Three Sigma	66,800 defects per million	
Four Sigma	6,210 defects per million	(relatively efficient)
Five Sigma	230 defects per million	(world class efficiency)
Six Sigma	3.4 defects per million	(perfection)

If provides a universal measurement standard for all processes throughout the organization. Sigma layers give an indication of how much failure is occurring within a process. It is estimated that a company operating between the third and fourth sigma can expect about a 10% loss in revenues from inefficiency. Moving from one sigma to the next is a major undertaking. A 30-fold improvement in quality is required to get from Four Sigma to Five Sigma.

Six Sigma is a very rigorous approach to improving quality within your products and services. Processes that are critical to products and services must be analyzed in detail. Techniques like process mapping and pareto charts are often used to understand the details within a process. Generally, Six Sigma will follow a four phase approach:

1. **Measure** - Determine the error or defect rate
2. **Analyze -** Understand the Process
3. **Improve -** Reach for a higher Sigma
4. **Control -** Monitor through measurement

Few companies have made it to the Six Sigma (3.4 errors per one million). However, where defect rates are extremely costly, reaching for the Sixth Sigma is now a given expectation. It is worth noting that Six Sigma requires formal training in the statistical methods that are used.

One reason Six Sigma has become so popular is because companies want to eliminate non-value added activities as quickly as possible. Other approaches to process improvement, such as Activity Based Management, can take considerable time with marginal improvements.

Example of Six Sigma

The **Dabbawalla's of Mumbai** have been into existence since the 1890s. During the time when India was still under the British rule. It was during those times that many people from different communities came to work in Mumbai. The tiffin box delivery service was started by Mahadeo Havaji Bacche. He recruited people from villages who were not able to earn a good living. And thus started the legacy of The Dabbawalla's of Mumbai.

The transport of lunch boxes from home to office. Thats all nothing much. Daily 4000-5000 dabbawallas carry 1,75,000 – 2,00,000 tiffin boxes everyday .

The **Six Sigma quality certification** was established by the International Quality Federation in 1986, to judge the quality standards of an organisation. The Six-sigma rating means that they have a 99.99 % efficiency in delivering the lunch-boxes to the right people. According to quality standards the dabbawalla's are at par with various companies like Motorola, Honeywell and GE. Apart from this the dabbawalla's have been called to various CII Conferences and leading institues like IIM's to deliver speech. The New York Times reported in 2007 that the 125 year old dabbawala industry continues to grow at a rate of **5-10%** per year. In its July 11, 2008 issue, The Economist news magazine reported that dabbawallas are a model of Six Sigma management, holding a **delivery accuracy rate of "99.9999%."**

Bench Marking

Today we have wide array of "Benchmarking" categories. Many of these distinction are quite orbitary and have nothing to do with the process itself, but deal more with the partners chosen and area, of business being analysed. The Benchmarking process does not vary significantly with the three categories of partners that can be selected : Internal organisations, direct competitors, or non-competitors. There are two forms of Benchmarking : strategic and functional or operational. Operational Benchmarking focuses on the operational processes and practices and service offered by an organisation. Strategic benchmarking focuses on strategic marketing, financial, organisational and technological issues facing an organisation.

Benefits of Benchmarking

- Benchmarking is particularly helpful in validating proposals for change.
- Benchmarking of ten results in creative imitation and the adoption of new practices that overcome previous industiy barriers.
- This search for diversity and for innovative breakthroughs applied elsewhere is at the core of benchmarking benefits.

- By sharing information, all parties benefits, because it is difficult to excel in all activites.
- Sharing information and data is often the first hurdle to be overcome in the Benchmarking process.
- Do not, however, attempt benchmarking in areas in which trade secrets or sensitive information determines the outcome of the process.
- Benchmarking, used in conjunction with other quality techniques or used alone, can influence how an organisation operates.
- If the search for "Best", or just "Better" practices is performed correctly, then the likelihood of successful outcomes is quite high.
- Success however, assumes that pitfalls are avoided and prerequisites have been met before Benchmarking is initiated.

Some of the Prerequisites for Success

- Management commitment and support can overcome many of the barriers to successful benchmarking.
- The key requisite for success is the organisation's readiness to accept change, given than it comprehends the needs for change.
- Rather than resting on their laurels and previous success, organisations must become receptive to new ideas.
- Sufficient resources need to be allocated, and both awareness and skills training need to be available.
- Benchmarking shares success factors with other quality management processes.
- Teamwork, analysis of data, decisions based on facts, focus on processes and continuous improvements (KAIZEN) are shared characteristics.
- The need for leaderships, a customer focus, and empowered employees are equally important.
- As in other Quality Management activities, there needs to be some one to manage the introduction and application of benchmarking in the organisation.
- Benchmarking teams need a clear understanding of both internal and external customer needs and expectations. Without this they will have difficulty selecting important subjects.
- An understanding of competitive strengths and weakness provides additional back- ground that aids the selection processes.
- Strategic and competitive assessments not only tell the team what is important to focus on, but also give them an idea of how effectively they are currently achieving important goals. Some Common Misconception about Benchmarking
- Benchmarking is not casual. It is a planned, systematic operation designed to achieve certain specific goals.
- Benchmarking is not a quick fix. It is an on-going process of setting increasingly higher goals for performance.
- Benchmarking is not copying others. It involves recognizing practices, which will fit into your operation, and adapting them.
- Benchmarking does not stand-alone. It is a facet of a broad Total Quality Program. The process must be integrated with rest of the TQM approach.

Forming the Team and Project Road Map

- A team needs to be formed and a project road map developed.
- These are integral activities in the subject selection step.

- The team should include four to eight members who are subject matter experts and represent the various functions affected by the project,
- Teams often include several people in an advisory capacity. The project, sponsor or "customer" and a benchmarking "coach" (an internal or external consultant).
- The road map serves several purposes : It keeps the team on track and it documents activities and decisions.
- This helps to educate others and to document the team's process for later use.
- Another advantage is that clearly defined projects help teams to ensure that the project scope is achievable.
- Basic elements of the road map include.
  - Project scope and objectives.
  - List of activities.
  - List of deliverables.
  - Individuals roles and responsibilities.
  - Meeting and review schedules.
  - Issues.

The Eight Most Common Benchmarking Errors

1. Lack of Self-Knowledge, Unless you've thoroughly analysed your own operations, your benchmarking efforts will not pay off. You have to know how things work in your company, how effective your current processes are, and what factor are critical. That's why internal benchmarking is an important first step.
2. Benchmarking everything. Be selective. Benchmarking another company's employee food service will usually not be worth the time, energy, and cost. Your TQM effort as a whole will point out the areas where benchmarking is most likely to pay off.
3. Benchmarking projects are broad instead of focused. The more specific the project, the easier it is and the more likely it will generate useful ideas. Benchmark a successful company's hiring procedures, not their entire human resources operations. Focus on accounts receivable handling, not the accounting department as a whole.
4. Benchmarking produces reports, not action. Studies have indicated that 50% of benchmarking projects result in no specific changes. The process is not an academic exercise. It should be geared toward generating and implementing actual changes.
5. Benchmarking is not continuous. Benchmarking is a process. Even before you reach the benchmark you've set, you should take another look at your partner's performance, or at other companies. New goals should be established and new techniques adopted. The process never ends.
6. Looking at the numbers, not the issues. While the measures are important, they are not the heart of the process. At some companies, benchmarking is used to set goals, but not to generate the important changes needed to meet them.
7. Participants are not motivated. Make sure benchmarking team members have the time to do the job. Even if the project is simply added on their regular jobs, make sure each has a stake in the success of the project. Don't consider benchmarking as "busy work" to be assigned to a group of low-level employees.
8. Too much data. Action are what's important, not information for its own sake. Don't measure benchmarking success by quantity of information. Always focus on key issues.

Common Pitfalls in Benchmarking

- Lack of management commitment and involvement.
- Not applied to critical areas first
- Inadequate resources.
- No line organisation involvement.
- Too many subjects ; scope not well defined.
- Too many performance measures.
- Critical success factors and performance drivers not understood or identified.
- Potential partners ignored : Internal organisations, Industry leaders, or friendly competitors.
- Poorly designed Questionnaires,
- Inappropriate data : Inconsistent data.
- Analysis paralysis, excess precision.
- Communication of findings without recommendations for projects to close gaps.
- Management resistance to change.
- No repeat Benchmarking.
- No Benchmarking report/documentation.

Eight Steps Benchmarking Process

The Benchmarking process consists of three general activities : Planning, Analysis, and Integration/action.

Overall, the process follows the Plan-Do-Sudy-Act Cycle of all quality processes. It is recommended to use eight steps benchmarking 7 process as mentioned below :

Eight Steps Benchmarking Process

		Activity	**Schedule**	**By Whom**
Planning:	1.	Select Benchmarking subject and appropriate team		
	2.	Identify performance indicators and Drivers		
	3.	Select Benchmark partners		
	4.	Determine data collection method and collect data		
Analysis :	5.	Analyse performance gaps.		
Integration	6.	Communicate Findings and identify projects to close gaps		
Action :	7.	Implement plans and monitor results !		
	8.	Recalibrate benchmarks.		

Study Note - 4

ECONOMICS OF MAINTENANCE AND SPARES MANAGEMENT

This Study Note includes

4.1 MAINTENANCE

Maintenance is defined as "that function of production management that is concerned with the day-to-day problem of keeping the physical plant in good operating condition. It is an essential activity in every manufacturing firm, because it is necessary to ensure the availability of the machines, buildings and services needed by other parts of the organisation for the performance of their function at an optimum return on investment in machines, materials and employees".

Maintenance Engineering

Maintenance Engineering is that function of production management that is concerned with the day-to-day problems of keeping the physical plant in good operating condition.

Maintenance Management

Maintenance Management is concerned with the direction and organisation of resources in order to control the availability and performance of the industrial plants to some specified level. It is a function supporting production function and is entrusted with the task of keeping the machinery/equipment and plant services in proper working condition. It also involves maintenance planning, maintenance scheduling, execution of maintenance activities (repair, breakdown and preventive maintenance) and also controlling costs of maintenance.

Scope of Maintenance

Every manufacturing organisation needs maintenance because machines break down, parts wear out and buildings deteriorate over a period of time of use. All segments of a factory - buildings, machinery, equipments, tools, cranes, jigs and fixtures, heating and generating equipments, waste disposal systems, air-conditioning equipments, wash rooms, dispensaries and so on need attention.

Maintenance covers two broad categories of functions as outlined below.

(a) Primary functions

(i) Maintenance of existing plant and equipments.
(ii) Maintenance of existing plant buildings and grounds.
(iii) Equipment inspection and lubrication.
(iv) Utilities generation and distribution.
(v) Alterations to existing equipments and buildings,
(vi) New installations of equipments and buildings.

(b) Secondary functions

(i) Storekeeping (keeping stock of spare parts)
(ii) Plant protection including fire protection.
(iii) Waste disposal.
(iv) Salvage.
(v) Insurance administration (against fire, theft, etc.).
(vi) Janitorial services.
(vii) Property accounting
(viii) Pollution and noise abatement or control.
(ix) Any other service delegated to maintenance by plant management.

Objectives of Maintenance Management

The following are some of the objectives of Maintenance Management:

1. Minimizing the loss of productive time because of equipment failure (i.e., minimizing idle time of equipment due to break down).
2. Minimizing the repair time and repair cost.
3. Minimizing the loss due to production stoppages.
4. Efficient use of maintenance personnel and equipments.
5. Prolonging the life of capital assets by minimizing the rate of wear and tear.
6. To keep all productive assets in good working condition.
7. To maximize efficiency and economy in production through optimum use of facilities.
8. To minimize accidents through regular inspection and repair of safety devices.
9. To minimize the total maintenance cost which includes the cost of repair, cost of preventive maintenance and inventory carrying costs due to spare parts inventory.
10. To improve the quality of products and to improve productivity.

Areas of Maintenance

The major areas of maintenance are :

1. Civil Maintenance

Building construction and maintenance, maintaining service facilities such as water, gas, steam, compressed air, heating and ventilating, air conditioning, painting, plumbing and carpentry work. Also included in civil maintenance are janitor, service, house-keeping, scrap disposal, fencing, land scaping, gardening and maintaining drainage, lawns and fire fighting equipments.

2. Mechanical Maintenance

Maintaining machines and equipments, transport vehicles, material handling equipments, steam generators, boilers, compressors and furnaces. Lubricating the machines is also part of mechanical maintenance work.

3. **Electrical Maintenance**

Maintaining electrical equipments such as generators, transformers, switch gears, motors, telephone systems, electrical installations, lighting, fans, meters, gages, instruments, control panels and battery charging.

Types of Maintenance

In all the above stated areas, organisation may use any or all the five type of maintenance:

(i) Break down maintenance or corrective maintenance,

(ii) Preventive maintenance,

(iii) Predictive maintenance,

(iv) Routine maintenance,

(v) Planned maintenance.

(i) Break Down Maintenance or Corrective Maintenance

As the name suggests, corrective maintenance occurs when there is a work stoppage because of machine breakdown. In this sense, maintenance becomes repair work. Repairs are made after the equipment is out of order - an electric motor will not start, a conveyor belt is ripped, or a shaft has broken. In cases such as these, the maintenance department checks into the difficulty and makes the necessary repairs. Role of the department is almost passive.

Nevertheless, corrective maintenance seeks to achieve the following objectives :

1. To get equipment back into operation as quickly as possible in order to minimise interruption to production. This objective can directly affect production capacity, production costs, product quality and customer satisfaction.
2. To control the cost of repair crews, including regular time and overtime labour costs.
3. To control the cost of the operation of repair shops.
4. To control the investment in replacement spare parts that are used when machines are repaired.
5. To control the investment in replacement spare machines which are also called standup or backup machines. These replace manufacturing machines until the needed repairs are completed.
6. To perform the appropriate amount of repairs at each malfunction. The decision about how far to go with a repair ranges from a band-aid and bubble gum fix to a complete overhaul. Some parts can be replaced early to extend the time until the next repair is required.

(ii) Preventive Maintenance

In marked contrast to corrective maintenance is preventive maintenance, which is undertaken before the need arises and aims to minimise the possibility of unanticipated production interruptions or major breakdowns. Preventive maintenance consists of :

1. Proper design and installation of equipment,
2. Periodic inspection of plant and equipment to prevent break downs before they occur,
3. Repetitive servicing, upkeep and overhaul of equipment, and
4. Adequate lubrication, cleaning and painting of buildings and equipment.

The key to all good preventive maintenance is inspection. Inspection should cover virtually everything, including production machinery, motors, controls, materials handling equipment, process equipment, lighting, buildings and plant services. Some organisations inspect only costly items, but others cover almost all. As a rule, if a failure in upkeep may harm an employee, stop production, or waste plant assets, then consideration should be given to including it in the preventive maintenance programme. Suitable statistical techniques have been developed for determining how often to inspect.

A well-conceived preventive maintenance programme should contain the following features:

1. Proper identification of all items to be included in the programme.
2. Adequate records covering, volume of work, cost and so forth.
3. Inspections on a definite schedule with standing orders on specific assignments.
4. Use of checklists by inspectors.
5. An inspection frequency schedule may vary from as often as once every six hours to as little as once a year.
6. Well-qualified inspectors have craftmen familiar with items being inspected and capable of making simple repairs as soon as a trouble is noticed.
7. Use of repair budgets for major items of equipment.
8. Administrative procedures that provide necessary fulfillment and follow-up on programme.

Benefits of Preventive Maintenance

Preventive maintenance offers several benefits to the users. They include greater safety for workers, decreased production downtime, fewer large scale and repetitive repairs, less cost for simple repairs made before breakdown, less standby equipment required, better spare parts control, identification of items with high maintenance costs, and lower unit cost of manufacture.

(iii) Predictive Maintenance

One of the newer types of maintenance that may be anticipated to gain increasing attention is called predictive maintenance. In this, sensitive instruments (e.g., vibration analysers, amplitude meters, audio gauges, optical tooling, pressure, temperature and resistance gauges) are used to predict trouble. Conditions can be measured periodically or on a continuous basis and this enables the maintenance people to plan for overhaul. This will allow an extension to the service life without fear of failure.

(iv) Routine Maintenance

This includes activities such as periodic inspection, cleaning, lubrication and repair of production equipments after their service life. Routine maintenance may be classified as :

1. Running maintenance in which the maintenance work is carried out while the equipment is in the operating condition (i.e., performing some operation) e.g., greasing or lubricating the bearings while the machine is running.
2. Shut down maintenance in which the maintenance work is carried out when the machine or equipment is out of service i.e., after shutting down the machine or equipment, e.g., repairing (i.e., discaling) boiler tubes of a boiler.

(v) Planned Maintenance

Break-down of a machine or an equipment does not occur in a planned manner but maintenance work can be planned well in advance. Planned maintenance according to a predetermined schedule is also known as scheduled maintenance or productive maintenance. It involves inspection of all plant and equipments, machinery, buildings in order to service, overhaul, lubricate or repair before actual break down or deterioration in service occurs. It aims to reduce machine stoppage due to sudden breakdowns necessitating emergency maintenance.

Planned approach to maintenance reduces the machine or equipment down time, reduces the cost of maintenance and increases productivity as compared to hapazard or unplanned maintenance.

4.2 PLANNING AND SCHEDULING OF MAINTENANCE

Once the types of maintenance are decided, the next step is to plan and schedule the maintenance activities to ensure that maintenance job is properly carried out to achieve the desired objectives. Hence, planning and scheduling of maintenance activities are important components of maintenance function.

Maintenance planning seeks answers for the following questions:

(i) What maintenance activities are to be carried out?

(ii) How these activities are to be carried out?

(iii) Where these activities are to be performed?

(iv) Why these activities are to be performed?

(v) When these activities are to be performed?

Steps in Maintenance Planning

(i) Know the equipment to be maintained, available technique for maintenance and the facilities available to carry out maintenance work.

(ii) Establish the priorities of maintenance activities by categorising the activities as emergency work, priority work and non priority work.

(iii) Investigate the maintenance work to be done at the workstation to ascertain physical access and space limitations, facilities for lifting and handling (moving), facilities for disposal of water, oil, gas and other hazardous materials, space for keeping the dismantled parts etc.

(iv) Develop the repair plan on the basis of

(a) Recommendation of original equipment manufacturer,

(b) Technical experience,

(c) Equipment history and

(d) Management decision for a new technique of maintenance work.

(v) Prepare a list of maintenance materials and spare parts required.

(vi) Prepare a list of special tools and special facilities such as material handling equipments (such as crane) required.

(vii) Estimate the time required to do the maintenance work.

(viii) Provide for necessary safety devices and safety instructions.

Knowledge regarding equipments and machines and how the maintenance work has to be carried out can be obtained from maintenance manuals, design drawings of the machines or equipments, instruction manuals for installation and repair etc. The maintenance manuals give in detail the procedures for dismantling, servicing, carrying out repairs/replacing spare parts, tools to be used etc., which are followed by maintenance mechanics or crew.

Scheduling Maintenance Work

Scheduling indicates what maintenance work has to be carried out when and also in what sequence the work has to be done.

Scheduling of maintenance work seeks answers for the following questions :

(i) Who should do the maintenance works which are already planned?

(ii) When the maintenance work has to be done?

All maintenance activities such as cleaning, lubricating, inspecting various parts of the machines or equipments, repairing or replacing parts periodically has to be properly scheduled.

Reasons for Maintenance Scheduling

(i) To utilise the maintenance crew effectively and optionally.

(ii) To utilise the maintenance equipments and tools effectively.

(iii) To reduce the interruption in production due to maintenance work, usually maintenance work is scheduled after the production shifts or on weekly holidays or on festival holidays or national holidays.

(iv) Proper scheduling of preventive maintenance reduces the abrupt break down or failure of equipments or machinery.

Considerations in Scheduling Maintenance

The following information should be collected before scheduling maintenance activities:

(i) Manpower (maintenance crew) available.

(ii) Pending maintenance work (in terms of man hours backlog).

(iii) Availability of machine or equipment for preventive maintenance service.

(iv) Availability of proper tools, handling equipments, consumables, spare parts etc.

(v) Availability special maintenance equipments if any, special fixtures and tools, cranes, etc.

(vi) Whether additional manpower is available at outside sources to be hired when needed.

(vii) When to start the maintenance work and when it should be completed,

(viii) Previous maintenance history records or charts.

Problems in Maintenance Scheduling

(i) Scheduling maintenance requires the prior concurrence of production personnel to release the machine or equipment for maintenance during a specified time. Hence, there should be proper cooperation and coordination between production department and maintenance department.

(ii) Proper priority must be worked out to prepare scheduling of breakdown maintenance or preventive maintenance as per the importance of the machine or equipment and the effect of breakdown and consequent machine down time on production.

(iii) Dovetailing of maintenance and production schedules is difficult.

(iv) Preventive maintenance schedules must be prepared for at least two weeks and circulated well in advance to production departments to get their consent before finalising the schedule.

Some of the maintenance activities scheduled for short-term and long term and the sources of information are given in **Table 4.1**.

Table 4.1: Time Schedule for Maintenance Activities

Time Schedule	Maintenance Activities	Sources of Information
(i) Long-term	(i) Lubrication	Manufacturer's recommendations
(ii) Short-term	(ii) Preventive maintenance inspection	Technical experience and maintenance manual
	(iii) Overhauling	Machine History Record
	(iv) Cleaning	Maintenance manual
	(v) Replacement of machines	Techno-economic evaluation (process capability) or accuracy
	(a) Repairs	
	(b) Replacements of parts	(i) Inspection reports
		(ii) Complaints of break down
		(iii) Analysis of history of break down
		(iv) Techno-economic evaluation

4.3 CONTROL OF MAINTENANCE

Maintenance involves cost, and the cost is quite high. Hence the need for control. Control is facilitated by the following measures:

(a) Maintenance work must commence only after it has been authorised by a responsible official.

(b) Maintenance schedule must be prepared stipulating the timing of maintenance and number of staff required.

(c) Materials such as bearings must be issued by the storekeeper against proper authorisation from the maintenance department.

(d) Maintenance budgets must be prepared and used to determine whether the actual expenses are within estimates.

(e) Equipment records must be maintained. Information from the records will be useful when ordering parts or when seeking clarification from the equipment supplier.

(f) Management should give serious thought to certain issues which have bearing on maintenance costs. The questions are:

  (i) How much maintenance is needed?

  (ii) What size maintenance crews should be used?

  (iii) Can maintenance be sub-contracted?

  (iv) Should maintenance staff be covered by wage incentive schemes?

  (v) Can effective use be made of computers for analysing and scheduling activities?

4.4 TRENDS IN MAINTENANCE

Several trends are taking place in the maintenance field. Increasing attention is being paid to the design of buildings, facilities and processes to eliminate as much maintenance as possible. There is greater emphasis on manufacturing system reliability and procurement of equipment with a prescribed level of quality assurance. Maintenance engineers will be using statistical tools to pinpoint problem areas so as to justify the need for equipment replacement periodically. Maintenance staff too need to be upgraded to cope with challenges of complex manufacturing systems.

Special training programmes have sprung up to give maintenance workers the skills necessary to service and repair today's specialised equipment.

Subcontracting services companies have developed to supply specialised maintenance services. Computers, automobiles, office machines, and other products are increasingly serviced by outside subcontracting companies.

Other technologies are developing that promise to reduce the cost of maintenance while improving the performance of production machines. An example is the network of computerised temperature sensing probes connected to key bearings in a machine system. When bearings begin to fail, they overheat and vibrate, causing these sensing systems to indicate that a failure is imminent. The massive damage to machines that can happen when bearings fail - snapped shafts, stripped gears, and so on - can thus be avoided.

Computers have entered the maintenance function in a big way. Five general areas in maintenance commonly use computer assistance today:

1. Scheduling maintenance projects;
2. Maintenance cost reports by production department, cost category and other classifications;
3. Inventory status reports for maintenance part and supplies;
4. Parts failure data; and
5. Operations analysis studies which may include computer simulation, waiting lines, and other analytical programmes.

Information from these uses of computers can provide maintenance staff with necessary failure patterns, cost data, and other details fundamental to the key maintenance decisions.

Computers, robots and high tech-machines cannot replace people in maintenance function. One important trend is the involvement of production workers in repairing their own machines and performing preventive maintenance on their own machines.

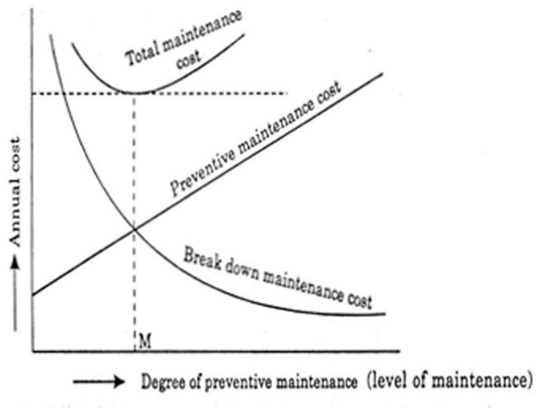
Maintenance today in production management is more than simply maintaining the machines of production. Maintenance function is expected to subserve the overall objectives of the organisation better customer service, higher return on investment, increased product quality, and improved employee welfare.

4.5 ECONOMIES OF MAINTENANCE

Maintenance is a costly activity, it is one of the sizeable indirect costs that enter into manufacturing and hence it should be given considerable attention by operations managers.

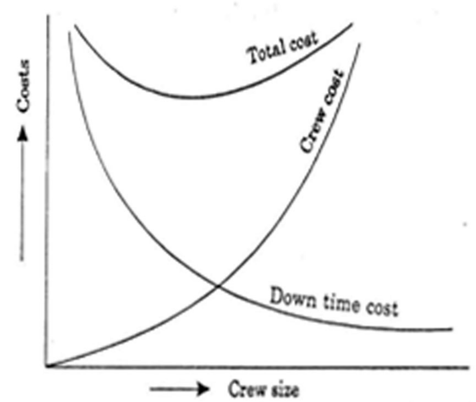
Exhibit 4.1 shows that total cost decreases up to point M under preventive maintenance and beyond this point, an increasingly higher level of preventive maintenance is not economically justified. The level or degree of maintenance at point M, which gives the minimum total maintenance cost is known as the **optimal level of maintenance activity or ideal level of maintenance.** It is seen from line **Exhibit 4.2** that at optimal level of maintenance, the preventive maintenance cost equals the breakdown maintenance cost.

Exhibit 4.1 : Optimal Level of Maintenance



Optimal level of maintenance activity is easily identified theoretically, in practice this necessitates knowing a good deal about the various costs associated with both preventive and breakdown maintenance activities. This includes knowledge of both the probability of breakdown and the amount of repair time needed.

Exhibit 4.2 : Crew Size Costs



Deciding on the size of maintenance crew is a specified application of the concept of minimizing the total of preventive and breakdown maintenance costs. When the crew size is increased the down time costs tend to be decreased but the cost of hiring the maintenance crew increases. Exhibit 18.2 illustrate the relationship between crew size and cost.

The crew costs are part of the overall preventive maintenance cost and the down time costs constitute a part of the breakdown maintenance costs.

The maintenance models described in the next section illustrate how the preventive and breakdown maintenance costs can be estimated and compared in order to minimize the total maintenance costs.

4.6 REQUIREMENTS OF A GOOD PREVENTIVE MAINTENANCE PROGRAM

(i) Good supervision and administration of maintenance department.

(ii) Consultation with production department personnel before fixing priority schedules for maintenance work.

(iii) A good lubrication schedule.

(iv) Clear, correct and detailed instruction to maintenance crew regarding maintenance work.

(v) Keeping proper records of maintenance, service manuals, maintenance hand book etc.

(vi) Adequate stock of spare parts recommended by equipment manufacturers.

(vii) Proper training for maintenance crew.

(viii) Adequate space around the machine for ease of maintenance work.

(ix) Data regarding failure of machines and the corrective maintenance work carried out earlier.

(x) A systematic approach to maintenance i.e., problem —> cause —> diagnosis —> rectification.

Procedure for Preventive Maintenance Programme

Preventive maintenance procedures are based on information about the following aspects:

(i) What is to be maintained?

(ii) How it is to be maintained?

(iii) Maintenance job specification.

(iv) Maintenance schedule (weekly or monthly).

(v) Machine history record.

(vi) Preventive maintenance inspection reports.

(vii) Maintenance requests from production personnel.

Exhibit 4.3 illustrates a step-by-step procedure involved in a preventive maintenance programme.

Steps in Preventive Maintenance Programme

(i) Job identification or preparing facility register : A facility register defines what is to be maintained. It gives a list of plant, equipments and machinery and other facilities which are to be brought under the purview of preventive maintenance.

(ii) Preparation of preventive maintenance schedule : A maintenance schedule indicates ! the method, time and place of carrying out maintenance work, it gives information about maintenance crew available and the time phasing of maintenance loading on maintenance crew.

(iii) Preparation of history card : Machine history card gives complete record of all repairs, replacement and engineering changes carried out on equipment or machinery during its service period. It also gives frequency of occurrence of break downs, rate of wear of different components, total machine or equipment down time due to failure and repair.

(iv) Preparation of job specification : Job specification is a document which provides useful information about the maintenance work to be done. They are prepared for each maintenance job and serve as guide for maintenance crew.

(v) Preparation of preventive maintenance program : It is a list which indicates allocation of specific maintenance work to a specific period.

(vi) Preparation of preventive maintenance schedule (weekly or monthly): According to the importance of machines/equipments, their maintenance frequency is decided and the weekly or monthly maintenance schedule is prepared.

The maintenance programme includes the following :

(a) Reconditioning or replacing of worn out parts or tools.

(b) Repairing or replacing worn out parts or tools.

(c) Checking all electrical connection of the machine or equipment.

(d) Checking the performance of each part of the machine or equipment.

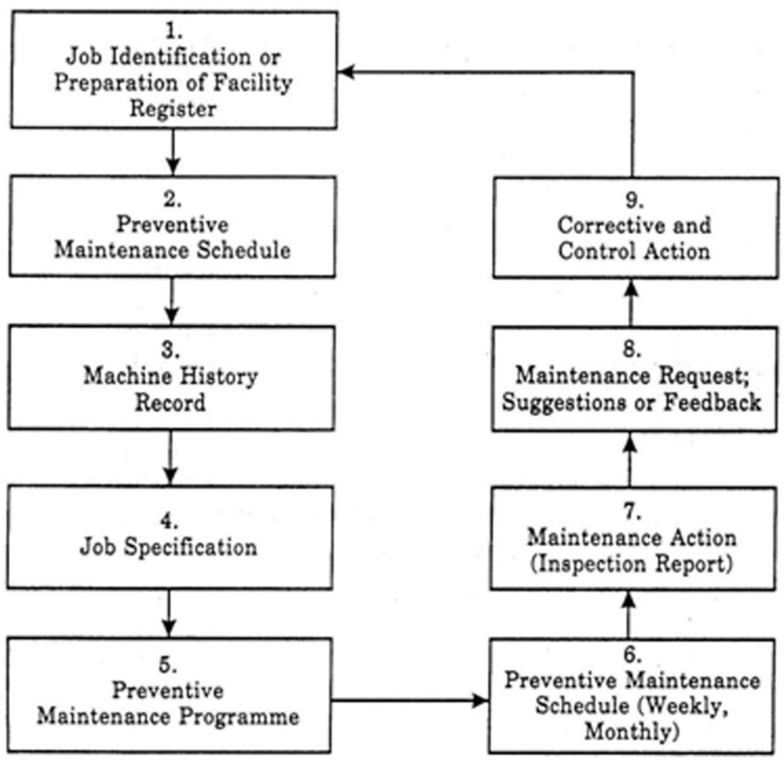
(e) Cleaning of interior parts such as gear box, radiator etc., of transport and material handling equipments.

(f) Checking of control systems.

(g) Complete overhauling.

(vii) Preparation of inspection report: The inspection staff periodically inspects the machines and equipments as per inspection schedule and submit a report regarding their finding to the maintenance foreman for necessary action.

Exhibit 4.3 : Procedure for Preventive Maintenance



(viii) Preparation of maintenance report : It is a document which indicates the various suggestions and recommendations given by inspection report. It includes feed back from operators also regarding the condition of the equipments or machines.

(ix) Feed back mechanism : This is the last step in which the corrective and control actions are applied as and when required on the basis of feed back information. This corrective action forms the basis for designing and improving the maintenance program for the future.

Elements of Preventive Maintenance

(i) An inventory of all plant and equipment.

(ii) A classification of equipment and machinery as very important (Class A), Essential (Class B) Important (Class C) and not important (Class D) machines to determine their relative importance and priority for preventive maintenance sequence.

(iii) A well designed inspection system.

(iv) A good lubrication system which includes regular cleaning of equipment and machines, putting grease or lubricating oil as per the recommendations given in maintenance manuals.

(v) Maintenance of records of maintenance work carried in the past.

(vi) Planning of maintenance work.

(vii) Controlling of maintenance stores and spare parts inventory.

(viii) Organisation (inspectors and maintenance crew) for preventive maintenance programme.

(ix) Replacement of worn-out-parts and other parts showing signs of failure, before the machine or equipment actually breaks down.

(x) Provision of stand-by machines for critical equipment.

Advantages of Preventive Maintenance

(i) Increase in life of machines and equipments by reduction of wear and tear.

(ii) Reduction in frequency of breakdowns.

(iii) Improvement in productivity due to lesser machine down-time and consequent loss of production.

(iv) High reliability of production system due to lesser breakdown and repairs.

(v) Higher worker safety while using the plant and equipment.

(vi) Planned shutdowns and start-ups of plant and equipment possible.

(vii) Lesser requirement of stand-by machines due to lesser breakdowns,

(viii) Minimum work-in-progress inventory due to reduced production hold ups due to equipment breakdowns.

(ix) Lesser rejection and better quality control.

(x) Less serious consequences of breakdowns and lesser breakdown maintenance costs.

Limitations of Preventive Maintenance

(i) More expensive in the short term and during the initial stages of introduction of preventive maintenance programme.

(ii) Inspection of plant, equipment and machinery will have to be carefully planned and implemented and improved over a period of time.

Planned Maintenance Programme

A planned maintenance programme has the following phases:

Phase I :

(a) Preparation of a list of all machines and equipments with codes for identification.

(b) Collection of all relevant information about each and every machine or equipment on a machine history card or equipment record card. The informations include manufacturer's name, specification, purchase date, installation data, service life expected, physical dimensions, operational specifications, recommended spare parts and services required.

(c) Classification of machines as critical, sub-critical and non-critical machines.

(d) Preparation of lubrication schedules and standards.

(e) Preparation of inspection schedule for all machines and equipments.

(f) Design of recording and paperwork procedure for proper communication and to maintain record for future use.

Phase II :

(a) Development of maintenance organisation specifying various line and staff functions.

(b) Determination of manpower requirements on the basis of estimated work load of maintenance work.

(c) Communication and explanation of maintenance plan to all concerned.

Phase III :

(a) Modification of the programme based on experience gained.

(b) Striking proper balance between preventive and break down maintenance.

Phase IV:

(a) Development of maintenance standard time based on synthetic time standards using built up time standard for maintenance activities.

(b) Deciding replacement policy for replacing spare parts and replacing machines.

(c) Use of modern techniques such as replacement theory, PERT and method study.

Maintenance Effectiveness: The effectiveness of maintenance can be evaluated in terms of maintenance costs incurred, equipment down time etc. Several indices used for measuring maintenance effectiveness are computed based on information relating to cost of maintenance, available machine hours, and down time, number of breakdowns, labour hours spent on both breakdown and preventive maintenance etc.

These indices are :

(i) Maintenance cost index (as a percentage) = $\dfrac{\text{(Annual Maintenance Cost)}}{\text{(Cost of Production)}} \times 100$

(ii) Frequency of break downs = $\dfrac{\text{(Number of break downs per week)}}{\text{(Available machine hours per week)}}$

(iii) Down time index (as a percentage)= $\dfrac{\text{(Down time per week)}}{\text{(Available machine hours per week)}} \times 100$

Available machine hours = (Weekly working days) × Hours per day× Number of machines

(iv) Break-down Maintenance index (as a percentage)

$$= \frac{\text{(Labour hour spent on break-down maintenance)}}{\text{(Labour hours spent on all forms of maintenance)}} \times 100$$

(v) Labour cost of planned maintenance index (as a percentage)

$$= \frac{\text{(Labour hour spent on planned maintenance)}}{\text{(Labour hours spent on all maintenance)}} \times 100$$

(vi) Equipment availability = $\dfrac{\text{(Operating time)}}{\text{(Operating time + Maintenance time)}}$

4.7 TOTAL PRODUCTIVE MAINTENANCE

Total Productive Maintenance (TPM) is an approach which brings the concept of total quality management in the practice of preventive maintenance. It involves the concept of reducing variability through employee involvement and excellent maintenance records.

Total productive maintenance is a method designed to eliminate the losses caused by breakdown of machines and equipments by identifying and attacking all causes of equipment breakdowns and system down-time. It places a high value on teamwork, consensus building and continuous improvement.

Specific actions of TPM require the following :

(i) restoring equipment to a like-new condition,

(ii) having operators involved in the maintenance of the equipment or machine,

(iii) improving maintenance efficiency and effectiveness,

(iv) training the labour force to improve their job skills,

(v) the effective use of preventive and predictive maintenance technology.

TPM aims at "Zero breakdown" or "Zero down time". The philosophy of TPM is that if equipment is in good condition and producing what it is designed to produce, most problems then arise only from human error. In such cases, the firms should aim to employ equipment that is easy to use correctly but difficult to use incorrectly under this approach, TPM focuses on improving the reliability of the complete manufacturing.

Total productive maintenance approach has the potential of providing almost a seamless integration of production and maintenance through development of strong partnership between production personnel and maintenance personnel. Work culture oriented towards excellence, presence of effective work teams and a basic maintenance management system functioning well will enhance and accelerate TPM implementation.

Total in "Total Production Maintenance" means :

(i) Total employee involvement,

(ii) Total equipment effectiveness (i.e., Zero breakdown) and

(iii) Total maintenance delivery system.

The crux of TPM is that production equipment operators share the preventive maintenance efforts, assist maintenance mechanics with repairs when equipments breakdown and they work together on equipment and process improvements in team activities.

Guiding Principles of TPM Programs

(i) Maximise equipment effectiveness by reducing down time to zero.

(ii) Establish a thorough system of preventive maintenance for entire life span of equipment from design and acquisition to disposal.

(iii) Implement maintenance program in all organizational areas such as engineering, operation, facility management and maintenance, to spread TPM through the system.

(iv) Involve every single member of the organisation from top managers to workers on the shop floor.

(v) Assign responsibility for preventive maintenance to small, autonomous groups of employees rather than managers.

TPM is a comprehensive system of equipment maintenance that encompasses all activities with any influence on equipment up time (i.e., working time). These activities are :

(i) Regulating basic conditions : TPM advocates keeping a well organised shop floor which should be very clean.

(ii) Adhering to proper operating procedures : The most significant cause of failure is operators deviating from procedures and introduce errors and variance into the process.

(iii) Restoring deterioration : TPM requires diligent efforts to discover and predict deterioration in equipment and then follow standard repair methods to eliminate any source of variation in the system.

(iv) Improving weaknesses in design : TPM tries to identify and correct any defects in equipment designs that contribute to break-downs or complicate maintenance.

(v) Improving operation and maintenance skills : Equipment users (i.e., workers) contribute to TPM by learning and following correct operating procedures to prevent errors and correct any problems on the first attempt. TPM enhances the skill of both users and maintenance workers through education and training.

Through these activities TPM attacks, variances and waste created by breakdowns by preventing problem and eliminating causes of defects.

Total productive maintenance is also known as total preventive maintenance which includes three main elements :

(i) Regular preventive maintenance including house-keeping,

(ii) Periodic pre-failure replacement or overhauls, and

(iii) Intolerance for breakdowns or unsafe conditions.

A comprehensive TPM program includes the following activities:

(i) TPM aims to change the corporate culture in order to maximise the overall effectiveness of production systems.

(ii) It establishes a sound system to prevent all kinds of wastes or losses (i.e., by Zero accidents, Zero defects, Zero breakdowns or Zero down time) based on equipment and workplace.

(iii) TPM involves participation of all departments.

(iv) TPM involves every employee from top management to workers on the shop floor.

Illustration 1:

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)× 300days

= 60×300 = ₹ 18,000

Illustration 2:

In a simulated operation, a firm's maintenance crew received requests for service and provided service during an 8 hour period as shown below :

Request arrival (clock) time	Service time (hours)
0.00	1.5
1.00	0.5
3.30	2.0
4.00	0.5
7.00	1.0

The maintenance labour cost is ₹ 140 per hour and the delay time cost is ₹ 450 per hour.

(a) Find the idle time cost for the maintenance crew.

(b) Find the delay time cost for the machinery.

Solution :

Request arival time (clock time)	Repair time for one crew		Repair time begins-ends (clock time)		Machine down time		
	hours	mines.			Waiting time	Repair time	Total time
00.00	1.50	90	00.00	01.30	Nil	1.5	1.5
01.00	0.50	30	01.30	02.00	0.5	0,5	1.0
03.30	2.00	120	03.30	05.30	Nil	2.0	2.0
04.00	0.50	30	05.30	06.00	1.5	0.5	2.0
07.00	1.00	60	07.00	08.00	Nil	1.0	1.0
Total	5.50 hrs.				2.0	5.5	7.5

Idle time for the maintenance crew = 8–5.5 = 2.5 hrs.

Idle time cost for maintenance crew = 2.5 × 140 = ₹ 350

Delay time or waiting time = 2.0 hours

Delay time cost for the machinery = 2.0 × 450 = ₹ 900

Illustration 3:

The number of breakdowns of equipment over the past 2 years is as below :

No. of breakdowns	No. of month this occurred
0	3
1	7
2	9
3	3
4	2
Total	24

Each break down costs an average of ₹ 300. Preventive maintenance service can be hired at a cost of ₹ 150 per month and it will limit the breakdowns to an average of one per month. Which maintenance arrangement is preferable, the current breakdown maintenance policy or a preventive maintenance service contract?

Solution :

Step 1 : Calculation of probability distribution of break downs :

No. of breakdown (x)	Frequency in month f(x)	Probability of breakdown P(x)
0	3	3/24 = 0.125
1	7	7/24 = 0.292
2	9	9/24 = 0.375
3	3	3/24 = 0.125
4	2	2/24 = 0.083
Total	24	1.000

Step 2 ; Calculation of expected value of breakdowns :

Probability of breakdowns P(x)	No. of breakdowns (x)	Expected value of breakdowns x.P(x)
0.125	0	0
0.292	1	0.292
0.375	2	0.750
0.125	3	0.375
0.083	4	0.332
Total		1.749 = 1.75

Step 3 : Calculating of breakdown cost :

Expected breakdown cost = (1.75 break-downs per month) × (cost per break-down)
= 1.75 x 300
= ₹ 525 per month

Step 4 : Cost of preventive maintenance service contract per month

= ₹150 + ₹300 (i.e., cost of one breakdown per month) = ₹450

Savings due to preventive maintenance service contract = ₹525 - ₹450 = ₹75 per month

Since there is a saving of ₹75 per month by entering into preventive maintenance service contract, it is preferable to go for preventive maintenance service contract.

Illustration 4:

Request for maintenance service made upon a centralised maintenance facility have been simulated for a typical 8 hour shift with arrival and service pattern as shown below:

Request arrival (clock) time	Repair service time
1:30	60 mins.
2:00	20 mins.
4:15	45 mins.
4:30	120 mins.
5.30	30 mins.
7:00	10 mins.

The labour charges of maintenance crew is ₹40 per hour whether working or idle. The waiting time of operators and machinery that has broken-down is costed at ₹70 per hour.

(a) Find the idle time cost of the maintenance facility.

(b) Find the waiting time cost of operators and machinery (not including repair time).

(c) Find the total facility idle time and machinery waiting time cost.

(d) Assuming that for an additional cost of ₹10 per hour the maintenance centre could add another crew and decrease the repair time by one third, would the additional cost be justified?

Solution :

Calculation of machine down time :

Request Arrival time	Repair time reqd. with one crew (mins)	Repair time begins (clock time)	Repair time ends (clock time)	M/c down time with one crew Idle time + Repair time = Total time
01:30	60	01:30	02:30	Nil + 1.0 = 1.00
02:00	20	02:30	02:50	0.5 + 0.33 = 0.83
04:15	45	04:15	05:00	Nil + 0.75 = 0.75
04:30	120	05:00	07:00	0.5 + 2.0 = 2.50
05:30	30	07:00	07:30	1.5 + 0.5 = 2.00
07:00	10	07:30	07:40	0.5 + 0.166 = 0.666
				Total (Hrs.) = 3.00 + 4.746 = 7.746 = 7.75 Hrs.

(a) Calculation of the idle time cost of maintenance facility :

Total repair service time = (60 + 20 + 45 + 120 + 30 + 10) mins.

= 285 mins. = 4.75 hrs.

Total idle time of maintenance facility = 8.00 - 4.75 = 3.25 hrs.

Total idle time cost of maintenance facility = 3.25 x 40 = ₹130

(b) Calculation of waiting time of operators:

Total waiting time for repair = 3.0 hrs

Waiting time cost = 3.0 × 70 = ₹210

(c) Calculation of total facility idle time and machinery waiting time cost:

Total idle time cost of maintenance facility + Machinery waiting time cost =130+210 = ₹ 340

(d) Adding one more maintenance crew at a cost of ₹10 per hour decreases repair time by one third.

Increase in labour cost/ shift of 8 hours = ₹10×8 = ₹80

Decrease in repair time = 1/3 of repair time with one crew

Saving in operator and machine time = $\frac{1}{3} \times 4.75 = 1.582$ hrs.

Idle time cost = 1.582 × 70 = ₹110.74

Since savings in operator and machinery idle time cost is (i.e., ₹110.74) more than the increase in repair cost (i.e. ₹80), it is justified to have one more maintenance crew.

4.8 OBSOLESCENCE & REPLACEMENT

In any establishment, sooner or later all equipment needs to be replaced. A replacement is called for whenever new equipment offers more efficient or economical service than the old, existing one. For example, the old equipment might fail and work no more, or is worn out and needs higher expenditure on its maintenance. The problem, in such situations, is to determine the best policy to be adopted with respect to replacement of the equipment. The replacement theory provides answer to this question in terms of optimal replacement period.

In our analysis, we shall consider the question of replacement in the following situations:

(a) In respect of equipment/assets that deteriorate in performance over a time and may be restored in whole or in part by expending maintenance costs. Thus, the existing assets might be good technically, yet on economic considerations, it may not be worthwhile continuing with them and hence replacement may be called for. Machinery, equipment, buildings fall in this category.

(b) In respect of units that perform adequately until sudden complete failure. The length of their service until failure varies randomly over some predictable range. Car bulbs, tubes, some electronic components etc. are the items that are considered in this category.

(c) In respect of replacement of staff of an organization which diminishes gradually due to death, retirement, retrenchment and other reasons.

We shall consider the three situations one by one.

(a) Replacement policy for equipment which deteriorates gradually: To determine the optimal replacement period, the period after which an equipment/machine should be appropriately replaced, we proceed in the following manner. Initially, we shall assume that there is no time value of money. That is to say, a rupee received at the end of a period, say 5 years, is regarded as good as a rupee received now.

We know that the cost of a piece of equipment over a given time period, say n years, has three elements:

Purchase price - Value remaining after n years + Maintenance cost for n years

Let C = the purchase price of the equipment, S = the scrap value of the equipment at the end of n years, and

M_t = the maintenance cost of the equipment in year t.

The total cost, T(n), of owning and maintaining the equipment for n years shall be

$$T(n) = C - S + \sum_{t=1}^{n} M_t$$

Correspondingly, the average cost, A(n), would be defined as,

$$A(n) = \frac{1}{n}\left[C - S + \sum_{t=1}^{n} M_t\right]$$

In such a case, the optimal replacement period would be the one corresponding to which A(n) would be the minimum. To find A(n), we shall, first of all, determine the maintenance costs accumulated to the n^{th} year. To this, the cost of equipment, net of its salvage value, would be added. The two would then be aggregated to get the total cost, T(n), and then the total cost divided by n, the number of years, would give the average cost.

Illustration 5:

A firm is using a machine whose purchase price is ₹ 13,000. The installation charges amount to ₹ 3,600 and the machine has a scrap value of only ₹ 1,600 because the firm has a monopoly of this type of work. The maintenance cost in various years is given in the following table.

Year	1	2	3	4	5	6	7	8	9
Cost (₹)	250	750	1,000	1,500	2,100	2,900	4,000	4,800	6,000

The firm wants to determine after how many years should the machine be replaced on economic considerations, assuming that the machine replacement can be done only at the year ends.

Solution:

Cost of machine, (C) = ₹13,000 + ₹3,600 = ₹16,600

Scrap value, (S) = ₹1,600

We can determine the optimal replacement period as in the Table below:

Table: Determination of Optimal Replacement Period

Year	Maintenance Cost, M_t	Cum. Main. Cost, $\sum M_t$	Depreciation C-S	Total cost T(n)	A(n)
(i)	(ii)	(iii)	(iv)	(v) = (iii) + (iv)	(vi) = (v)/n
1	250	250	15,000	15,250	15,250
2	750	1,000	15,000	16,000	8,000
3	1,000	2,000	15,000	17,000	5,667
4	1,500	3,500	15,000	18,500	4,625
5	2,100	5,600	15,000	20,600	4,120
6	2,900	8,500	15,000	23,500	3,917*
7	4,000	12,500	15,000	27,500	3,929
8	4,800	17,300	15,000	32,300	4,038
9	6,000	23,300	15,000	38,300	4,256

Here the lowest average cost, A(n), is ₹ 3,917 approximately, which corresponds to n = 6. In the above Table, it is indicated by an asterisk mark,(*). Therefore, the machine may best be replaced every 6 years.

In this and other examples, we implicitly assume that a machine is to be used to do a job that has to be done forever and we are concerned with doing the job as cheaply as possible (and not with whether the job should be done or not). In other words, in replacement analysis, we do not view machine or equipment as a capital investment decision*. Because when we consider it so, we have to look to the profit arising from the product/s the equipment produces and not merely the costs involved.

Illustration 6:

The Simple Engineering Company has a machine whose purchase price is ₹80,000. The expected maintenance costs and resale price in different years are as given here:

Year	1	2	3	4	5	6	7
Maintenance Cost ₹	1,000	1,200	1,600	2,400	3,000	3,900	5,000
Resale Value ('000 ₹)	75	72	70	65	58	50	45

After what time interval, in your opinion, should the machine be replaced?

Solution:

Here Cost of machine (c) = ₹80,000

The optimal replacement period determination is shown in Table below:

Table: Determination of Optimal Replacement Period

Year	Maintenance Cost, M_t	Cum. Main. Cost, $\sum M_t$	Resale Value (1000) (s)	C-S	T(n)	A(n)
(i)	(ii)	(iii)		(iv)	(v) = (iii) + (iv)	(vi) = (v)/n
1	1,000	1,000	75,000	5,000	6,000	6,000
2	1,200	2,200	72,000	8,000	10,200	5,100
3	1,600	3,800	70,000	10,000	13,800	4,600*
4	2,400	6,200	68,000	15,000	21,200	5,300
5	3,000	9,200	58,000	22,000	31,200	6,240
6	3,900	13,100	50,000	30,000	43,100	7,183
7	5,000	18,100	45,000	35,000	53,100	7,586

Here minimum A(n) = ₹ 4,600, for n = 3 (shown by *mark). The machine should, therefore, be replaced every three years.

Illustration 7:

(a) A machine M_1, costing ₹9,000 has a maintenance cost of ₹200 in the first year of its operation which rises by ₹2,000 in each of the successive years. Assuming that the machine replacement can be done only at the end of a year, determine the best age at which the machine be replaced.

(b) There is an offer to replace the machine M_1 which is a year old, by another machine M_2 which costs ₹8,000. The machine M_2 needs ₹2,000 to be spent on installation, has no salvage value, and requires ₹400 on maintenance in the first year followed by an increase of ₹800 per annum in the yearly expenditure on maintenance. Should the machine M_1 be replaced by machine M_2? If so, when?

Solution:

The calculation of optimal replacement period is shown in Table below:

Table: Determination of Optimal Replacement Period for M_1

Year	Maintenance Cost, M_t	Cum. Maint. Cost, $\sum M_t$	C-S	T(n)	A(n)
1	200	200	9,000	9,200	9,200
2	2,200	2,400	9,000	11,400	5,700
3	4,200	6,600	9,000	15,600	5,200*
4	6,200	12,000	9,000	21,800	5,450
5	8,200	21,000	9,000	30,000	6,000
6	10,200	31,200	9,000	40,200	6,700
7	12,200	43,400	9,000	52,400	7,485
8	14,200	57,600	9,000	66,600	8,325

Thus, optimal replacement period = 3 years.

(b) To determine as to whether M_1 should be replaced by M_2, we shall obtain the least average cost, A(n), value. If it is found to be smaller than ₹5,200 (for M_1) we shall replace, otherwise not. Its calculation is shown in Table below.

Table: Determination of Minimum Average Cost for M_2

Year	Maintenance Cost, M_t	Cum. Maint. Cost, $\sum M_t$	C-S	T(n)	A(n)
1	400	400	10,000	10,400	10,400
2	1,200	1,600	10,000	11,600	5,800
3	2,000	3,600	10,000	13,600	4,533
4	2,800	6,400	10,000	16,400	4,100
5	3,600	10,000	10,000	20,000	4,000*
6	4,400	14,400	10,000	24,400	4,067
7	5,200	19,600	10,000	29,600	4,229

Since the minimum average cost for M_2 is lower than that for M_1 the machine should be replaced.

To decide the time of replacement, we should compare the minimum average cost for M_2 (₹4,000) with yearly cost of maintaining and using the machine M_1. Since there is no salvage value of the machine, we shall consider only the maintenance cost. We would keep the machine M_1 so long as the yearly maintenance cost is lower than ₹4,000 and replace when it exceeds the 4,000 mark.

On the one-year old machine M_1 ₹2,200 would be required to be spent in the next year; while ₹ 4200 would be needed in the year following. Thus, we should keep the machine M_1 for one more year and replace it thereafter.

When time value of money is considered: In the problems discussed so far, we have assumed that there is no time value of money. When we drop this assumption, we have to discount the future payments on maintenance costs (and receipts possible due to salvage value) so as to express them all in terms of present value.

Now, if the rate of interest be r, then the present value of a rupee paid at the end of one year would be $1/(1 + r)$, paid at the end of two years would be $1/(1 + r)^2$ . . . and so on.* The present value of one rupee paid at the end of 1, 2, . . . , n years is called the present value factor (PV factor, in short) or discount factor in respect of 1, 2, . . . , n years. The table of present value factors from which values for different combinations of time periods and interest rates may be read off directly. Any payments made at different times be converted into their present worth by multiplying them by appropriate PV factors.

To consider the problem of replacement when time value of money is taken into consideration, we shall assume that (i) the equipment in question has no salvage value, and (ii) the maintenance costs are incurred in the beginning of the different time periods (which we shall take to be years). Working under these assumptions, we first determine the annualized cost, or the weighted average of costs, for different years of the life of the equipment. This is done as follows:

Step 1 Find the present value of the maintenance cost for each of the years, by multiplying the cost value by an appropriate present value factor (based on the given rate of discount and the time).

*We have the compound interest formula to determine the amount A, which a present amount P would become after n periods when the rate of interest is r, as $A = P(1 + r)^n$. With A = 1, the present value P equal $1/(1 + r)^n$.

Step 2 Accumulate present values obtained in *step 1* upto each of the years 1, 2, 3, ... Add the cost of the equipment to each of these values.

Step 3 Accumulate present value factors upto each of the years 1, 2, 3…..

Step 4 Divide the cost plus cumulative maintenance costs for each year, obtained in step 2, by the corresponding cumulative present value factors in *Step 3*. This gives the annualized costs for the various years. It may be noted that the annualized cost is also the weighted average of costs—the PV factors serve as weights here and the average is calculated, as in the usual way, by dividing the summation of the products of the costs and their respective weights by the summation of the weights.

Once the weighted average of costs for different years is obtained, the following rules are followed to decide on the replacement:

(a) Do not replace if the next period's cost is less than the weighted average of the previous costs, and

(b) Replace if the next period's cost is greater than the weighted average of the previous costs.

In operational terms, the criterion for optimal replacement is: replace every n years where A_n, the annualized cost of replacing every n years (that is, the weighted average of costs for n years) is the minimum.

Illustration 8:

A machine X costs ₹5,000. Its maintenance cost is ₹1,000 in each of the first four years and then it increases by ₹200 every year. Assuming that the machine has no salvage value and the maintenance cost is incurred in the beginning of each year, determine the optimal replacement time for the machine assuming that the time value of money is 10% p.a.

Solution:

The given information about the costs is contained in the second column of the Table below. The present value factors corresponding to the 10% interest rate, for various years are given in the third column. The fourth column represents the present value of each year's maintenance cost, which is computed by applying the discount factor to the maintenance cost. In the fifth column of the table is presented the present value of the ₹5,000 purchase price plus the cumulative maintenance cost (at present value) to the end of each year. The cumulative sums of present value factors of the third column are given in the sixth column while the seventh column represents the annualized costs obtained by dividing fifth column values by the corresponding column values.

Table: Determination of Optimal Replacement Period

Year	Maint. Cost, M_t	P V Factor	P Value of M_t	Cost Plus Cum. M_t	Cum. P V Factor	Annualized Cost
1	1,000	1.0000	1,000.0	6,000.0	1.0000	6,000
2	1,000	0.9091	909.1	6,909. 1	1.9091	3,619
3	1,000	0.8264	826.4	7,735.5	2.7355	2,828
4	1,000	0.7513	751.3	8,486.8	3.4868	2,434
5	1,200	0.6830	819.6	9,306.4	4.1698	2,232
6	1,400	0.6209	869.2	10,175.6	4.7907	2,124
7	1,600	0.5645	903.2	11,078.8	5.3552	2,069
8	1,800	0.5132	923.8	12,002.6	5.8684	2,045
9	2,000	0.4665	933.0	12,935.6	6.3349	2,042*
10	2,200	0.4241	933.0	13,868.6	6.7590	2,052
11	2,400	0.3855	925.2	14,793.8	7.1445	2,071
12	2,600	0.3505	911.3	15,705.1	7.4950	2,095

In the table, we compare the second column, wherein values are constantly increasing, with the last column, where values first decrease and then increase. Looking to this we should decide to replace the machine in the latest year that the seventh column value exceeds the corresponding second column value. Here, the year 9 is the last because in the year next to it, the maintenance cost of ₹2,200 exceeds the value of ₹2,052 in the seventh column. It is the year in which the annualized cost is the least. Thus, optimal replacement interval for the machine is 9 years.

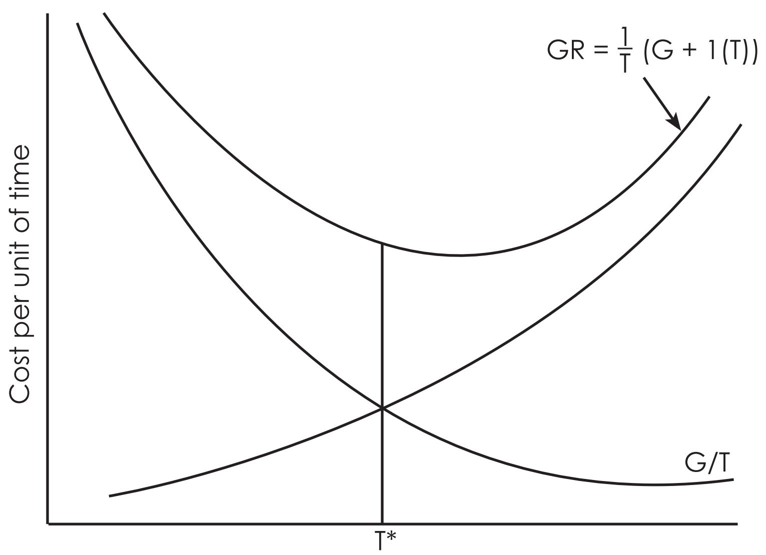
Notes:

1. In the analysis, we have assumed that the equipment in question has no salvage value. We can drop this assumption to incorporate into analysis the salvage value that an equipment might have. For this purpose, the given salvage value at the end of a particular year is translated into present value terms by applying an appropriate discount factor (keeping in mind that for a given year, the maintenance cost is assumed to be incurred in the beginning of the year while the salvage value represents the asset value at the end of the year, so that the same discount rate should not be applied to both of them). This value is then subtracted from the cost of the equipment and the difference added to the cumulative maintenance costs upto the year in question.
2. A second assumption made in this analysis is that the costs are incurred in the beginning of each year. If the costs are incurred during the year instead, they may be discounted to the start of the year. If we could assume that the costs are incurred continuously over the year, then discounting can be done using integral calculus. A more reasonable assumption for most problems of the type considered, sufficient accuracy may be achieved if we assume that the expenditure takes place half way through the year. If j be the rate of interest per half year, and r is the rate per annum, then one rupee invested for six months would become (1 +*j*) rupees and if this amount is invested for a second six-month period, the total at the end of the year would be $(1 + j)^2$ rupees. Thus $1 + r = (1 + j)^2$ or $1 + j = \sqrt{1+r}$. Thus, one rupee due in six months would have a present value of $1/\sqrt{1+r}$.
3. As mentioned earlier also, an implicit assumption in our analysis is that the equipment/machine concerned is to be used for ever. If the equipment is required for a certain fixed time period, then the formulation needs to be modified.

(b) Replacement of items that fail suddenly Now we shall consider the question of determining optimal policy for replacing items used in large numbers which do not deteriorate gradually but fail all of a sudden. They may not involve any maintenance cost, but fail without warning. Light bulbs and fluorescent tubes are examples of this type. It may, however, be observed that although the failure of a single unit, a bulb for instance, is random, the behaviour of the group as a whole is expected to be fairly stable.

Generally, in such situations, the replacement of individual units, upon their failure, costs relatively high, whereas if the entire group is replaced, the unit cost works out to be comparatively a much lower value. Thus, we might be inclined to replace the whole lot at certain intervals together with the individual replacements as and when needed. If the group replacement is done at short intervals, the cost per period shall be high. As the time interval between group replacements increases, the cost of group replacement per period declines. But, the cost of individual replacements increases because of larger number of replacements needed. Thus, the total cost starts declining upto a certain point when the time interval increases, and then it starts rising where the individual replacement component of the cost exerts a greater influence on the cost. Our problem is to determine this optimal interval of time. **Figure 4.1** portrays these ideas.

GR represents the sum of the cost of group replacement per unit of time (G/T) and the cost of individual replacement of items which fail during the replacement interval (also per unit of time) and, hence, equal to



Group replacement interval

Fig. 4.1: Determination of Optimal Replacement Interval

I (T/T). In the figure, the optimal group replacement interval is determined as T*, corresponding to the lowest point on the GR curve.

(c) Staff replacement As mentioned earlier, the staff of an organisation calls for replacements because people leave the organisation for several reasons. For planning a suitable recruitment policy, historical data are collected to estimate the likely stay of individuals with the organisation through time. Here also, the stay of an individual employee may be a random variable but the characteristics of the group of employees are likely to be fairly stable. We use this fact for the purpose at hand.

Illsutration 9:

A company plans to have a strength of 80 sales persons over time. The people employed by the company leave their job, the distribution of which is assumed to be as follows:

Year	1	2	3	4	5	6	7	8	9	10	11	12
% Expected to Leave by End of Period	5	18	35	45	62	75	88	90	95	96	99	100

Using this information, answer the following questions :

What recruitment level per annum would be necessary to maintain this strength?

Solution:

With an intake of 100 sales people every year, the distribution of the length of service of the sales-force, when equilibrium has been reached, shall be as follows:

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	Total
Number of People Continuing	100	95	82	65	55	38	25	12	10	5	4	1	0	492

Recruitment of 100 sales people every year would thus give a total strength of 492. To maintain a strength of 80 sales people, we need to recruit 80 × 100/492 = 16.26 persons per year.

Limitations: The assumption in the models relating to the replacement of depreciable assets that the future costs and resale prices of an equipment are predictable is quite unrealistic. In practice, they are likely to be random variables calling for probabilistic approach to the analysis. Similarly, the assumption that the historical costs in respect of an equipment requiring replacement are appropriate estimates of the costs for the equipment by which it is sought to be replaced may not hold. Besides, the maintenance costs do not always follow a smooth pattern over time. Very often, they are incurred in discrete lumps caused by such things as, for example, installing a new gearbox in a van, or overhauling and reconditioning the body of a truck. In such cases, the best policy might be to decide whether to scrap the vehicles (or other equipment) or undertake the major repair work and use it further.

In respect of the group replacement decisions in case of items that fail suddenly, a practical objection is that all the items are replaced (when group replacement takes place) whether they are working (or not)—even if they are the ones that were installed only recently. Further, a common limitation of both the replacement situations discussed is another assumption that the replacements could be carried out only at certain fixed time—at the year-ends or week-ends, for example. In reality, the replacement can be, and is, done at any point during a given time.

Illustration 10:

The data on the operating costs per year and resale prices of equipment A whose purchase price is ₹10,000 are given here:

Year	1	2	3	4	5	6	7
Operating Cost (₹)	1,500	1,900	2,300	2,900	3,600	4,500	5,500
Resale Value (₹)	5,000	2,500	1,250	600	400	400	400

(a) What is the optimum period for replacement?

(b) When equipment A is 2 years old, equipment B, which is a new model for the same usage, is available. The optimum period for replacement is 4 years with an average cost of ₹3,600. Should we change equipment A with that of B? If so, when?

Solution:

(a) The Purchase Price(c) : ₹10,000

The determination of the optimal period of replacement of equipment A is given in Table below.

Table: Determination of Optimal Replacement Period

Year	M_t	Cum M_t	Resale value (₹) (s)	C-S	T(n)	A(n)
1	1,500	1,500	5,000	5,000	6,500	6,500,0
2	1,900	3,400	2,500	7,500	10,900	5,450.0
3	2,300	5,700	1,250	8,750	14,450	4,816.7
4	2,900	8,600	600	9,400	18,000	4,500.0
5	3,600	12,200	400	9,600	21,800	4,360.0*
6	4,500	16,700	400	9,600	26,300	4,383.3
7	5,500	22,200	400	9,600	31,800	4,542.9

Since the average cost corresponding to the 5-yearly period is the least, the optimal period for replacement = 5 years.

(b) As the minimum average cost for equipment B is smaller than that for equipment A, it is prudent to change the equipment. To decide the time of change, we would determine the cost of keeping the equipment in its 3rd, 4th and 5th year of life and compare each of these values with ₹3,600 (the average cost for equipment B). The equipment A shall be held as long as the marginal cost of holding it would be smaller than the minimum average cost for equipment B. The calculations are given here:

Year	Operating Cost	Depreciation	Total Cost
3	2,300	1,250 (= 2500 - 1250)	3,550
4	2,900	650 (= 1250 - 600)	3,550
5	3,600	200 (= 600 - 400)	3,800

Since the cost incurred in keeping the equipment A in the third and the fourth years is less than the average cost for equipment B, the replacement should be done after 2 years.

Illustration 11:

The Mini Transport Company owns three mini buses, two of which are two years old while the third one is only a year old. Each of these buses was purchased for ₹80,000. The company contemplates replacing the three buses by two full-sized buses, each such bus containing 50% more seating capacity than a mini bus. Cost of each is ₹1,20,000. Using the following data on the running costs and the resale value of both the types of buses, state whether the mini buses be replaced by the full-sized buses. If not, state why? If yes, state when?

Year	For a Mini Bus		For a Full-sized Bus	
	Running Cost	Resale Value	Running Cost	Resale Value
1	3,000	70,000	3,400	1,00000
2	3,600	61,000	3,900	92,000
3	4,800	55,000	4,700	86,000
4	5,000	49,000	5,800	81,000
5	8,000	32,000	7,200	76,000
6	11,200	20,000	9,000	66,000
7	15,000	10,000	12,000	54,000
8	20,000	5,000	16,000	40,000

Solution:

We shall first calculate the minimum average cost for each type of the buses. This is given in Tables below.

For Mini Bus: Cost of the Minibus (c) = ₹80,000

Table: Determination of Average Cost

Year	M_t	Cum M_t	Resale Value (₹)	C-S	T(n)	A(n)
1	3,000	3,000	70,000	10,000	13,000	13,000
2	3,600	6,600	61,000	19,000	25,600	12,800
3	4,800	11,400	55,000	25,000	36,400	12,133
4	5,000	16,400	49,000	31,000	47,400	11,850*
5	8,000	24,400	32,000	48,000	72,400	14,480
6	11,200	35,600	20,000	60,000	95,600	15,933
7	15,000	50,600	10,000	70,000	1,20,600	17,229
8	20,000	70,600	5,000	75,000	1,45,600	18,200

For Full Sized Bus

Cost of full Sized buses (c) = ₹1,20,000

Table: Determination of Average Cost

Year	M_t	Cum. M_t	C-S	T(n)	A(n)
1	3,400	3,400	20,000	23,400	23,400
2	3,900	7,300	28,000	35,300	17,650
3	4,700	12,000	34,000	46,000	15,333
4	5,800	17,800	39,000	56,800	14,200
5	7,200	25,000	44,000	69,000	13,800*
6	9,000	34,000	54,000	88,000	14,667
7	12,000	46,000	66,000	1,12,000	16,000
8	16,000	62,000	80,000	1,42,000	17,750

Thus, the minimum average cost for a mini bus is ₹11,850 p.a. and ₹13,800 p.a. for a full-sized bus. However, these two should not be compared directly because three mini buses are equivalent to two full-sized buses. Thus,

average cost for all 3 mini buses = 11,850 × 3 = 35,550

average cost for 2 large buses = 13,800 × 2 = 27,600.

Clearly, then, it is prudent to replace the mini buses by the full-sized buses.

To decide the timing at which the replacement be done, we shall first find the total yearly costs for the new buses. The year in which the average cost of the new buses shall be lower than the total cost of maintaining and running the old ones shall be the year when the replacement should be done. The calculations are given in Table below.

Table : Determination of Yearly Cost of a Mini Bus

Year	Running Cost	Depreciation	Total Cost
1	3,000	10,000	13,000
2	3,600	9,000	12,600
3	4,800	6,000	10,800
4	5,000	6,000	11,000
5	8,000	17,000	25,000
6	11,200	12,000	23,200
7	15,000	10,000	25,000
8	20,000	5,000	25,000

Total cost for next year would be: 2 × 10,800 + 12,600 = ₹34,200 (since two of the buses would be running in the third year and the third one in the second year). Total cost for the subsequent years shall be:

2 × 11,000 + 10,800 = ₹32,800

2 × 25,000 + 11,000 = ₹61,000 etc.

Since the total average cost of running the two buses is ₹27,600 whereas in the years to come the cost of owning and running the old buses would be greater than this, the conclusion is that the buses should be replaced immediately.

Illustration 12:

A firm has a machine whose purchase price is ₹20,000. Its maintenance cost and resale price at the end of different years are as given here:

Year	1	2	3	4	5	6
Maintenance Cost	1,500	1,700	2,000	2,500	3,500	5,500
Resale Price	17,000	15,300	14,000	12,000	8,000	3,000

(a) Obtain the economic life of the machine and the minimum average cost.

(b) The firm has obtained a contract to supply the goods produced by the machine, for a period of 5 years from now. After this time period, the firm does not intend to use the machine. If the firm has a machine of this type that is one year old, what replacement policy should it adopt if it intends to replace the machine not more than once?

Solution:

(a) Here Cost of the Machine(c) = (₹) 20,000

The calculation of average cost is shown in Table below.

Table : Determination of Optimal Replacement Interval

Year	M_t	Cum. M_t	Resale Price (₹)	C-S	T(n)	A(n)
1	1,500	1,500	17,000	3,000	4,500	4,500
2	1,700	3,200	15,300	4,700	7,900	3,950
3	2,000	5,200	14,000	6,000	11,200	3,733*
4	2,500	7,700	12,000	8,000	15,700	3,925
5	3,500	11,200	8,000	12,000	23,200	4,640
6	5,500	16,700	3,000	17,000	33,700	5,617

Since the minimum average cost, ₹3,733, corresponds to year 3, the economic life of the machine is 3 years.

(b) To consider the situation regarding the one-year old machine, we shall first obtain the yearly cost of keeping this machine in second, third year of its life. This is given in Table below.

Table : Determination of Yearly Costs for Existing Machine

Year	Maintenance Cost	Depreciation	Total Cost	Cum. Total Cost
1	1,700 [17,000-15,300]	1,700	3,400	3,400
2	2,000 [15,300-14,000]	1,300	3,300	6,700
3	2,500 [14,000-12,000]	2,000	4,500	11,200
4	3,500 [12,000-8,000]	4,000	7,500	18,700
5	5,500 [8000 - 3000]	5,000	10,500	29,200

Alternate policies and the costs associated with each one are as follows:

Policy 1 : Keep old machine for the zero year and buy a new one for full 5 years.

Total cost = 0 + 23,200 = ₹23,200

Policy 2 : Keep old machine for 1 year and buy a new one for 4 years

Total cost = 3,400 + 15,700 = ₹19,100

Policy 3 : Keep old machine for 2 years and buy a new one for 3 years

Total cost = 6,700+ 11,200 = ₹17,900

Policy 4 : Keep old machine for 3 years and buy a new one for 2 years

Total cost = 11,200 + 7,900 = ₹19,100

Policy 5 : Keep old machine for 4 years and buy a new one tor 1 year

Total cost = 18,700 + 4,500 = ₹23,200

Policy 6 : Keep old machine for 5 years and don't buy a new one

Total cost = 29,200 + 0 = ₹29,200

Therefore policy 3 is the optimal policy.

Illustration 13:

Consider Illustration 8 again. Suppose that there is another machine Y which costs ₹8,000. It requires maintenance cost equal to ₹200 in the first year, which increases by ₹400 in each succeeding year. Assuming that other conditions are same, determine the optimal replacement time for machine y. If a choice is to be made between X and Y, which one would be preferred?

The determination of the replacement period is shown in Table below.

Table : Determination of Optimal Replacement Period

Year	M_t	P V Factor	P Vof M_t	(Cum. P V of M_t) + Cost	Cum. P V Factor	Average
1	200	1.0000	200.0	8,200	1.0000	8,200
2	600	0.9091	545.5	8,745.5	1.9091	4,581
3	1,000	0.8264	826.4	9,571.9	2.7355	3,499
4	1,400	0.7513	1,051.8	10,623.7	3.4868	3,047
5	1,800	0.6830	1,229.4	11,853.1	4.1698	2,843
6	2,200	0.6209	1,366.0	13,219.1	4.7907	2,759
7	2,600	0.5645	1,467.7	14,686.8	5.3552	2,743*
8	3,000	0.5132	1,539.6	16,226.4	5.8684	2,765
9	3,400	0.4665	1,586.1	17,812.5	6.3349	2,812

Optimal replacement interval for the machine, therefore, is 7 years.

Since minimum average cost for X (= 2,042) is less than the corresponding cost for Y(= 2,743), machine x' would be preferable to machine Y.

4.9 FAILURE

The phenomenon of breakdown or failure is very important in Maintenance Management. A vital information in this regard relates to Failure Statistics. An important statistic is the relative frequency of failure or probability density of failure with respect to the age of the item in question. It has been observed that there are three prominent kinds of failure probability distribution:

(a) Normal Distribution

(b) Negative exponential Distribution

(c) Hyper-exponential Distribution

Most wear-out phenomena show Normal Failure Behaviour, the items failing at some mean operating age, with some failing sooner and some later. Some items fail, not because they wear out, but due to overload or defect in the system external to them; e.g., an electrical fuse. The failure rate, here, is not age-specific; it is constant. The Negative Exponential distribution fits well in this case. For many equipments the probability density of failure is much higher during the initial 'teething' periods than during their subsequent life. Hyper-exponential distribution fits these types of failure behaviours.

The above information on failure behaviour will be of much help in planning various maintenance actions. The following problems illustrate this fact.

Illustration 14:

Automobile wheel assembly bearings exhibit times of failure which are normally distributed with a mean of 25,000 km run. The times of failure have a dispersion which has a standard deviation of 3,000 km. If a transport company has 90 automobiles, how many of them could be expected to have the problem of bearing failure

(i) by 20,000 km?

(ii) between 20,000 and 35,000 km?

Each automobile has 4 such bearings.

Solution:

(i) $Z = \dfrac{\chi - \mu}{\sigma}$

Here μ = 25,000 km; σ = 3,000 km and χ = 20,000 km

Therefore $Z = \dfrac{20{,}000 - 25{,}000}{3{,}000} = -1.667$

From the Standard Normal Distribution table, we have:

Area = 0.4522

So, the desired area = 0.5000 - 0.4522 = 0.0478

Therefore, 0.0478 x 90 x 4 = 17.2 bearings may be expected to fail by 20,000 km.

(ii) Between 20,000 and 35,000 km can be translated in Z values as follows.

$$Z_1 = \frac{20{,}000 - 25{,}000}{3{,}000} = -1.667$$

$$Z_2 = \frac{35{,}000 - 25{,}000}{3{,}000} = +3.333$$

Referring to the Standard Normal table:

Area between 20,000 and 35,000 km

= (Area between 20,000 and 25,000) + (Area between 25,000 and 35,000)

= (0.4522) + (0.4988) = 0.9510

Therefore, the number of bearings expected to fail in this range = (0.9510) (90 × 4) = 342.36

Illustration 15:

The sprinklers used for irrigating a farm generally go bad because the soil sediments in water get stuck in the system. Kartar Singh has studied the past data of failure of these sprinklers and has come up with the findings as per Table given below.

Failure Data on Sprinklers

	1st	2nd	3rd	4th	5th	6th	7th	8th	9th
Time to Failure*	Week	Week	Week	Week	Week	Week	Week	Week	Week
Number of failures	50	30	18	11	7	4	3	2	1

*(Note: Sprinklers are repaired and installed to be as good as new)

(a) The mode of failure?

(b) The average time to failure?

(c) The mean rate of failure?

Solution:

(a) It has already been hinted that the failure of the sprinklers is due to causes external to the sprinkler; which means we would expect a negative exponential failure mode. We can verify this by arranging the failure data as follows: First, we note that the data pertain to (50 + 30 + 18 + 11 + 7 + 4 + 3 + 2 + 1) = 126 cases.

Re-arrangement of Sprinkler Data

Time Period Week No.	No. Failing at the end of the Period*	No. Surviving until the end of the Time Period	Ratio of the No. Failing out of the No. that had Survived until the end of the Period
1	50	126	50/126 = 0.3968
2	30	(126 - 50) = 76	30/76 = 0.3947
3	18	(76 - 30) = 46	18/46 = 0.3913
4	11	(46 - 18) = 28	11/28 = 0.3929
5	7	(28 - 11) = 17	7/17 = 0.4118
6	4	(17 - 7) = 10	4/10 = 0.4000
7	3	(10 - 4) = 6	3/6 = 0.5000
8	2	(6 - 3) = 3	2/3 = 0.6667
9	1	(3-2 =) = 1	1/1 = 1.0000
	126		

*(Note: Here all failures are taken as occurring only at the end of a time period; i.e., no failures occur in between).

The 'ratio' in the-last column in Table is the Age Specific Failure Rate, Z(t}. The Z(t) values are constant until Period 7, the last three values showing end effects due to limitations in the collection of data in terms of:

(i) small number of periods as against theoretical infinite number of periods and

(ii) sizable span of time-periods as against the theoretical time spans, which are very small.

Since the Z(t) values are constant, ignoring the end effects, the failures seem to follow a negative exponential mode with an average rate of failure of about 0.4000.

(b) The average time to failure can be computed as per table given below.

Life in Weeks	Fraction Having this Life
1	50/126
2	30/126
3	18/126
4	11/126
5	7/126
6	4/126
7	3/126
8	2/126
9	1/126

Therefore, average time to failure or mean time to failure (MTTF)

$$=\left(1\times\frac{50}{126}\right)+\left(2\times\frac{30}{126}\right)+\left(3\times\frac{18}{126}\right)+\left(4\times\frac{11}{126}\right)+\left(5\times\frac{7}{126}\right)+\left(6\times\frac{4}{126}\right)+\left(7\times\frac{3}{126}\right)+\left(8\times\frac{2}{126}\right)+\left(9\times\frac{1}{126}\right)$$

= 2.484 weeks

(c) Therefore, mean rate of failure

$$=\frac{1}{\text{mean time to failure}}$$

$$=\frac{1}{2.484}=0.4025 \text{ failure per week}$$

4.10 PREVENTIVE REPLACEMENT

Preventive replacement of parts and equipments at a certain periodicity, before they fail is many a time a prudent policy as the costs of replacement/repair following a breakdown of the components or equipment, outweigh that of preventive replacement. Thus, a cost comparison between preventive replacement and breakdown replacement/repair would many a time favour the choice of the former. The following examples illustrate such comparisons and consequent decisions. Breakdown repair/ replacement is generally more costly as (a) breakdowns occur randomly and suddenly thus injecting an element of chaos and (b) a breakdown or failure of one component may lead to breakdowns or extra-wear of other components thus complicating or accentuating the situation. However, it should be noted that there are factors such as human safety which should also be kept in view while making a decision in such cases although such factors are usually non-quantifiable.

Illustration 16:

The breakdown probability of an equipment is given below:

Month	Probability
1	0.05
2	0.15
3	0.30
4	0.30
5	0.20

There are 50 such equipments in the plant. The cost of individual preventive replacement is ₹15 per equipment and the cost of individual breakdown replacement is ₹30 per equipment. Which is the most suitable maintenance policy in this case?

Solution:

In comparing the two maintenance policies, we should compare the expected cost per month of the policies (or expected cost per some other unit of time).

Individual Breakdown Replacement Policy

The average number of individual breakdown replacements per month are:

$$\frac{\text{Number of equipments in the plant}}{\text{Average life of an equipment}}$$

Average (Mean) life of an equipment, i.e., the mean operating time before failure

= (1 × 0.05) + (2 × 0.15) + (3 × 0.30) + (4 × 0.30)+(5 × 0.20) = 3.45 months

This is obtained easily from the given data. The average number of individual breakdown replacements per month

$$\frac{\text{No. of equipments}}{\text{mean life of an equipment}} = \frac{50}{3.45} = 14.49$$

Therefore, per month cost of individual breakdown maintenance

Individual Preventive Replacement Policy

The description of a preventive replacement policy is complete only when it also includes the periodicity of the replacement. Thus, in the given problem we could consider various periodicities – such as replacement every one, two or three, or four months. Each of these constitutes a different case of the individual preventive replacement.

Case I: Replacement Period = 1 month

The total cost per unit replacement comprises two components: (a) the possibility that the equipment may fail before its replacement age, needing a breakdown replacement and (b) the possibility that the equipment may not fail till its replacement age.

Cost component (a) = (0.05) × (₹ 30) = ₹1.50

Cost component (b) = (0.95) × (₹ 15) = ₹14.25

Total cost of replacement per equipment = ₹15.75

Now, $$\text{Cost per month} = \frac{\text{Total cost of replacement for all the equipments in the plant}}{\text{Expected life of an equipment}}$$

The expected life of an equipment, under preventive replacement period of one month is one month only, as the first breakdown coincides with the preventive replacement.

Thus $$\text{Cost per month} = \frac{(₹\,15.75) \times (50)}{1} = ₹\,787.50$$

Case II: Preventive Replacement Period = 2 months

Cost component (a) = (0.05 + 0.15) × (₹30) = ₹6.00

Cost component (b) = (0.80) × (₹15) = ₹12.00

Total cost of replacement per equipment = ₹18.00

Expected life of an equipment = (1 × 0.05) + (2 × 0.95) = 1.95 months

$$\text{cost per month} = \frac{(₹\,18.00) \times (50)}{1.95} = ₹461.54$$

Case III: Preventive Replacement Period - 3 months

Cost component (a) = (0.05 + 0.15 + 0.30) × (₹ 0) = ₹15.00

Cost component (b) = (0.50) × (₹15) = ₹7.50

Total cost of replacement per equipment = ₹22.50

Expected life of an equipment = (1 × 0.05) + (2 × 0.15) + (3 × 0.80) = 2.75 months

Therefore, $\text{cost per month} = \dfrac{(₹\ 22.50) \times (50)}{2.75} = ₹\ 409.09$

Case IV: Preventive Replacement Period = 4 months

Cost Component (a) = (0.05 + 0.15 + 0.30 + 0.30) x (₹30) = ₹24.00

Cost Component (b) = (0.20) x (₹15) = ₹3.00

Total cost of replacement per equipment = ₹27.00

Expected life of an equipment, in this case

= (1 × 0.05) + (2 × 0.15) + (3 × 0.30) + (4 × 0.50)

= 3.25 months

$\text{Total cost per month} = \dfrac{(₹\ 27.00) \times (50)}{3.25} = ₹\ 415.38$

The costs (per month) of the different policies are presented in the table below:

Cost Comparisons of Different Maintenance Policies

Policy	Cost per Month, ₹
Individual Breakdown Maintenance	434.70
Individual Preventive Maintenance	
I every 1 month	787.50
II every 2 months	461.54
III every 3 months	409.09
IV every 4 months	415.38

Therefore, individual preventive replacement every three months is the best option.

4.11 PLANNING AND CONTROL OF SPARE PARTS

Spare parts constitute significant portion of inventory investment and therefore, their planning and control are important. Spare parts are required for maintenance: preventive and breakdown. Since preventive maintenance is basically a planned activity, the requirement of spare parts for preventive maintenance can be easily computed along with the plan/ schedule for preventive maintenance. For example, if we decide on a preventive group replacement of a set of 10 items every three months, then we need 40 spares during the year for such preventive replacement.

However, no amount of preventive maintenance can completely eliminate failures necessitating breakdown maintenance. Spare parts are required for this purpose also. Therefore the planning for a spare part item requires that, based on the failure pattern we compute the number of spares to be stocked, having decided on the availability or service-level for that spare-part item.

Failure statistics are useful in the calculation of both, (a) the spares for preventive maintenance and (b) the spares for breakdown maintenance. However, the latter is uncertain or stochastic and, therefore, requires the use of the concept of service level or the down time/ understocking cost.

For stocking policy analysis, the spares may be classified as follows:

- Spare Parts
  - Regular Spares
  - Insurance Spares
  - Capital Spares
  - Rotable Spares

Regular Spares

(Also called as Maintenance spares and Breakdown spares)

These are required regularly and so, in substantial numbers. Both the reliability and the per unit cost of these items are not very high. The service level as mentioned in the earlier chapter on inventories, is given:

$$\text{Service level } = \frac{Ku}{Ku + Ko}$$

where Ku = opportunity cost of understock of one unit, and

Ko = opportunity cost of overstock of one unit.

The breakdown rates occur either according to a Normal distribution (wear-out of the parts) or according to a Poisson distribution (system overloads). The mean and variance characteristics of it are known through the past experience. Thus, having decided/computed the service level, it is easy to compute the regular stock required (based on the mean) and the buffer stock required based on the service level and variance (or standard deviation).

Insurance Spares

Spares of this class have a very high reliability and are required rarely, if ever, during the life time of an equipment besides being a high cost item. Thus, a company or organisation which decides to buy such a spare does so only to keep it for the life time of the equipment. Now if the spare was not expensive the decision is simple: buy a spare along with the equipment. Also if the down-time costs of these spares were low it would be easy to decide in favour of procuring them when, if at all, required. But our insurance spare is also a critical item whose non-availability has a very heavy down-time cost, and hence the question: should the spare be purchased along with the equipment required or not? The answer is: If (Probability of Failure) × (Downtime Cost) ≥ Purchase Price of a Spare the decision should be to buy and keep the spare and vice versa.

Capital Spares

Regular spares and Insurance spares are two ends of the spectrum; Capital spares fall somewhere in between. A few—say five or ten—of these spares are required, over the lifetime of an equipment. These spares are expensive and therefore it would be desirable to keep only as many as would be required from the viewpoint of service level. This decision is guided by the probability that a certain number of them are required over the life of the equipment.

$$\sum_{i=0}^{N^*-1} P_i \leq \frac{C_3 - C}{C_3 - S} \leq \sum_{i=0}^{N^*} P_i$$

Rotable Spares

These are repairable and re-usable spares, such as a jet engine or an electric motor which can be reconditioned after failure and put back in operation. This situation can be visualised in a Multiple Channel Single Service Queueing theory format, where the defective equipments are the arrivals and the spares are the servers. The service times are given by the distribution of time to recondition a spare. The inter-arrival times of the defective items can also be modelled in terms of a probability distribution.

Illustration 17:

Compute the requirement of spares for breakdown maintenance for an item that exhibits a Poissonian behaviour 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.

$$\text{Mean consumption rate, } \lambda = 5 \text{ per month}$$

Referring to the Poisson distribution table for a $\lambda = 5$, we have for

x = 7. ... Cumulative probability = 0.867

x = 8 ... Cumulative probability = 0.932

Thus, with seven items only 86.7 per cent service level is attained; with eight items 93.2 per cent service level is obtained. Since one would err on the higher side of the service level, the value of x = 8 is chosen.

This means, the amount of spares stock that has to be kept must correspond to a maximum demand rate D_{max} of eight during the lead time. In other words we should keep a Buffer Stock = D_{max} - $D_{average}$ during a lead time = 8 - 5 = 3 items.

Thus, buffer stock desired is three numbers of the given spare part.

Illustration 18:

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.

4.12 MAINTENANCE POLICY

There is nothing like a purely preventive maintenance; rather there is always an appropriate mix of the preventive and breakdown maintenance.

Moreover, not all items are amenable to all types of preventive maintenance. If, for instance, an item is showing a time-independent, i.e. a negative exponential failure behaviour, then the cause of the failure is external to the item; therefore, any amount of preventive replacement is not going to serve the intended purpose. Preventive or fixed-time replacement of parts (individually or in a group) is a policy that is appropriate for items that wear out with time due to use, i.e. for items that show a normal failure mode. Moreover, such a policy may be useful only if the costs of preventive action are significantly lower than those of the breakdown maintenance replacement, which means, that the item should preferably be a "simple replaceable" item and not a complex one for replacement action. Of course, preventive replacement is not ruled out for a complex part; the "cost-cum-safety" factors have to be taken into account while deciding on a policy.

However, if the Negative Exponential failure mode shows a low mean time to failure (MTTF), perhaps there is more cause to worry about the design of the item which may not be suited to the operating conditions or vice versa. In either case, the action is external to the usual maintenance action. And, of course, if a breakdown is not costly (cost - monetary-plus-human life or anguish), then it may be worthwhile to let the item be used till it breaks down.

Illustration 19:

A private organisation which provides city transport, has a fleet of 20 buses. The useful life of tyres on these buses followed a probability distribution as given in the table below:

Months to replacement	< 6	12	18	24	30
Cumulative Probability	0.05	0.25	0.60	0.25	1.00

If each bus uses six tyres on it, estimate the number of tyres used by the fleet over a period of two and a half years. It may be assumed that

(a) Reconditioning/retreading of the tyres is not carried out.

(b) All buses are in operation for the entire two and a half year period.

(c) Each bus has to start with six new tyres.

(d) The wearing out of one tyre is independent of the wearing out of the other tyres.

(e) A worn-out tyre is replaced by a new one similar to the previous tyre/s.

Solution:

From the given cumulative probabilities, the probabilities in each time interval can be easily worked out as shown in the following table:

	Time Interval 1	**Time interval 2**	**Time Interval 3**	**Time Interval 4**	**Time Interval 5**
Months to replacement	< 6	12	18	24	30
Cum. Probability	0.05	0.25	0.60	0.85	1.00
Probability	0.05	0.20	0.35	0.25	0.15

Let us call the probabilities in each of the intervals as p_1, p_2, p_3, p_4 and p_5 respectively.

As there are 20 buses with 6 tyres each, we start with 20 × 6 = 120 tyres. By the end of two and a half years (30 months), in addition to the 120 tyre wearouts, we also have the failures of tyres which have been replaced in different time intervals. Thus, for example, the replacements for failures of tyres in the 1st interval come for their own (failure and so) replacements in subsequent periods (2, 3, 4 and 5) and so on.

If 'n' is the number of tyres to start with (we have n = 120), we can formulate the required replacements as follows: No. of replacements required by the end of the total time horizon.

Substituting the values n - 120; p_l = 0.05; p_2 = 0.20; p_3 = 0.35; p_5 = 0.25; and p_s = 0.15 we get the total number of tyres required during the 2V2 years as:

120 + 120 (0.05) × [0.85 + 0.05 (0.60) + (0.05)2 (0.25)
+ (0.05)3 (0.05) + 0.20 (0.25) + 0.20 (0.05)2
+ 0.35 (0.05)]
+ 120 (0.20) [0.60 + 0.05 (0.25) + 0.20 (0.05) + (0.05)3]
+ 120 (0.35) [0.25 + (0.05)2] + 120 (0.25) [0.05]
= 120 + 5.692 + 15.000 + 10.605 + 1.500
= 152.797 (or, rounding off, 153)

Thus, our estimate is 153 tyres.

(Note: It must be stressed again that the problem involved very broad time intervals. This, in itself, constitutes considerable approximation. Also, it is assumed that the tyres replaced during a time period/ interval are taken to be so replaced at the end of that time interval. Therefore, the replacement will come for failure only from the next time interval onwards).

Illustration 20:

Hindustan Electronics tests its product, the colour TV tube, for 2000 hours. A sample of 100 TV tubes was put through this quality test, during which two tubes failed. If the customers use the tube for an average of four hours per day, and if 10,000 TV tubes were sold, then in one year from their selling how many tubes will be expected to fail? What is the Mean Time Between Failures for these TV tubes?

Solution:

The total time of testing

= (100 tubes) × (2000 h) = 2,00,000 tube-hours

However, two tubes have failed and, therefore, the real testing time is less than the total time computed above. The latter has to be adjusted for the number of testing hours lost due to the failures during the testing. These lost hours are: (assuming each of the failed tubes has lasted an average of half of test period)

$$= (2 \text{ tubes}) \times \left(\text{Average of } \frac{2000}{2} \text{ hours for each tube}\right)$$

= 2,000 tube-hours

Therefore, the test shows that there are two failures during (2,00,000 - 2,000) = 1,98,000 tube-hours of testing.

Hence, during 365 days of the year (four hours a day) for 10,000 tubes there are expected failures of:

$$\left(\frac{2}{1,98,000} \begin{array}{c}\text{failures}\\ \text{per}\\ \text{tube} - \text{hour}\end{array}\right) \times (10,000 \text{ tubes}) \times (365 \times 4 \text{ hours})$$

= 147.47 = 148 approximately

$$\text{The mean time between failures} = \frac{1,98,000 \text{ tube-hours of testing}}{2 \text{ failures}}$$

= 99,000 tube-hours per failure

$$= \left(\frac{99{,}000}{(4 \times 365)}\right) \text{tube-years per failure}$$

$$= 67.68 \text{ tube-years per failure}$$

Illustration 21:

The probability of failure of a replaceable item is given below. There are four such similar replaceable items. The maintenance manager is thinking of a group replacement of all the four items when any one of them fails.

The cost of replacing a part individually is ₹100, but the cost of replacing all the four items together is only ₹200.

(a) What is the cost per month of such a group breakdown replacement policy?

(b) How does the cost for the above policy compare with the cost for independent breakdown replacement?

Month	Probability of Failure
1	0.1
2	0.2
3	0.3
4	0.4

Solution:

Let us first consider the Group Replacement policy. Since as per this policy the items are all replaced as soon as one of the items fails, the average life of an item corresponds to average life for first failure.

$$\text{The per month cost (for this policy)} = \frac{₹\ 200}{\text{Average life for first failure}}$$

Average life for first failure = 1 (Probability that the first failure occurs at month 1)
+ 2 (Probability that the first failure occurs at month 2)
+ 3 (Probability that the first failure occurs at month 3)
+ 4 (Probability that the first failure occurs at month 4)

Note that we are making all calculations as though the failures in an interval occur at the end of that time-interval.

Probability of an item surviving up to 1st month = 1 - 0.1 = 0.9

Thus, the probability of all four items surviving up to the (end of) 1st month = $(0.9)^4 = 0.6561$

Therefore, the probability of the first failure occurring at month 1 = 1- 0.6561 = 0.343 We can calculate the other first failure probabilities in a similar manner. The probability of all 4 items surviving up to two months

$= [1 - (0.1 + 0.2)]^4 = (0.7)^4 = 0.2401$

Therefore, the probability of any one item failing either in the 1st month or in the 2nd month is

= 1 - 0.2401 = 0.7599

Therefore, the probability that the first failure occurs in the 2nd month is

= 0.7599 - Prob. of first failure in month 1

= 0.7599 - 0.3439 = 0.4160

Similarly, we have:

the probability that the first failure occurs in 3rd month

$$= [1-\{1- (0.1 + 0.2 + 0.3)\}^4] -[1-\{1- (0.1 + 0.2)\}^4]$$

$$= [1 - (0.4)^4] - [1 - (0.7)^4]$$

$$= 0.9744 - 0.7599$$

$$= 0.2145$$

the probability that the first failure occurs in the 4th month

$$= 1 - 0.9744 = 0.0256$$

Therefore, average life for first failure

$$= 1(0.3439) + 2(0.4160) + 3(0.2145) + 4(0.0256) = 1.9218$$

The per month cost for this policy $= \dfrac{₹200}{1.9218} = ₹104.07$

The per month cost for individual breakdown replacement policy

$$= \frac{₹100 \times 4 \text{ items}}{\text{Average life of item}}$$

Now, Average life of an item = 1(0.1) + 2(0.2) + 3(0.3) + 4(0.4) = 3.0 months

Therefore, the per month cost $= \dfrac{100 \times 4}{3} = ₹\ 133.33$

The group breakdown replacement policy is the better of the two policies.

4.13 QUEUEING THEORY APPLICATIONS IN MAINTENANCE

Some of the problems in the management of maintenance, particularly those pertaining to the determination of the size of the maintenance resources, can be represented in a queueing format. For instance, machines may await (a) repairs by the available maintenance crew or (b) the replacement of the damaged parts by reconditioned spares. Thus, the machine breakdowns are the "arrivals" in the queue and they may have their own frequency distribution. The service times of the maintenance crew for the repairs of the machines, or the servicing times taken for the reconditioning of the reconditionable spares may constitute a particular frequency distribution. From the view-point of policy considerations, some characteristics of the queueing system such as (a) the average waiting time of the failed machines; (b) the average number of machines waiting in the queue, and (c) the utilisation of the repair crew or of the reconditioning facilities would be useful. This information will help the maintenance manager in:

(a) determining cost trade-offs between down-time of machines and the number of maintenance hands or spares,

(b) determining the queue discipline which will improve the breakdown maintenance service, and

(c) appropriately improving preventive maintenance, thereby reducing the breakdown rate, etc.

Many of the problems mentioned above fall into the category of Multiple Channel Single Service queue systems. While some of these are likely to have a large number of 'arrivals' which can be approximated to infinite arrivals, some of the situations represent finite arrivals as the number machines (population) may be small.

Three Queuing Models

Due to limitation of space, we are dealing with only following three models:

1. **Single-**channel or single server queuing model,
2. **Multi-**channel queuing model, and
3. **Erlang's** queuing model.

1st Model : Single- channel queuing model

This model fits in the situations, where following conditions are satisfied:

(i) The number of arrivals per unit of time is described by a Poisson distribution.

(ii) Service times are described by exponential distribution.

(iii) Queue discipline is 'first come, first served' basis.

(iv) There is only one channel.

(v) The calling population is infinite.

(vi) The mean arrival rate is less than the mean service rate, i.e., $\lambda < \mu$ (These, symbols are explained below). It is a very important characteristic.

(vii) The waiting space available for customers in the queue is infinite.

This model makes use of the following symbols:

λ = Mean arrival rate per unit of time (say, an hour).

μ = Mean service rate per unit of time.

Lq = Mean number in the queue.

Ls = Mean number in the system (number, in the queue plus number being served).

Wq = Mean time in queue.

Ws = Mean time in system (time in queue plus service time).

P = Probability the service facility is busy.

ρ(rho) = Utilization factor

E = Constant (Its value should be taken as 2.7184 in calculations).

Following formula will be used under this model:

Important (λ < μ)

1. Probability that service channel is busy (traffic intensity or utilization factor)

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

2. Probability of an empty or idle system :

$$P_0 = 1 - \frac{\lambda}{\mu}$$

Or P_o = 1-ρ where, $\rho = \frac{\lambda}{\mu}$

3. Probability that there are n customers in the system is

$$\left.\begin{aligned} P_n &= \left(\frac{\lambda}{\mu}\right)^n . P_o \\ &= \left(\frac{\lambda}{\mu}\right)^n . \left(1 - \frac{\lambda}{\mu}\right) \end{aligned}\right\} \text{Where } n \geq o$$

4. Probability of queue length (number of customers or units) being greater than or equal to n :

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

5. Probability that there are more than n customers in the system is:

$$P(> n) = \left(\frac{\lambda}{\mu}\right)^{n+1}$$

6. Probability that there are more than n customers in the queue:

$$P(> n+1) = \left(\frac{\lambda}{\mu}\right)^{n+2}$$

7. Probability that the waiting time in a queue is greater than and equal to t is:

$$P(\text{Waiting time in queue} \geq t) = \left(\frac{\lambda}{\mu}\right)e^{-(\mu-\lambda)t}$$

8. Probability that the waiting time in a system is greater than and equal to t is:

$$P(\text{waiting time in system} \geq t) = e^{-(\mu-\lambda)t}$$

Number of Customers

9. Average (expected) number of customers in the system :

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

10. Average (expected) number of customers in the queue :

$$L_q = \frac{\lambda}{\mu}.\ L_s = \frac{\lambda}{\mu}.\left(\frac{\lambda}{\mu-\lambda}\right)$$

11. Average (expected) number of customers in non-empty queue (length of queue that is formed from time to time):

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

Expected (Average) Time

12. Expected (average) time a customer spends in the system :

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

13. Expected (average) waiting time of a customer in the queue:

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

14. Expected (average) waiting time of a customer in non-empty queue (average) waiting time of customer who has to wait):

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

2nd Model: MULTI-CHANNEL MODEL - SINGLE LINE WITH MULTI-SERVICES

3rd Model : POISSON ARRIVALS AND ERLANG SERVICE DISTRIBUTION ($M/E_x/1$):

NOTE: This will be discussed on final course

TYPICAL EXAMPLES

Illustration 22:

A repairman is to be hired by a company to repair machines that breakdown at an average rate of 3/hour. Breakdown occurs randomly (Poisson distribution) over time. Non-productive time on any machine is considered to cost the company ₹10 per hour. The management has narrowed down the choice to 2 repairmen; one 'slow but cheap' and other 'fast but expensive'. The 'slow but cheap' repairman has a rate of ₹5 per hour and he will service breakdown machines at an average rate of 4/hour. The 'fast but expensive' repairman has a rate of ₹7 per hour and he will service breakdown machines at an average rate of 6/hour. Which repairman should the company hire? Assume exponential repair time for both repairmen.

Solution:

	'Slow but cheap' repairman	'Fast but expensive' repairman
μ = rate of service Labour rate	4/ hour ₹5/hour	6/hour ₹7/hour

In the given situation, breakdown rate = λ = 3 machines per hour

(i) For 'slow but cheap' repairman :

Average (expected) number of breakdowns in the system:

$$L_s = \frac{\lambda}{\mu - \lambda} = \frac{3}{4-3} = 3 \text{ machines}$$

Cost of idle machine hours = 3 ×1× ₹10 = ₹30

Total charges = (Wages + Cost of idle machines) per hour

= ₹5 + ₹30 = ₹35

(ii) For 'Fast but Expensive' repairman:

Average (expected) number of breakdowns in the system:

$$L_s = \frac{\lambda}{\mu - \lambda} = \frac{3}{6-3} = 1 \text{ machine}$$

Cost of idle machine hours = 1 × 1 × ₹10 = ₹10

Total charges = (Wages + cost of idle machine) per hour

= ₹7+ ₹10 = ₹17

Decision. When total cost of two workmen is taken into consideration, it will be economical to hire 'fast but expensive' repairman.

Illustration 23 :

A large granary receives stocks of food grains delivered in truck loads which arrive randomly at an average rate of 9 per hour. Considerable delays are experienced in the current manual system of unloading and trucks have to be kept idle awaiting unloading and a waiting charge at the rate of ₹60 per hour has to be paid. The granary is considering the installation of a mechanised unloading system and are evaluating three alternatives A, B, C. The operating costs and other data of the systems are given below:

Using the principles of (MM1) queue system and taking into account all relevant costs recommend with justification system of mechanisation to be installed.

Products	A	B	C
Fixed costs (₹ per hour)	100	200	300
Variable costs (₹ per hour)	60	35	15
Unloading rate (Trucks per hour)	12	18	30

Solution:

	Product A (Per hour)	**Product B (per hour)**	**Product C (per hour)**
1. Arrival rate λ =	9	9	9
2. Service rate μ =	12	18	30
3. Traffic intensity or probability that service channel is bus y. $\left(\rho = \frac{\lambda}{\mu}\right)$	0.75	0.50	0.30
4. Probability of nil waiting Or $\rho_o = 1 - \frac{\lambda}{\mu} = 1 - \rho$	0.25	0.50	0.70
5. Mean Q size or average number of customers in the queue $L_q = \frac{\lambda^2}{\mu(\mu - \lambda)}$	$\frac{81}{12 \times 3}$	$\frac{81}{12 \times 9}$	$\frac{81}{30 \times 21}$
6. Idle time cost @ ₹60			
Cost estimates per hour	=2.25	=0.50	=0.129
Fixed	₹135*	₹30*	₹7.71*
Variable [0.75 × ₹60 = 45; 0.50 × ₹35 = 17.50; 0.30 × ₹15 = ₹4.50]	₹100 45	₹200.00 17.50	₹300.00 -4.50
Idle time (Refer to S.N = 6)	135	30.00	7.71
Total	280	247.50	312.21

Decision: For minimum cost system B should be installed.

*{2.25 × ₹60= 135; 0.50 × ₹60 = ₹30; 0.129 × ₹60 = 7.71 approx.

Illustration 24 :

A duplicating machine maintained for office use is used and operated by people in the office who need to make copies, mostly secretaries. Since the work to be copied varies in length (number of pages of the original) and copies required, the service rate is randomly distributed, but it does approximate a Poisson having a mean service rate of 10 jobs per hour. Generally, the requirements for use are random over the entire 8-hour working day but arrive at a rate of 5 per hour. Several people have noted that a waiting line develops occasionally and have questioned the policy of maintaining only one unit. If the time of a secretary is valued at ₹350 per hour, make an analysis to find:

(i) equipment utilization,

(ii) the percent time that an arrival has to wait, and

(iii) the average system time

(iv) the average cost due to waiting and operating the machine.

Solution:

Here we are given:

λ = 5 jobs per hour

μ = 10 jobs per hour

(i) Equipment utilization $= \rho = \frac{\lambda}{\mu} = \frac{5}{10} = 0.50$

Thus equipment is in use for 50% of the time.

(ii) The probability that arrival has to wait

$$= 1 - \frac{1}{2} = \frac{1}{2}$$

(iii) The average system time:

$$W_s. = \frac{1}{\lambda - \mu} = \frac{1}{10 - 5} = \frac{1}{5} \text{ hr or 12 minutes}$$

(iv) Average cost per day = Average cost per job × No. of jobs processed per

We know that average jobs processed per day = $L_s = \frac{\lambda}{\mu - \lambda}$

$$= \left(\frac{5}{10 - 5}\right) \times 8 \times ₹3.50 = ₹28 \text{ per day.}$$

Illustration 25 :

At Dr. Amit's clinic patients arrive at an average of 6 patients per hour. The clinic is attended to by Dr. Amit himself. Some patients require only the required prescription. Some come for minor checkup while some others require thorough inspection for the diagnosis. This takes the doctor six minutes per patient on an average. It can be assumed that arrivals follow a Poisson Distribution and the Doctor's inspection time follows an exponential distribution. Determine:

(i) The percentage of time that a patient can walk to the doctor without having to wait;

(ii) The average number in the system.

(iii) The average number in the queue.

(iv) The average waiting time/unit in the system.

Solution:

λ = 6 per hour

μ = × 60 = 10 per hour

(i) The probability that a patient can walk to a doctor without waiting or the probability of an empty or idle system :

$$P_O = 1 - \frac{\lambda}{\mu} = 1 - \frac{6}{10} = \frac{4}{10} \text{ or } 40\%$$

(ii) The average number in the system:

$$L_s = \frac{\lambda}{\mu - \lambda} = \frac{6}{10 - 6} = \frac{6}{4} = \frac{3}{2}$$

(iii) The average number in the queue:

$$L_q = \frac{\lambda}{\mu} \times \frac{\lambda}{\mu - \lambda} = \frac{6}{10} \times \frac{3}{2} = \frac{9}{10}$$

(iv) The average waiting time/unit in the system:

$$W_s = \frac{1}{\mu - \lambda} = \frac{1}{10-6} = \frac{1}{4} \text{ hour or 15 minutes.}$$

Cumulative Poisson Distribution Table

Table shows cumulative probability functions of Poisson Distribution with various α. Example: to find the probability $P(X \leq 3)$ where X has α Poisson Distribution with $\alpha = 2$, look in row 4 and column 4 to find $P(X \leq 3) = 0.8571$ where X is Poisson(2).

x	0.5	1	1.5	2	α 2.5	3	3.5	4	4.5	5
0	0.6065	0.3679	0.2231	0.1353	0.0821	0.0498	0.0302	0.0183	0.0111	0.0067
1	0.9098	0.7358	0.5578	0.4060	0.2873	0.1991	0.1359	0.0916	0.0611	0.0404
2	0.9856	0.9197	0.8088	0.6767	0.5438	0.4232	0.3208	0.2381	0.1736	0.1247
3	0.9982	0.9810	0.9344	0.8571	0.7576	0.6472	0.5366	0.4335	0.3423	0.2650
4	0.9998	0.9963	0.9814	0.9473	0.8912	0.8153	0.7254	0.6288	0.5321	0.4405
5	1.0000	0.9994	0.9955	0.9834	0.9580	0.9161	0.8576	0.7851	0.7029	0.6160
6	1.0000	0.9999	0.9991	0.9955	0.9858	0.9665	0.9347	0.8893	0.8311	0.7622
7	1.0000	1.0000	0.9998	0.9989	0.9958	0.9881	0.9733	0.9489	0.9134	0.8666
8	1.0000	1.0000	1.0000	0.9998	0.9989	0.9962	0.9901	0.9786	0.9597	0.9319
9	1.0000	1.0000	1.0000	1.0000	0.9997	0.9989	0.9967	0.9919	0.9829	0.9682
10	1.0000	1.0000	1.0000	1.0000	0.9999	0.9997	0.9990	0.9972	0.9933	0.9863
11	1.0000	1.0000	1.0000	1.0000	1.0000	0.9999	0.9997	0.9991	0.9976	0.9945
12	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9999	0.9997	0.9992	0.9980
13	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9999	0.9997	0.9993
14	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9999	0.9998
15	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9999
16	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

x	5.5	6	6.5	7	α 7.5	8	8.5	9	9.5	10
0	0.0041	0.0025	0.0015	0.0009	0.0006	0.0003	0.0002	0.0001	0.0001	0.0000
1	0.0266	0.0174	0.0113	0.0073	0.0047	0.0030	0.0019	0.0012	0.0008	0.0005
2	0.0884	0.0620	0.0430	0.0296	0.0203	0.0138	0.0093	0.0062	0.0042	0.0028
3	0.2017	0.1512	0.1118	0.0818	0.0591	0.0424	0.0301	0.0212	0.0149	0.0103
4	0.3575	0.2851	0.2237	0.1730	0.1321	0.0996	0.0744	0.0550	0.0403	0.0293
5	0.5289	0.4457	0.3690	0.3007	0.2414	0.1912	0.1496	0.1157	0.0885	0.0671
6	0.6860	0.6063	0.5265	0.4497	0.3782	0.3134	0.2562	0.2068	0.1649	0.1301
7	0.8095	0.7440	0.6728	0.5987	0.5246	0.4530	0.3856	0.3239	0.2687	0.2202
8	0.8944	0.8472	0.7916	0.7291	0.6620	0.5925	0.5231	0.4557	0.3918	0.3328
9	0.9462	0.9161	0.8774	0.8305	0.7764	0.7166	0.6530	0.5874	0.5218	0.4579

x	5.5	6	6.5	7	α 7.5	8	8.5	9	9.5	10
10	0.9747	0.9574	0.9332	0.9015	0.8622	0.8159	0.7634	0.7060	0.6453	0.5830
11	0.9890	0.9799	0.9661	0.9467	0.9208	0.8881	0.8487	0.8030	0.7520	0.6968
12	0.9955	0.9912	0.9840	0.9730	0.9573	0.9362	0.9091	0.8758	0.8364	0.7916
13	0.9983	0.9964	0.9929	0.9872	0.9784	0.9658	0.9486	0.9261	0.8981	0.8645
14	0.9994	0.9986	0.9970	0.9943	0.9897	0.9827	0.9726	0.9585	0.9400	0.9165
15	0.9998	0.9995	0.9988	0.9976	0.9954	0.9918	0.9862	0.9780	0.9665	0.9513
16	0.9999	0.9998	0.9996	0.9990	0.9980	0.9963	0.9934	0.9889	0.9823	0.9730
17	1.0000	0.9999	0.9998	0.9996	0.9992	0.9984	0.9970	0.9947	0.9911	0.9857
18	1.0000	1.0000	0.9999	0.9999	0.9997	0.9993	0.9987	0.9976	0.9957	0.9928
19	1.0000	1.0000	1.0000	1.0000	0.9999	0.9997	0.9995	0.9989	0.9980	0.9965
20	1.0000	1.0000	1.0000	1.0000	1.0000	0.9999	0.9998	0.9996	0.9991	0.9984
21	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9999	0.9998	0.9996	0.9993
22	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9999	0.9999	0.9997
23	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9999	0.9999
24	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

x	10.5	11	11.5	12	α 12.5	13	13.5	14	14.5	15
0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1	0.0003	0.0002	0.0001	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000
2	0.0018	0.0012	0.0008	0.0005	0.0003	0.0002	0.0001	0.0001	0.0001	0.0000
3	0.0071	0.0049	0.0034	0.0023	0.0016	0.0011	0.0007	0.0005	0.0003	0.0002
4	0.0211	0.0151	0.0107	0.0076	0.0053	0.0037	0.0026	0.0018	0.0012	0.0009
5	0.0504	0.0375	0.0277	0.0203	0.0148	0.0107	0.0077	0.0055	0.0039	0.0028
6	0.1016	0.0786	0.0603	0.0458	0.0346	0.0259	0.0193	0.0142	0.0105	0.0076
7	0.1785	0.1432	0.1137	0.0895	0.0698	0.0540	0.0415	0.0316	0.0239	0.0180
8	0.2794	0.2320	0.1906	0.1550	0.1249	0.0998	0.0790	0.0621	0.0484	0.0374
9	0.3971	0.3405	0.2888	0.2424	0.2014	0.1658	0.1353	0.1094	0.0878	0.0699
10	0.5207	0.4599	0.4017	0.3472	0.2971	0.2517	0.2112	0.1757	0.1449	0.1185
11	0.6387	0.5793	0.5198	0.4616	0.4058	0.3532	0.3045	0.2600	0.2201	0.1848
12	0.7420	0.6887	0.6329	0.5760	0.5190	0.4631	0.4093	0.3585	0.3111	0.2676
13	0.8253	0.7813	0.7330	0.6815	0.6278	0.5730	0.5182	0.4644	0.4125	0.3632
14	0.8879	0.8540	0.8153	0.7720	0.7250	0.6751	0.6233	0.5704	0.5176	0.4657

x	10.5	11	11.5	12	α 12.5	13	13.5	14	14.5	15
15	0.9317	0.9074	0.8783	0.8444	0.8060	0.7636	0.7178	0.6694	0.6192	0.5681
16	0.9604	0.9441	0.9236	0.8987	0.8693	0.8355	0.7975	0.7559	0.7112	0.6641
17	0.9781	0.9678	0.9542	0.9370	0.9158	0.8905	0.8609	0.8272	0.7897	0.7489
18	0.9885	0.9823	0.9738	0.9626	0.9481	0.9302	0.9084	0.8826	0.8530	0.8195
19	0.9942	0.9907	0.9857	0.9787	0.9694	0.9573	0.9421	0.9235	0.9012	0.8752
20	0.9972	0.9953	0.9925	0.9884	0.9827	0.9750	0.9649	0.9521	0.9362	0.9170
21	0.9987	0.9977	0.9962	0.9939	0.9906	0.9859	0.9796	0.9712	0.9604	0.9469
22	0.9994	0.9990	0.9982	0.9970	0.9951	0.9924	0.9885	0.9833	0.9763	0.9673
23	0.9998	0.9995	0.9992	0.9985	0.9975	0.9960	0.9938	0.9907	0.9863	0.9805
24	0.9999	0.9998	0.9996	0.9993	0.9988	0.9980	0.9968	0.9950	0.9924	0.9888
25	1.0000	0.9999	0.9998	0.9997	0.9994	0.9990	0.9984	0.9974	0.9959	0.9938
26	1.0000	1.0000	0.9999	0.9999	0.9997	0.9995	0.9992	0.9987	0.9979	0.9967
27	1.0000	1.0000	1.0000	0.9999	0.9999	0.9998	0.9996	0.9994	0.9989	0.9983
28	1.0000	1.0000	1.0000	1.0000	1.0000	0.9999	0.9998	0.9997	0.9995	0.9991
29	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9999	0.9999	0.9998	0.9996
30	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9999	0.9999	0.9998
31	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9999
32	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

Study Note - 5

INFORMATION SYSTEM ANALYSIS AND DESIGN

This Study Note includes

5.1 CONTRIBUTION OF INFORMATION TECHNOLOGY IN THE SOCIAL LIFE AND INDUSTRIAL FIELDS

Information Technology has become the most dynamic area in human life today. In social life, from education, entertainment to economic development programme, everywhere information processing gives direction for plans and programmes. The world has become a global village with the power of communication technology. Physical location is no barrier for communication. Power of computers and communication technology has redefined information technology and has brought a new dimension in its use. A business cannot run with information flow. The visualization of importance of timely information has created new atmosphere for intensive research and development programme for evolving new techniques and tools in the field of information technology. This is why we call that the present age is the age of Information.

We see the marvelous power of computer and it has grabbed all areas of modern life. Its speed, accuracy and storage facility have charmed everybody. The inherent aptitude of man for mathematics felt the need for a machine to calculate the arithmetical figures. With this urge man could develop a device which has brought a new taste of life. Innovations in the use information technology are examples of human brain power. No body can guess the end of it. A small list can only give an amazing dimension - use of robot to control production and quality in the factory, conference among people at different corners in the world through communication, remote control of space craft from Earth Station and so on. Nothing is left on earth which is untouched by IT today. Each and every activity of day–to-day life like to have a golden touch of it. Let us have the glimpses of its small range which are

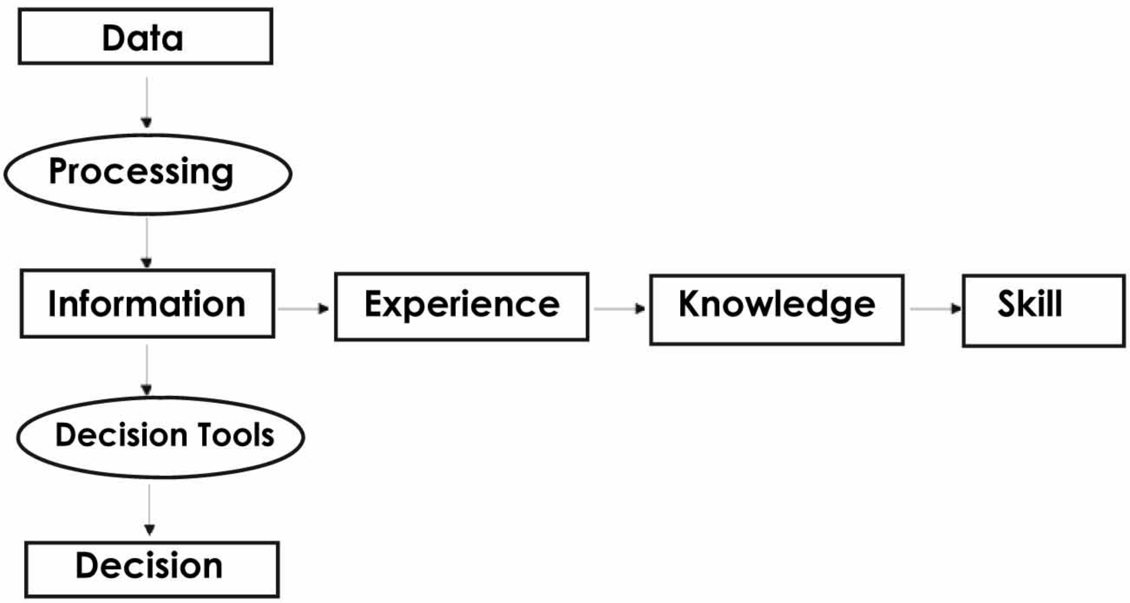
- Education and Training
- Medical science
- Engineering science
- Space research
- Research in bio-technology
- Entertainment etc.

Information is the backbone in a business organization. In today's competition, managing information is the most critical task for survival. Information Technology plays a crucial role in dissemination of information towards controlling business operation. The work of computer has been extended from data processing to on-line Management Information system, Sales information to E-commerce, Decision making to Expert system. The challenges ahead are the fields like:

- Process Control in production management
- Flow of information through internet
- Integration of functional systems with network
- E-Commerce in business
- Knowledge based Expert System in decision making etc.

Information

Information is nothing but refined data. Data before processing is said to be raw data. Raw data are collected, screened and processed to make it organized for effective use. Data after processing become linked with other data and carry meanings and, strictly speaking, to be termed as information. Information is data that has been processed into a form that is meaningful to the user in effective interpretation and decision making. Information involves communication and reception of intelligence. Information consists of data, text, images, voice etc. The term data in normal sense includes all these.



Characteristics of useful Information:

The following are the characteristics of information. These characteristics determine the quality and usefulness of information :

- Timeliness – This parameter is important to increase effectiveness in the use.
- Accuracy – The most important ingredient for quality of information.
- Comprehensive – Information should be integrated one with all other related issues to make it more meaningful.
- Relevance - The need for type of information differs from user to user. Relevant information filtered for a purpose ensures its effective and best use.
- Understandability - The information must be presented in a form that users can interpret the same for decision making.

Characteristics of Information/Attributes of information

The important characteristics of useful and effective information are as follows:

(a) Timeliness: For effective decision-making, decision maker should get the informations in right time. Timeliness refers to when user needs the information. Some information is required on regular, periodic basis - perhaps daily, weekly, monthly or quarterly, while much other information is generated on the request of the manager.

(b) Purpose: Information must have purposes at the time it is transmitted to a person or machine, otherwise, it is simple data. It helps in creating new concepts, identifying problems, solving problems, decision making, planning and controlling.

(c) Mode and Format: The mode of communicating information in business are either visual, verbal or in written form. Some information may also be presented in the form of diagram, graph, curves.

(d) Completeness: The information should be as complete as possible. Incomplete information can result in a wrong decision which may lead to a high cost to the organization. Hence, whenever there is an incomplete information, it should be communicated to the user of the information.

(e) Reliability: Information should be reliable and it must be from the reliable sources.

(f) Cost benefit analysis: The benefits that are derived from the information must justify the cost incurred in procuring information.

(g) Quality: It refers to the correctness of information, hence, proper internal controls and procedures should be developed.

(h) Transparency: If information does not reveal directly what we want to know for decision making, it is not transparent.

Types of Information

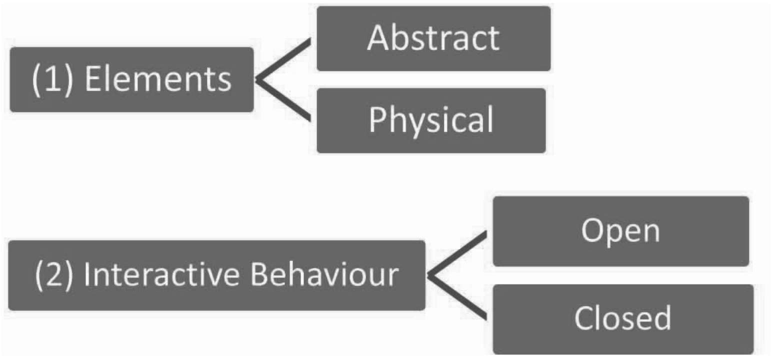
Information, broadly can be divided into two different types: Internal Information and External Information

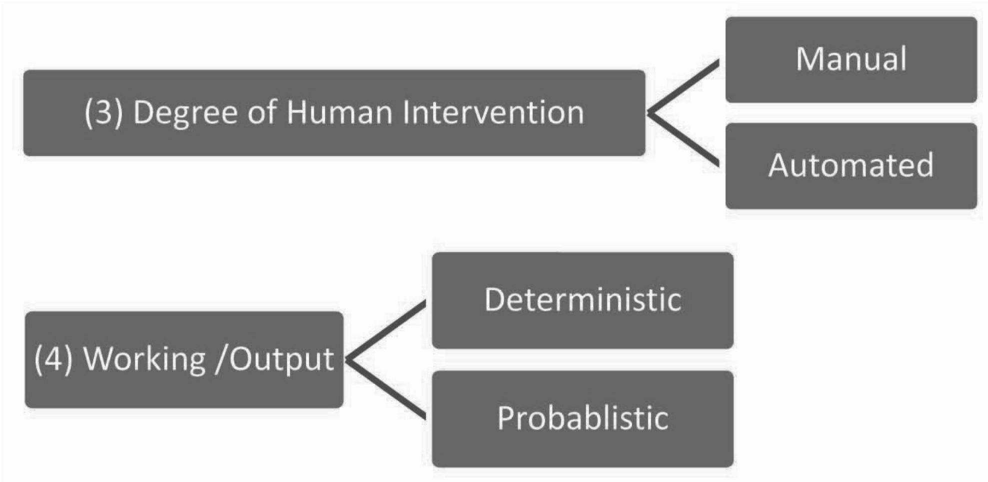
(a) Internal Information: The Internal Information is generated and summarised within the organization. Examples of internal information would be production figures, sales figures, information about personnel, accounts, material etc.

(b) External information: The external information is collected from the external environment of the business organization. For example, Information such as Government, policies, competition, economic status etc.

What is System?

A system is a collection of inter-related and inters deponent elements or components that operate collectively to achieve some common purpose or goal. For example – Human body is a system, consisting of various parts such as head, heart, hands, legs etc and they work well together. A computer based information system is also a system consist of collection of people, hardware, software, data and procedures that interact to provide timely information to authorized people for such decision making and for the other purposes.





Types of System

(1) According to Elements:

Abstract System: Abstract System are Conceptual System which are just an orderly arrangement of interdependent ideas. Ideas here mean just the idea which does not contain any physical place. For example, ideas about God and the relationship of humans to God.

Physical System: A physical system is a collection of tangible elements.

Physical System	**Particulars**
Circulatory System	The heart and blood vessels which move blood through the body.
Transportation System	The personnel, machines, and organizations which transport goods.
Weapons System	The equipment, procedures, and personnel which make it possible to use a weapon.
School System	The buildings, teachers, administrators, and textbooks that function together to provide education to students
Computer System	The buildings, teachers, administrators, and textbooks that function together to provide education to students

The equipment which function, together to accomplish Computer Processing.

(2) According to Interactive Behaviour:

1. Open System
2. Closed System

Differentiate between open and closed systems:

Open Systems: Open systems actively interact with their environment. Such systems regularly get inputs and give outputs to its environment. Open systems are also able to adapt to environmental changes for their survival and growth. Business organization is an example of such system. Marketing System is an open system. The system takes inputs/feedbacks and gives outputs to its environment by way of giving products of the company and also creates new customers.

Closed Systems: A closed system is self contained and does not interact or make exchange across its boundaries with its environment. Closed systems do not get the feedback they need from the external environment and tend to deteriorate eventually. For example, if a marketing system does not get feedback from the market, its efficiency will gradually continue to decrease.

It is not subject to disturbances from its environment. A computer program can be taken as an example of relatively closed system because, it accepts only previously defined inputs, processes them and provides previously defined outputs and it does not change with the change in environment.

Entropy: Entropy is the quantitative measure of disorder in a system. Entropy requires inputs of energy to repair replenish and maintain the system. This maintenance input is termed as Negative Entropy. Open systems require more negative entropy than relatively closed systems for keeping at a steady state.

System	Manifestation of Entropy	Negative Entropy
Automobile	Engine won't start, tyres too thin.	Tune up engine, Replace tires.
Computer Program	User dissatisfaction with features and errors.	Program enhancements.

(3) According to Degree of Human Intervention

Manual Systems: Manual Systems are the systems where data collection, manipulation, maintenance and final reporting are carried out absolutely by human efforts.

Automated Systems: Automated Systems are the systems where computers or microprocessors are used to carry out all the tasks of data collection, manipulation, maintenance and final reporting.

Importance of using computer in business area is as follows:

- It handles huge volume of data that is not manageable by human efforts.
- It stores enormous volume of data for indefinite period.
- It provides quick retrieval of information on query.
- It quickly and efficiently transports data/information to distant places almost at less/no cost.

(4) According to Working/Output:

Deterministic System : A deterministic system operates in a predictable manner wherein the interaction among the parts is known with certainty. An example is a correct computer program, which performs exactly according to a set of instructions.

Probabilistic System: The probabilistic system can be described in terms of probable behavior, but, a certain degree of error is always attached to the prediction. Where a set of instructions given to a human who, for a variety of reasons, may not follow the instructions exactly as given. Forecasting is also a Probabilistic System.

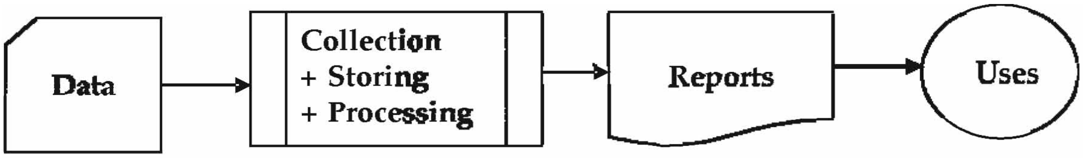
Information System

An Information System is designed by an user according to the business operation involved and the need for his decision making. It is a vehicle which supplies necessary information for decision making. Before computer being used in an business environment, Information System also existed in some form to support management in decision making. Today business environment has become very complex and highly competitive. If an organization has to survive, it has to plan and develop its own Information System. Of course, the size, structure and set up may vary depending upon the need of the organization, policy and capability. In today's business environment computer has become a must for an information system. The information system is to feed the management for control purpose. This is why Information System is generally called as Management Information System (MIS) or Computer Based Information System (CBIS).

Generally, an MIS uses Computer System and Communication technology to collect information from different operational points and disseminate them at different users for decision making. The activities in an Information System are :

- Collection, Storing and Processing Data

- Generation of Information Reports
- Dissemination of Information to Right Users



An MIS provides timely information of right quality for better management decision making for developing business strategy. The advantages of CBIS are :

- Reduction in cost of record maintenance
- Improvement in the efficiency of human resources
- Regular flow of information at different levels of management
- Easy use of scientific tools and models for quality decision making
- Faster response to customers
- Better control over resources
- Faster access to records in case of dispute
- Effective use of manpower etc.

Characteristics of an Information System :

The following are the general characteristics of an Information system :

(i) Specific objective : The information system should have some specific objective. An Information System in highly scientific research centre will have an objective to accumulate data from different activities, display of some information instantly for controlling activities and so on. In a business environment, the objective will be sharing information from different functional areas and smooth flow of information for management decision making.

(ii) Structured : An information system should have a definite structure with all modules of sub-systems. The structure depends on the sub-modules, their interactions and integration requirements, operational procedure to be followed and the solution sets. The structure of the information system refers to diagrammatic representation of the system showing sub-systems, their inter-relation and the procedure to be followed to fulfill the process requirements.

(iii) Components : The sub-systems are the components. The sub-systems should be distinguishable among themselves but have well-defined relation among. For example, a Sales system may be sub-systems like Invoicing, Delivery Monitoring, and Sales Proceeds Collection system. The inter-link between these systems must be well defined.

(iv) Integrated: An Information System should be designed in such a fashion that proper integration among sub-systems are taken care to establish correct linkage and generate meaningful information. An information in isolation may not be that meaningful but its usage is improved if it is integrated with information of other closely related issues. For example, Sales information of a region becomes more meaningful if other information like previous period sales, sales in other regions, sales of competitive products are also combined in the information set.

(v) Life-Cycle: An Information system will have its own life-cycle. The duration of life-cycle varies from the system to system. An information system has the similar stages of life-cycle as seen in any other system. Every information system will have distinctly different phases - Initial, Growth, Maturity and Decline.

(vi) Behaviour: A system has its own set of reaction and outcome depending on the environment. A well managed business information system behaves nicely with its users by satisfying them with correct and timely information. The design of the system plays a good role in setting its behaviour pattern.

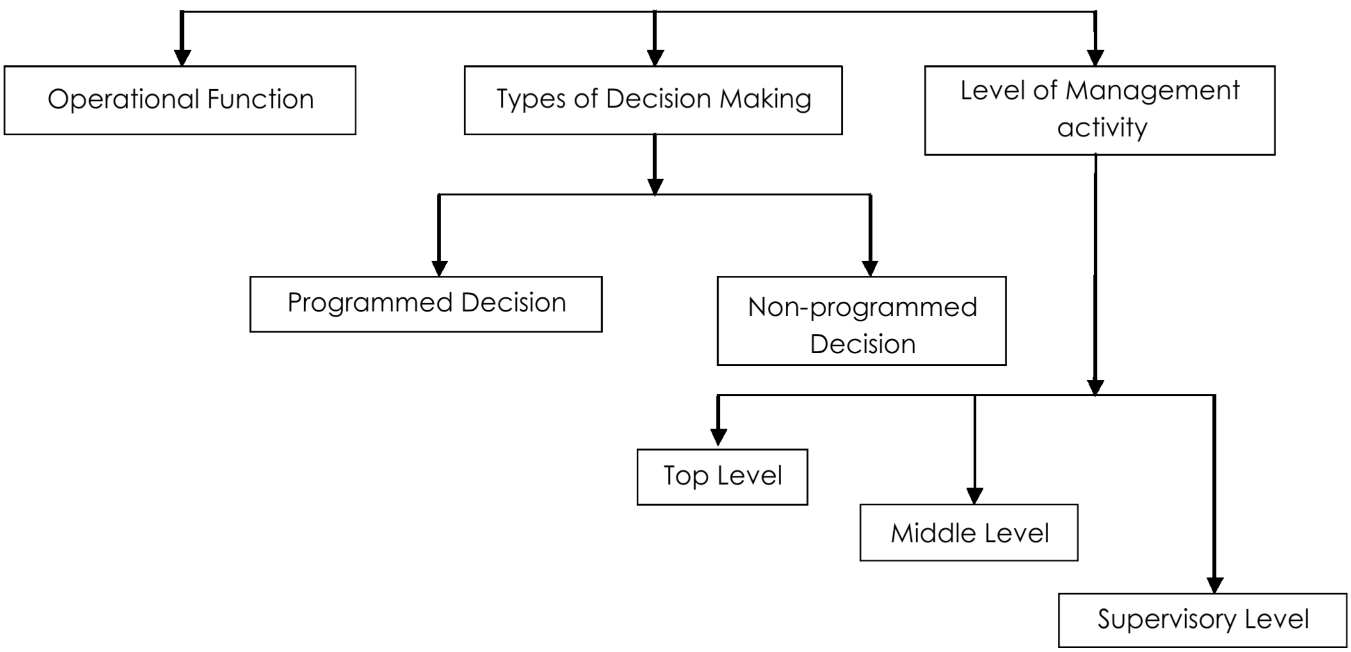
(vii) Self-regulatory: An Information System which may have different sub-systems interacting with the each other in a desired fashion to be operative smoothly and in the process they regulate themselves. This is what is self-regulatory nature of the system. A payroll system involves three activities – first, maintaining attendance of employees, second, pay calculation and third pay disbursement. If the target date for pay disbursement is last date of a month, the second adjusts its start time accordingly and the first one is also regulated in such a fashion that it can provide input to the second in time.

Information System and its Implications/Role in Management

An Information System can provides effective information for decision-making and control of some functionalities of an organization. Enterprises use information system to reduce costs, control wastes or generate revenue. Some of important implications of information system in business are as follows:

- Information system helps managers in effective decision-making to achieve the organizational goal.
- Innovative ideas for solving critical problems may come out from good Information System.
- Knowledge gathered through Information System may be utilized by managers in unusual situations.
- It helps in taking right decision at right time.
- Based on the well designed information system, an organization will gain edge in the competitive environment.

The factors on which information requirements of executives depend are discussed below:



(a) Operational function: The grouping and clustering of several functional units is termed as a operational function. For example, in a business enterprise, marketing is an operational function, as it is the clustering of several functional units like market research, advertising, sales analysis etc. The content of information depends upon the activities performed under an operational function. For example, in case of production, the information required may be about the production targets to be achieved, resources available etc. Whereas in the case of marketing function, the content of information may be about the customer behavior, new product impact in the market etc.

(b) Type of decision making: Organisational decisions can be categorized as programmed and non programmed ones.

- **Programmed decisions:** Decisions which are of repetitive and routine nature are known as programmed decisions, for example, preparation of payroll and disbursement of pay through bank account are programmed decision. Generally, guidelines and rules are already established for taking programmed decision.
- **Non-programmed decisions:** Decisions which are unstructured, complex are known as non-programmed decisions. In other words, decisions which are not automated are Non-programmed decisions. For example, new product line, capital budgeting etc. Non-programmed decision making has no pre established decision procedure.

Strategic-level information systems help senior management to tackle and address strategic issues and long-term trends, both within the firm and external environment. Their principal concern is matching changes in the external environment with existing organisational capability - What will be the cost-trends, where will our firm fit in, what products should be made etc ? In other words, these systems are designed to provide top-management with information that assists them in making long –range planning decisions for the organization.

Tactical-level information systems serve middle level managers and help in taking decisions for a period of 2-3 years. The managers are typically concerned with planning, controlling and use summaries of transactions to aid their decision- making. In other words, these systems provide middle-level managers with the information they need to monitor and control operations and to allocate resources more effectively. In tactical systems, transactions data are summarized, aggregated, or analysed. Their purpose is not to support the execution of operational tasks but to help the manager control these operations.

Operational-level information systems are typically transaction processing systems and help in the operational level managers to keep track of elementary activities and transactions of the organisations such as sales, receipts, cash deposits, flow of materials etc. Their purpose is to answer routine questions and to track flow of transactions. Thus, the primary concern of these systems is to collect, validate, and record transactional data describing the acquisition or disbursement of corporate resources. Thus, each type of information system serves the requirements of a particular level in the organisation, providing the needed basis for decision making.

Evolution of Information System

The evolutions in Information Systems can be distinctly divided into five Generations of Information System which are as follows :

1. Manual System
2. Mechanical System
3. Electronic Data Processing (EDP)
4. Management Information System (MIS)
5. Decision Support System (DSS)
6. Executive Information System (EIS)
7. Expert System

Manual System (before 1930)

- It was old and primitive
- It involved highly clerical work and chance of procedural errors was high
- Procedure was time consuming and there used to be delay in preparation of reports
- There was no alternative cost-effective procedure

Mechanical System (1930-1955)

- Unit Record Machines came into existence
- Improved Computational accuracy
- Comparative faster data processing

Electronic Data Processing (EDP) System (1955-1970)

- Focus was on volume-oriented applications
- Use of computers improved processing efficiency
- Well defined processing rules
- Development of scientific programming and system designing

In 1979, Richard Nolan suggested a model for evolution of information system which has been widely accepted by academicians and practitioners. The model suggest that the level of data processing expenditure of an organization can be seen to progress through six different stages which are as follows :

Stage	Activities
Initiation	The First introduction of Computer System was for cost saving. The job which were repetitive in nature and needed high manpower deployment used to be done in computer. Use of computers restricted to accounting function. Knowledge became barrier for future development.
Contagion	The blossoming of computer application in different areas came in a totally uncontrolled way. This stage became chaotic and many application fail.
Control	Senior Managers became conscious about the expenditure and lack of control. Staff are centralized and formal Information System organization started to be established. Application concentrated on saving money, rather than making money.
Integration	The control introduced in stage 3 is slackened in order to introduce innovation. The Information system function was re-organized to allow the specialists to become involved with users in development of systems. Large expenditure was made in core system.
Data Administration	Developments were driven by the organization's demand for information. The business recognized the value and potential of information system. Corporate databases creation started.
Maturity	Planning and organization in Information System got incorporated into development of the organization. Strategy was embedded in decision making.

Management Information System – MIS has an objective to provide best possible timely information with the use of modern sophisticated technology. The strategy in MIS is to exploit the technological tool in ensuring the flow of information of right quality at right time at right place (user's place) for effective decision making. Its important features are :

- It is an improved version of EDP system
- It enables the management to have access to desired set of data only
- It meets information requirement at different levels with pre-defined reports
- It undertake transaction processing for different functional areas
- It provides on-line access to data and efficient reporting system
- It supports routine decision making

Decision Support System – It is a sophisticated decision making model with the help of high powered software to take semi-structured decisions. The basic features of a DSS are :

- It is based on one or more corporate databases
- It must be supported by a set of quantitative models
- It has the ability to solve unstructured problems
- It should have the network computing facilities embedded in the system
- It is used for solution in a complex business situation
- It provides supports to Executive Information system for decision making
- Software at different locations facilitates group decision making.

Executive Information System : An Executive Information System is a advanced model of Decision Support System which can take care of unstructured problem situation. It aims at providing information to top executives of an organization who are involved in strategic decision making.

Expert System : An Expert system is a knowledge based system which acts an expert in devising solutions. An expert system acts in a specific area only with the support of knowledge database on this specific area. Knowledge data base means structured information stored on previous solution sets in unstructured problem situations. In other words, an expert system operates on previous experience which is stored in a database. Even the present solution devised from the system and the information on its outcome will also be stored.

Growth of Business Information System

In recent times there has been substantial growth for scientific information system in business system. Modern business managers have perceived the importance of support from good information system in business decision making. The following factors have contributed towards growth of business information system :

Change in Computer Technology: Cost of hardware has gone down. Thanks goes to technological innovations. Computing speed has gone up tremendously and storage capacity has increased enormously. The revolution in communication technology induced every activity in the business and society to be under its call. The change in the computing capabilities in Information systems due to technological innovations have brought significant changes in the attitude of the management towards effective use of information.

Fast Transaction Processing: Today network technology has brought the concept of intranet in an organization. This has helped fast and accurate transaction processing based on instant updation of information from point-of-sale (POS) and warehouse. Large Banks are using the intranet for having on- line information for exchange and control. Information system in banking service has brought a new dimension in control, efficiency, productivity and profitability.

Customer Support: Market place is full of suppliers. Products are flooded from domestic and international supply. The expectations of the customers has increased. They have become more knowledgeable about the quality, cost and availability of the products. A business organization can not survive unless it demonstrates its customer orientation. There has been a trend to manage the total supply chain system through computer system primarily to satisfy customer need and to efficiently control inventory.

Changing Product Technology: In the global competition of trade, the technology is fast changing. Innovations are revolutionary. Products have shorter life-cycle. Risk of business obsolesce is very high. Only a good Information system can provide right kind of support with right flow of information for scientific control mechanism and decision making. Business Managers are under tremendous pressure to cope up with the speed of development. The magic tools under IT provide continuous information to update with the changes taking place throughout the world.

Continuous Improvement Effort : Cost Competitiveness and quality improvement are two important aspect on which survival of an business depends. Only continuous efforts with better control mechanism can help to achieve the results. The information system is providing the best support. Is it possible to adopt Just-in Time for Inventory Control without computer based information system? Quality information with the help of computer provides the right kind of database for analysis and corrective measures.

Strategic Decision Making : Business Strategy and Information system of a modern organization is inseparable. A sound strategic decision is based on analysis of various factors – both internal and external. Strategic Analysis model of Michel Porter can provide strategic solutions to business problems based on scientific and comprehensive information data base. The Model is an eye opener to the business world to develop a new generation of information system for spontaneous strategic business solutions.

Wide Areas of applications in Offices : Computers are being widely used for different purpose in business environment to support the cause of business. They are :

- Text management
- E-mail
- Document management with the use scanner
- Communication through network etc.

Strategic Planning for Development of an Information System

An Information System is developed with a definite set of objectives and plan to achieve them. For development of a better system, change in the management system in regards to accountability, responsibility and control in different functional areas related to system is essential for effective flow of information, decision making and monitoring.

Until most recently, most organizations regarded their Information systems as a resource that is necessary but not strategically significant. The IT department was treated like any other service department and the information system was allowed to evolve rather than being formally planned. Major benefits for formal information system strategy :

- To achieve goal congruence between information system objectives and corporate objectives
- To create and sustain competitive advantage
- To exploit Information Technology to the optimum benefit of the organization

Linking Corporate Strategy with Information System Strategy

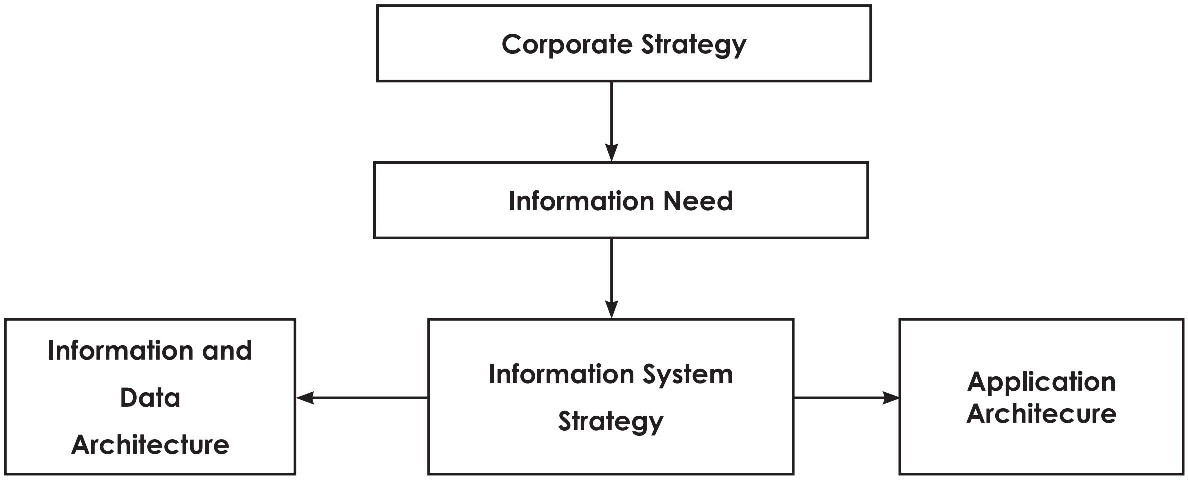
The basic objective of information system strategy is to exploit IT to provide best advantage for the organization.

The following points are to clearly understood before venturing into designing an information system :

1. Identification of sub-systems involved and their interactions
2. Level of Management
3. Decision making process

Today, success of corporate strategy depends on decision making skill. The support of efficient information system needs no clarification. The decisions at different levels of management vary. A standard decision making pattern is shown below :

Level of Management	Decision making on	Information Support from
Lower Level	Operational Control	Transaction Processing
Middle Level	Planning & Control	Management Information System
Top Level	Strategic Planning and Implementation	Executive System Expert System



Information and data architecture :

What is needed is to understand the following :

- Information need for the organization for corporate decision making
- Who will provide the data and who will use it.
- When and how data will be collected.
- How should the data be stored to provide easy access.

Application Architecture

Application architecture development requires the evaluation of the application software requirement in the consideration with the following :

- What application software is required
- What is the most logical sequence of operations

Budgeting and Planning the Implementation details

To plan for future information system the following issues should be critically evaluated :

- Organizations growth plan, business strategy and support needed from Information system
- Information System Budget
- Quality of Human Resources and possible approach to improve their skill
- Applicability of business process re-engineering
- Integration of information from different functional areas

Planning the Operation

To make the information system more effective, the action plan has to be devised for :

- Development of organizational structure in IT department
- Fixation of new role and responsibilities
- Security management
- Risk Management

How to Support the Decision making Process

The important process in the planning is how to improve the use of information in efficient decision making to formulate business strategy. For doing this, through review of the current system and procedure for Information Management is essential which involves the review of the following :

- Current work volume
- Current application software and their life cycles
- Current technology environment and skill level
- Current performance of Information system
- User satisfaction
- Current Business Process and information structure

Some of the characteristics of Computer Based Information Systems are as follows :

- All systems work for predetermined objectives. ,
- In general, a system has a number of inter-related and interdependent subsystems or components.
- If one subsystem or component of a system fails, in most cases the whole system does not work. However, it depends on how the subsystems are inter-related.
- The different subsystems interact with each other to achieve the goal of the system

Areas of Computer-Based Applications

Major areas of computer-based applications are finance and accounting, marketing and sales, manufacturing, inventory/stock management, human resource management etc.

(a) **Finance and Accounting:** It helps forecasting revenues. It determines the procurement of funds and its optimum utilization and also managing other financial resources. The areas in Finance and accounting are:-General Ledger, cash management, accounts receivable/payable, fund management etc.

(b) **Marketing and Sales:** The marketing system facilitates the chances of order procurement by marketing the products of the company, creating new customers and advertising the products. The objective of this system is to maximize sale and ensure customer satisfaction.

(c) **Production or Manufacturing:** The system generates production schedules and schedules of material requirements. It monitors the product quality, control the waste and try to utilize its full ca-pacity for producing goods and services.

(d) **Inventory/Stores Management:** The system is used to regulate the maximum and minimum level of stocks, identification of important items in terms of stock value (ABC analysis), identification most moving items and also non moving items.

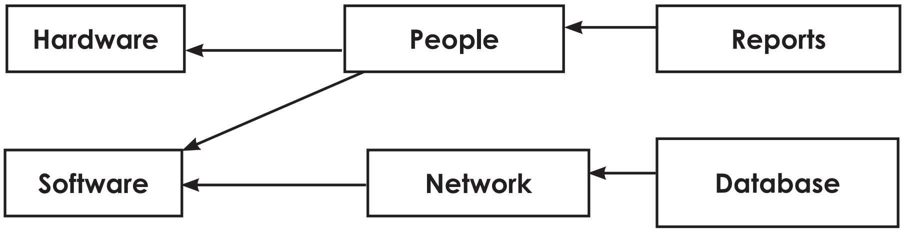
(e) **Human Resource Management :** Less disputes, right utilization of manpower and quiet environment in this functional area ensure smooth conducting of business. HRM maintain the database of employee qualifications, experience and helps the management in allocating the people at right place.

Information System Infrastructure

Information System Infrastructure means the physical resources and organizational support required for operation of an information system. It consists of following six basic components:

- Hardware – Devices which store software, database and process data
- Software – Programs process data to generate reports
- Database – Data collected is stored in databases
- Network – Technology for sharing the data and other hardware resources
- People – Human resources to make the system operational.

Reports – Reports are generated by the software with the help of databases for the use by users (people).



The role of information system architecture is to support and reinforce the organization structure and decision making mechanism. If we accept that IT can change the performance of an organization, the real challenge before the management is to ensure the management that the components of IS architecture provides the most suitable solution in the environment under which an organization works. The change management is the most critical issue and change in the architecture should be taken up well before the technology becomes obsolete.

The following exercises are to be made for effective use of resources with the use of technology:

Arranging required hardware and software

Management has to ensure the most suitable hardware and suitable to fulfill the information requirement for decision making. The choice between centralized processing or distributed processing has to be made first. The architecture design is dominated by issue of compatibility of hardware platform and software package.

- Assessment of hardware configuration on the basis of volume of data and type of processing need
- Software requirement in compatible with hardware
- Networking and communication technology requirement
- Assessment of investment requirement and phasing the investment
- Vendor selection
- Procurement plan

Human Resource Management

The system developed by IT specialist often fail to meet the user need. The persons who will be in-charge of development of software must have clear understanding of how the business operates so that technically-perfect solution is evolved. What is needed is personnel involved in Information system must be properly trained on the pattern of functioning of the organization, change needed, plan for changes, stages of transformation and actions plan for the same. The policies of the relevant issues are to be framed to achieve the objectives. The issues are :

- Recruitment
- Training

- Restructuring
- Retention of employees etc.

Implementation

Implementation of infrastructure requires project management skill. What is required is to develop time targets for implementation activities like procurement of hardware, software, allocation of resources and implementation of the system. The time frame may vary from organization to organization for implementation and level of sophistication depends on present system, possibility of skill improvement and acceptance in change in management of the system. Strategies are to be developed for achieving a time targeted system with desired effectiveness. Careful considerations should be taken about the following criteria of an dynamic information system :

- Information needs of an organization change constantly
- The information system should be open and adaptive
- The information system should focus on supportive role in the business process

Information System Organization

Organization structure should be based on established policy and have well defined rules of responsibilities and authority at different levels. The load of data processing, resource requirement in terms of both manpower and machine must be assessed properly. Job specifications at different levels must be clearly given to avoid gaps in responsibility and performance standard also be rationally established to make the organization more scientific. The objectives of sound organization structure are to provide all possible infrastructure facilities for a good information system. To be more specific, a scientific organization structure for information system means provisions of the following :

- Proper Information Technology environment with right kind of machine, manpower & work culture
- Right resources balancing the hardware, software and skill
- Adequate security system on data, processing and output
- Adoption of scientific and modern software development methodology etc.

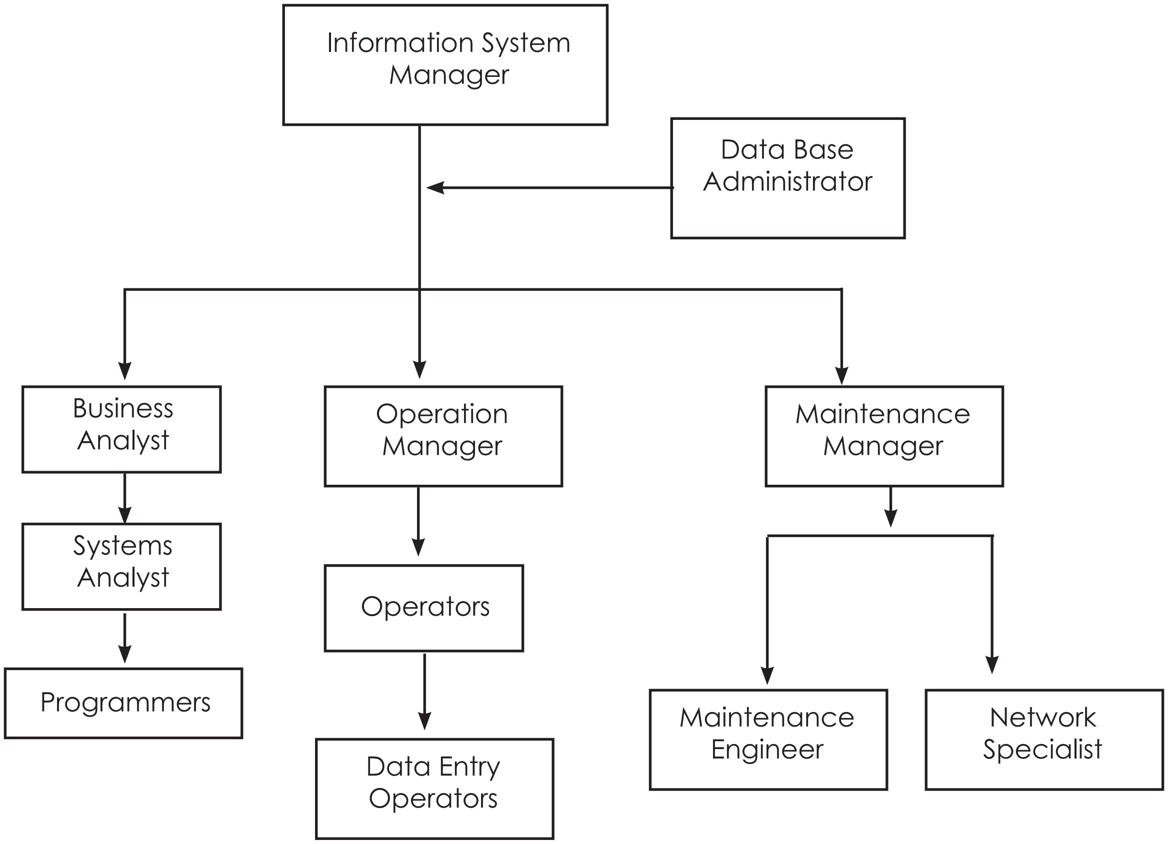
For successful implementation and operation of an information system, organizational set up has to be built to take care certain activities on a day to day basis. Let us understand the activities involved in the information system and the responsibilities of the Information System Department.

The organizational structure of information system in an organization may vary depending on various resources available and their quality but the objectives remain almost same with main focus on effective use of information for better business control.

Activities involved in the department are :

1. System Development
2. Programming
3. Data administration
4. Security management
5. Operation management
6. Quality assurance

The different specialist groups of employees are assigned the responsibilities of the above activities in the Information System Department. The chart below will show the organization structure of a Computer based Information System department :



The following table will explain their activities and responsibilities:

Designation	**Duties and responsibilities**
Information System Manager	• Planning the resources and time frame of implementation • Supervising the overall implementation of system and day to day operation
Database Administrator	• Database Management • Database Library Management • Security of data
Business Analyst	• Development of new Information System. • Acting as co-ordinator between users and IS developers
Systems Analyst	• Analysis of the requirements of the IS, development of system specification • Designing the IS.
Programmer	• Development / modification of programs according to systems specifications and design.
Maintenance Engineer	• Maintenance of Hardware
Network Specialist	• Maintenance of network
Systems Operation Manager	• Planning and controlling the flow of data and processing. • Network management. • Co-ordination with users.

Operator	• Computer Operations • Communication network control • Process Documentation • Data Entry Supervision
Data Entry Operator	• Data Entry, Data verification and editing

Information Systems Personnel Management

Managing the human resources effectively is very critical issue. Success of a Information Sytem depends on the quality of human resources and their support.

The turnover in Information Technology field is comparatively high compared to other industry. Thus, following important issues should be taken into :

- Growth prospect
- Motivational aspects
- Provision for management of gap in skill and expertise

For effective management of human resources, the following policy and procedure must be followed :

1. Job description for different positions should be clearly spelt out to avoid conflict and confusion.
2. Job responsibility for each position should be clearly defined.
3. Recruitment policy must be well defined one to hire right quality personnel.
4. Training programs should aim at skill improvement of the personnel in line with technological change and organization's requirement.
5. Regular screening of security check must be followed to plug all possible motive for fraudulent activities and to avoid risk of any damage.
6. Performance evaluation should be rational, scientific and unbiased to motivate the employees.

Quality of a Business Information System

Main quality criteria of a business information system are reliability of information, timeliness and correctness of reports. These depend on technology in use, manpower, ethical standard maintained and security of the system. To ensure good quality, system requirements must be properly understood and system infrastructure must be developed.

Reliability of Information : Internet has flooded the information. Today business managers are burdened with analysis of huge volume of information. The exact of relevant information only can lead to sensible use of information. The role of Business Analyst will be of paramount importance with the growth of technological evolutions. There is a saying in computer information system – Garbage In Garbage Out (GIGO). The correctness or quality of reports depends on quality of information. Source of correct data, flow of data and procedure of authorization has to be established.

Processing Time : Processing time is an important factor for information system. Information is generated for control in different business parameters in the operation and decision making. Naturally, the time associated with dissemination of information is very important. Information not in time becomes useless.

Matching Management Requirements : The information system should be well planned to fulfill the requirement of the management i.e. the owner of the system in terms of time, quality and frequency. At the time of designing the system the reports, contents, formats etc. are to taken care to exactly fulfill the requirements of users of different levels.

Technology : Technology refers to :

- Configuration of computer in terms of capability, security etc
- Software in use
- Communication system – network efficiency
- Type of processing - batch, real-time or on-line

Human Resources : The employees need new orientation in the knowledge of computer products, technological change taking place, expertise to handle these and managerial complexity evolving out of these. They are to develop the skill to develop appropriate IT infrastructure, use effective methods to store and access data and navigate them to properly use them. Quality of human resources is the most important component in an Information System organization.

Ethical standard : Ethical issues relating to employees, customer, supplier etc must be properly dealt with to maintain the right kind of image of the organization. Ethical standard must be maintained in dealing with the information being handled in an organization.

Security : The security of information system must be taken care properly. Here, security means security of information and assets. In an processing environment under network, the system is more vulnerable by unauthorized assess, leakage of sensitive information and sabotage. Loss of assets due to fire, theft, natural disaster must be protected.

Business opportunities due to Development of Computers

Development in Computer has also evolved following business opportunities for Different Business activities relating to Hardware and Software.

1. **Computer Manufacturing :** This a function generally taken up by big companies. Earlier days manufacturers used to market their own products. Leading manufacturers in the world were IBM (International Business Machine), DEC (Digital Equipment Corporation), CDC (Control Data Corporation), Burrough, Honeywell, NCR, ICL, Hewlett Packard etc.
2. **Peripheral Equipment Manufacturing :** Some companies are involved in manufacturing peripheral devices like disk drives, tape drives, printers, plotters, monitors, communication equipments. Leadingperipheral manufacturers in the world are Intel Corporation, Motorola, Texus Instruments, Toshiba, Phillips, Fujitsu, Hitachi, NEC Corporation etc.
3. **Computer Leasing :** Earlier days Computer Leasing was a very attractive business. The cost of Computer was high. Users generally were not ready to afford huge investment. Some computer manufacturer and some companies were involved in the business of computers leasing. Lease Rent was high. IBM used to provide machines in lease.
4. **Software Developers :** Companies and individuals undertake the responsibilities of developing software for third party companies. The job of contract used to be system designing, program development and system implementation.
5. **Time-Sharing Companies :** In earlier days when hardware used to be costly and users were using only selective application systems for data processing, the time sharing facilities provided by different companies on their Computer were found to be cost-efficient and widely acceptable to many users. Some Companies took the opportunities for business purpose. Generally, companies used to buy a mainframe computers with multi-users facilities and charges used to on the basis of usage time of different components like CPU, Printers, Disk, Magnetic tape etc.
6. **Networking Parlour :** With the acceptance of networking to be the most efficient communication, use of e-mail and net-working surfing has gone up. It will further multiply when the e-commerce will take a formidable shape to be effectively operative. Providing networking facilities by small shop has become a good business in big and small towns.
7. **BPO Services :** The advantages of fast communication though internet technology has opened a new dimension for Business Process Outsourcing of commercial jobs. The data in being transmitted from one part of the globe to other for processing. The same being processed.

5.2 SYSTEM DEVELOPMENT PROCESS

Systems development is the process used by system analyst for analyzing a business situation with the goal of improving these situations through better procedures and methods. It provides system designers and developers to follow a sequence of activities, although it includes hardware and software development but generally system development is related with the software development. System development has two major components:

(a) **System Analysis** is a step which involve in breaking a system into different parts and process of gathering and interpreting facts, diagnosing problems, and using the information to recommend improvements to the system.

(b) **System Design** describe the desired software and replace an existing system.

The stores manager ask a system analyst to organize the stock room operations for better control of inventory and an access of update information about stock levels.

Before designing a system, the analyst needs to know how the stores currently operate and what the flow of information through the system looks like. An analyst also seeks information about the outstanding purchase orders, records of stock on hand and other reports. After system analysis, he will make a plan which will includes all system design features, file specifications, operating procedures, and design features, and equipment and personnel requirements. The system design is like the blue print for a building, it specifies all the features that should be there in the finished product.

Achieving System Development Objectives

Why organizations fail to achieve their systems development objectives. Some of the major reasons are as follows :

- There is a lack of user participation in the development effort.
- Due to Lack of senior management support and involvement in information systems development.
- Personnel are not as familiar with the new technology.
- Systems developers often lack sufficient education background and they are under-trained development staff.
- When personnel perceive that the project will result in personnel cutbacks, they always resist to change new technology.
- Inadequate Testing before installation is also a major reason for which organizations fail to achieve their system development objectives.

System Development team

System Development is not so easy that one single person can handle it. System development need the effort of whole team. First the top management level steering committee is established. The steering committee ensures that ongoing systems development activities are consistently aimed at satisfying the information requirements of managers and users within the organization. Several people in the organization are responsible for systems development. System analysts are subsequently assigned to determine user requirements, design the system and assist in development and implementation activities.

What Accountants can do in Development work?

Accountants have specialized skills - such as accounting and auditing - that can be applied to the development of project. An analysis of proposed systems in terms of cost and benefits can also be done by the Accountants.

The Prototyping Model :

Organizations are increasingly using prototyping techniques to develop smaller/pivot/part of a total system such as DSS, MIS and Expert systems. A prototype is an usable system or system component that is built quickly and at a lesser cost, and with the intention of being modifying or replacing it by a full scale and fully operational system. Prototyping can be viewed as a series of four steps:

Step 1 - Identify Information System Requirements : Under prototype approach, the design team needs only fundamental system requirements to build the initial prototype.

Step 2 - Develop the Initial Prototype : In this step, the designers create an initial base model and emphasize on system characteristics such as simplicity, flexibility, and ease of use.

Step 3 - Test and Revise : Using the feedback from the users ,the design team modifies the prototype Thus iterative process of modification and reevaluation continues until the users are satisfied.

Step 4 - Obtain User Signoff of the Approved Prototype : As users work with the prototype ,they make suggestions about the ways to improve it .users finally approve the final version of the prototype which commits them to the current design.

Strengths / Advantages :

(i) It provides quick implementation of an incomplete, but functional, application.

(ii) Prototyping requires intensive involvement by the system users.

(iii) A very short time period is normally required to develop and start experimenting with a prototype.

(iv) Since system users experiment with each version of the prototype through an interactive process, errors are hopefully detected and eliminated early in the developmental process.

(v) It reduces the cost of user training.

(vi) It improves the fact finding process.

(vii) It helps to identify confusing or difficult functions and missing functionality.

(viii) Prototyping model encourages innovation and flexible designs.

5.3 SYSTEM DEVELOPMENT LIFE CYCLE

The process of system development starts when management or sometimes system development personnel realize that a particular business system needs improvement. The System Development Life Cycle (SDLC) consists of a set of phases/activities in which each phase of the SDLC uses the results of the previous one.

The system development life cycle method consists of the following activities:

(a) Preliminary investigation: Users submit a formal request for a new system to the MIS department, when they come across a problem. This activity consists of three parts-

  (i) Request clarification

  (ii) Feasibility study

  (iii) Request approval

(b) Requirements analysis or systems analysis:

Several fact-finding techniques and tools such as questionnaires, interviews, observing decision-maker behaviour and office environment, etc. are used for understanding the requirements of the users. As details are gathered, the analysts study the present system to identify its problems and shortcomings and identify the features which the new system should include to satisfy the new or changed user application environment.

(c) Design of the system:

The analyst designs various reports/outputs, data entry procedures, inputs, files and database. These detailed design specifications are then passed on to the programming staff for software development.

(d) Acquisition and development of software:

Specific type of hardware, software and services are determined. Subsequently, choices are made regarding which products to buy or lease from which vendors. Software developers then install purchased software or they may write new custom designed programs.

(e) System testing:

Special test data are input for processing, and then the results are examined. Various types of testing is made such as Unit testing, Integration testing, System testing etc.

(f) Implementation and maintenance:

Implementation and Maintenance is the final stage in SDLC. When system is found to be fit, it is implemented. After implementation, the system is maintained and it is modified to adapt to changing users and business needs.

The Preliminary Investigation

The basic objective of preliminary investigation is to outline the necessity of SDLC. It also analyse in terms of productivity gains, cost savings, and Intangible benefits like improvement in morale of employees.

The steps involved in the preliminary investigation phase are as follows:

(i) Identification of Problem

(ii) Identification of objective

(iii) Delineation of scope

(iv) Feasibility study

The following issues are typically answered in the Feasibility Study :

(i) Whether the existing system can rectify the situation without a major modification?

(ii) What is the time frame for which the solution is required?

(iii) What will be the approximate cost to develop the system?

(iv) Whether the vendor product offers a solution to the problem?

Identification of Problem

Due to shifting business requirements, changing organizational environments, and evolving information technology may render systems ineffective or inefficient and hence, managers and users may feel compelled to submit a request for a new system to the IS department. It can be concluded that the purpose of the preliminary investigation is to evaluate the project request. Problems must be identified. A problem that has a considerable impact on the organization is likely to receive immediate management attention.

The analyst working on the preliminary investigation should accomplish the following objectives:

- Clarify and understand the project request.
- Determine the size of the project.

- Determine the technical and operational feasibility of alternative approaches.
- Assess costs and benefits of alternative approaches.
- Report findings to the management with recommendation outlining the acceptance or rejection of the proposal.

Identification of Objective

After the identification of the problem, objectives of the proposed solution can be defined.

For instance, inability to provide a convenient reservation system, for a large number of intending passengers was the major problem of the Railways. So its objective was "to introduce a system wherein intending passengers could book a ticket from source to destination, faster than in real-time."

Delineation of Scope

The following questions should be answered while stating the scope:

(i) **Functionality requirements:** What functionalities will be delivered through the solution?

(ii) **Data to be processed:** What data is required to achieve these functionalities?

(iii) **Control requirements:** What are the control requirements for this application?

(iv) **Performance requirements:** What level of response time, execution time and throughput is required?

(v) **Interfaces:** Is there any special hardware/software that the application has to interface with? For example-Payroll application may have to capture from the attendance monitoring system that the company installs.

(vi) **Reliability requirements:** The reliability required for an application depends on its criticality and the user profile.

The two primary methods by which the scope of the project can be analyzed are as follows :

(i) **Reviewing internal documents:** In reviewing the internal documents the analyst can first understand the organization chart and operating procedures.

(ii) **Conducting Interviews:** Interviews allow analysts to know more about the nature of the project request and the reasons for submitting it.

Feasibility Study

It is essential to carry out the feasibility study of the project before its implementation. Feasibility Study refers to a process of evaluating alternative systems through cost/benefit analysis so that the most feasible and desirable system can be selected for development.

Different angles through which the feasibility study of the system is to be conducted :

(i) **Technical Feasibility:** In this study an analyst ascertains whether the proposed system is feasible with existing or expected computer hardware and software technology. The technical issues include the following:-

- Does the proposed equipment have the technical capacity to hold the data required to use the new system?
- Can the proposed application be implemented with existing technology?
- Can the system be expanded in future?
- Are there technical guarantees of accuracy, reliability, ease of access, and data security?

(ii) Economic Feasibility/Cost-Benefit Analysis: It includes an evaluation of all the incremental costs and benefits expected if the proposed system is implemented. The financial and economic questions raised by analysts during the preliminary investigation for estimating the following:

- The cost of conducting a full systems investigation.
- The cost of hardware and software for the class of applications being considered.
- The benefits in the form of reduced costs .
- The cost if the proposed system is not developed

(iii) Operational Feasibility: It is concerned with ascertaining the views of workers, employees, customers and suppliers about the use of computer facility. Some of the questions which help in testing the operational feasibility of a project are stated below :

- Is there sufficient support for the system from management and from users?
- Are current business methods acceptable to users?
- Are the users been involved in planning and development of the project?
- Will individual performance be poorer after implementation than before?

Feasibility study can also be done in some other areas :

(iv) Financial Feasibility: It is to be analysed that whether the cost of the proposed system is communesrate with the size of the organization.

(v) Schedule or Time Feasibility: If new system will take long time, the organizations can go for other alternative that the company can implement in a shorter time frame.

(vi) Resources Feasibility: This focuses on human resources and their reluctance to move to such other locations.

(vii) Behavioral Feasibility: If the data input for the system is not readily available or collectable, then the system may not be successful.

(viii) Legal Feasibility: A revised system should comply with all applicable federal and state statutes about financial reporting requirements, as well as the company's contractual obligations.

Estimation of costs and Benefits

System costs can be sub divided into Development, Operational and Intangible costs.

(a) Development costs for a computer based information system include salaries of the system analysts and computer programmers who design and program the system,cost of converting and preparing data files ,cost of testing and documenting the system, training employees, and other costs incurred for development process.

(b) Operating costs of a computer based information system include - hardware/software rental or depreciation charges, Cost of maintaining proper physical facilities including power, light, heat, air conditioning, or other facility charges such as equipment, building maintenance charges, overhead charges of the business firm.

(c) Intangible costs are costs that cannot be easily measured. For example, the development of a new system may disrupt the activities of an organization, Customer sales and goodwill may be lost by errors made during the installation of a new system.

Benefits : The benefits can be subdivided into -

1. Tangible and
2. Intangible benefits.

Advantages of System Development Life Cycle from the perspective of IS audit

(i) If the detailed documentation is maintained during each phase of the SDLC the IS auditor can easily understand each phases,

(ii) The IS Auditor on the basis of his examination, can write in his report about the compliance by the IS management of the procedures, if any, set by the management,

(iii) If The IS Auditor has a technical knowledge and ability of the area of SDLC, the IS Auditor can guide during the various phases of SDLC.

(iv) The IS auditor can also provide an evaluation of the methods and techniques used through the various development phases of the SDLC.

Risks Associated with SDLC

Some of the shortcomings of the SDLC are as follows :

(i) The development team may find it cumbersome,

(ii) The users may find that the end product is not visible for a long time,

(iii) It may not be suitable for small and medium sized projects.

5.4 SYSTEM REQUIREMENT ANALYSIS / SYSTEM ANALYSIS

This is the second stage of System Development life cycle (SDLC). This analysis involves determining users needs, studying the present system of the organization in depth, and determining the features which the new system should possess. The significance of studying the present system is to know why organization is not satisfied by this system. What are its strong and weak points?

Analysis / Investigation of the Present System

Examination of existing methods, procedures, data flow, outputs, files, input and internal controls should be done in order to fully understand the present system and its related problems.

The following areas would help in analyzing/investing the Present System:

(a) Review historical aspects: A review of annual reports and organization chart can identify the hierarchy of management levels . The historical facts should identify the major turning points that have influenced its growth. The system analyst should also investigate what system changes have occurred in the past.

(b) Analyze inputs: Source documents are used to capture the originating data The system analyst should study in depth various sources from where the data are initially captured to understand the existing system. The system analyst must understand the nature of each form, the distribution of the form.

(c) Review data files maintained: The analyst should investigate the data files maintained by each department and should know where they are located, who uses them. System and procedural manual should also be checked.

(d) Review methods, procedures and data communications : System analyst must review the types of data communication equipments including data interface, data links, modems, dial-up and leased lines and multiplexers to understand how the data communication network is used in the present system. A procedure's review is an intensive survey of the methods by which each job is accomplished, the equipment utilized and the actual location of the operations.

(e) **Analyze outputs:** The outputs or reports should be scrutinized carefully by the system analysts in order to determine whether they meet the organization's needs.

(f) **Review internal controls:** A review of the present system of internal controls may indicate weaknesses that should be removed in the new system. Locating the control points helps the analyst to visualize the essential parts and framework of a system.

(g) **Undertake overall analysis of present system:** Based upon the aforesaid investigation of the present information system, the final phase of the detailed investigation includes the analysis of the present work volume, the current personnel requirements, the present benefits and costs and each of these must be investigated completely.

Fact finding Techniques

Various fact-finding techniques, which are used by the system analyst for determining the needs/ requirements of an organization are briefly discussed below :

(i) **Documents:** Analysts collect the hierarchy of users and manager responsibilities, job descriptions for the people who work with the current system, procedure manuals, program codes for the applications associated with the current system to understand the existing system.

(ii) **Questionnaires:** Users and managers are .asked to complete questionnaire about the problems with the existing system and requirement of the new system. Using questionnaires, a large amount of data can be collected fastly.

(iii) **Interviews:** Users and managers may also be interviewed to extract information in depth.

(iv) **Observation:** Observation plays a key role in requirement analysis. Only by observing how users react to prototypes of a new system, the system can be successfully developed.

System Analysis of Proposed System

After each functional area of the present information system has been carefully analyzed, the proposed system specifications begins. The required systems specifications which should be in conformity with the project's objectives are as follows:

- Outputs produced
- Database to be maintained with online processing capabilities
- Input data prepared directly from original source documents
- Work volumes and timings carefully considered for present and future periods

Software Packages which serve as aids in program analysis

1. Automated flowcharting programs
2. Automated decision table programs
3. Scanning routines
4. Mapping programs
5. Program tracing

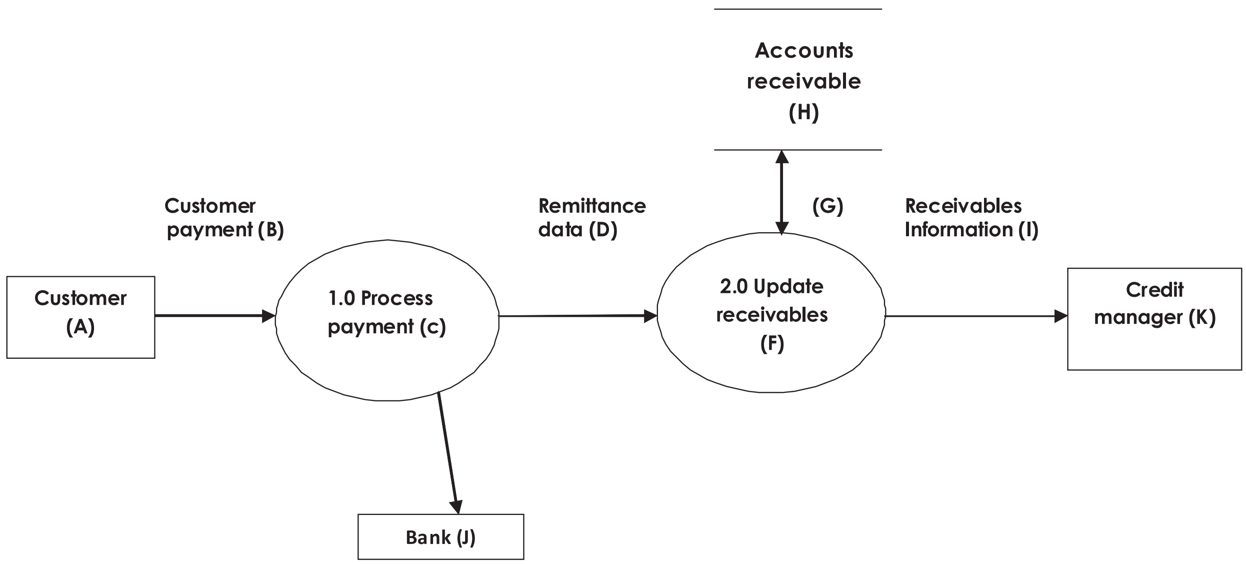
System Development Tools

Many tools and techniques have been developed to improve current information systems. Its main purpose is to conceptualize, clarify, document and communicate the activities and resources involved in the organization and its information systems and to analyze present business operations, management decision making.

The major tools used for system development can be grouped into four categories. These are as follows:

(i) System components and flows: System flow charts are typically used to show the flow of data media. A data flow diagram uses a few simple symbols to illustrate the flow of data among external entities. The tools help the system analysts to document the data flow among the major resources and activities of an information system.

Example of System Components and flows-



(ii) User interface: Dialogue flow diagrams analyze the flow of dialogue between computers and people. Layout forms and screens are used to construct the formats and contents of input/output media and methods.

Example of user interface-

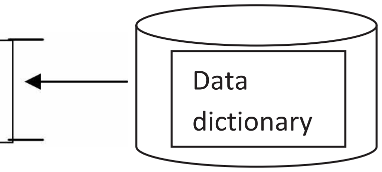
	CUSTOMER ORDER FORM		
DATE			
ORDER NUMBER			
CUSTOMER NAME			
SAMPLE NUMBER	**LOCATION**	**COST**	**DELIVERY MODE**

(iii) Data attributes and relationships:

- A Data Dictionary provides the description of the characteristics of all data elements and their relationships to each other as well as with the external systems.
- Grid charts help in identifying the use of each type of data element in input/output or storage media of a system. File layout forms document the type, size, and names of the data elements in a system.

Example of data attributes and relationships:-

Name of data field	**File in which stored**	**Source document**
Order on hand	**Customer master file**	**REF number 111**



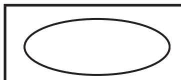
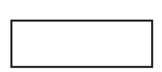
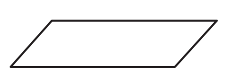
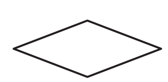
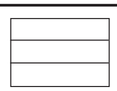
(iv) Detailed system process: These tools are used to help the programmer to develop detailed procedures and processes required in the design of a computer program. Decision trees and decision tables use a tabular form to document the complex conditional logic.

	Granting Credit Facility	**R1**	**R2**	**R3**
A1	Credit Limit Accepted	Y	N	N
A2	Pay Experience Favourable	-	Y	N
B1	Allow Credit Facility		X	X
B2	Reject Order			X

(a) Structured English: Structured English, also known as Program Design Language (PDL) or Pseudo Code, is the use of the English language with the syntax of structured programming. In structured English, Conditional blocks are indicated by keywords such as IF, THEN, and ELSE.

(b) Flowcharts: Flowcharting is a graphic technique that can be used by analysts to represent the inputs, outputs and processes of a business in a pictorial form.

Symbols used in Flowcharts: Some important symbols used in flowchart are:-

						
Start / Stop	Assignment / Calculation	Input / Output	Decision Making	Connector	Flow Lines	Subroutine

Types of Flow charts

Flowcharts are divided into four major categories:

- **Document flowchart -** showing a document- flow through systems.
- **Data flowchart -** showing data flows in a system.
- **System flowchart -** showing controls at a physical or resource level.
- **Program flowchart -** showing the controls in a program in a system.

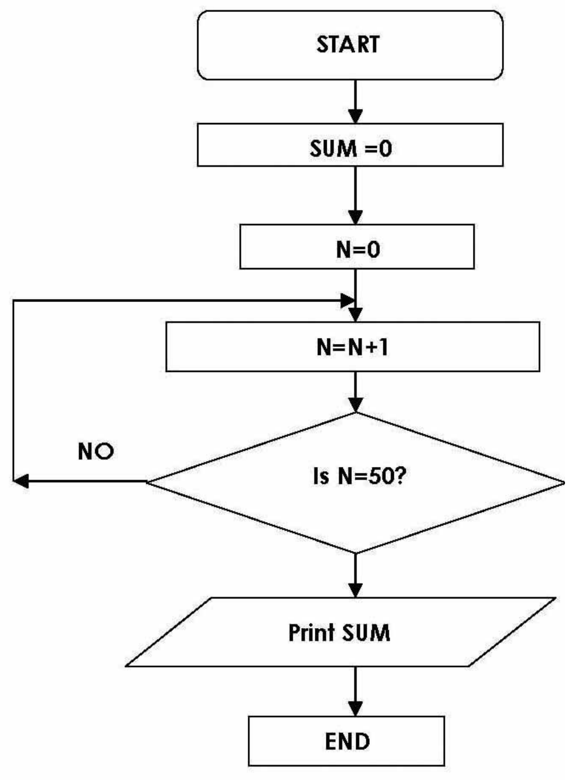
Benefits of Flowchart

- **Communication:** Flowcharts are better way of communicating the logic of a system and easily understandable.
- **Effective analysis:** With the help of flowchart, problem can be analyzed in more effective way.
- **Proper documentation:** Program flowcharts serve as a good program documentation.
- **Efficient Coding:** The flowcharts act as a guide during the systems analysis and program development phase.
- **Proper Debugging:** The flowchart helps in debugging process.
- **Efficient Program Maintenance:** The maintenance of operating program becomes easy with the help of flowchart. It helps the programmer to put efforts more efficiently on that part.

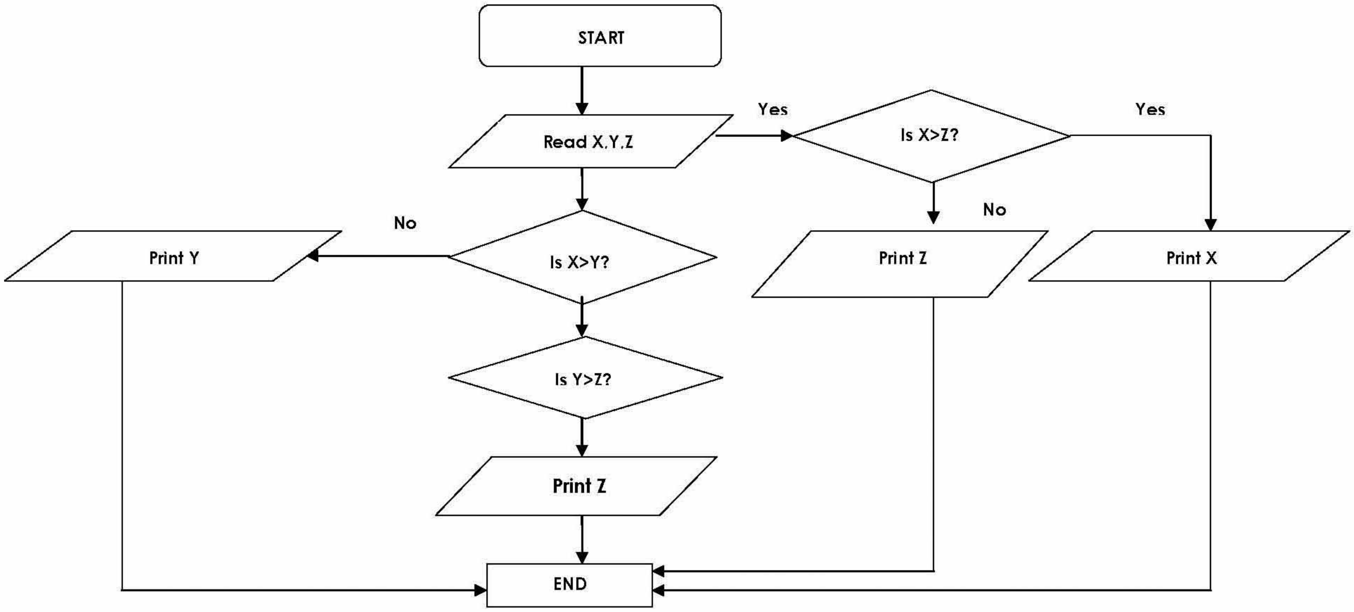
Limitations of Using Flowcharts

- **Complex logic:** Sometimes, the program logic is quite complicated. In that case, flowchart becomes complex.
- **Alterations and Modifications:** If alterations are required, the flowchart may require redrawing completely.
- **Reproduction:** As the flowchart symbols cannot be typed, reproduction of flowchart becomes a problem.

Draw a flowchart to find the sum of first 50 natural numbers:



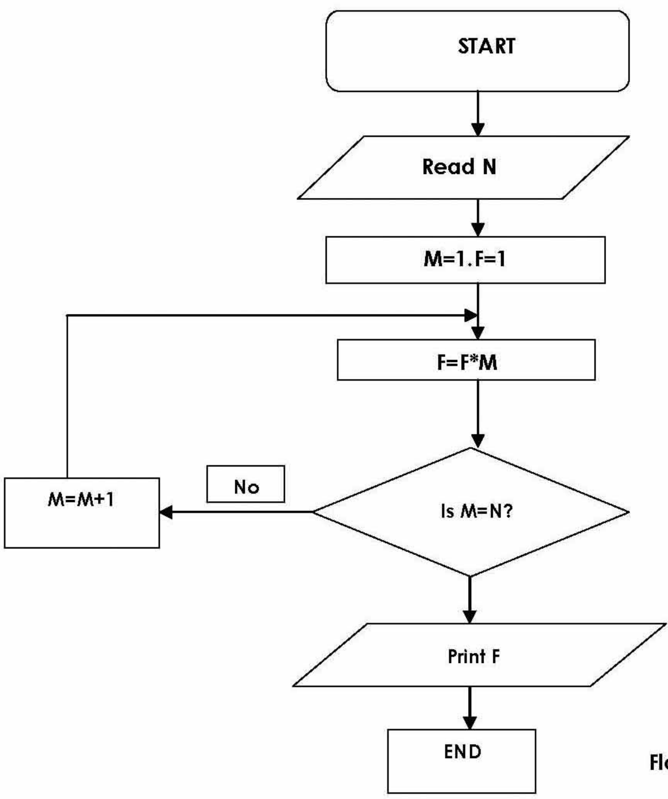
Sum of first 50 natural numbers



Flowchart for finding out the largest of three numbers

Flowchart for finding out the largest of three numbers

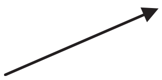
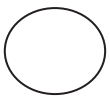
Draw a flowchart for computing fractional N (N!)Where N! =1*2*3*….N.



Flowchart for computing fractional N

(c) Data Flow Diagrams: A Data Flow Diagram represents flow of data among external entities such as people, organizations, etc. A Data flow diagram is composed of four basic elements : Data Sources and Destinations, Data Flows, Transformation processes, and Data stores.

Data flow Diagram

	**Data Sources and Destination**
	**Data Flow**
	**Transformation Process**
	Data Stores

(d) Decision Tree: A Decision Tree is commonly used in operations research, specifically in decision analysis and to calculate conditional probabilities. For example:-

David, a manager of a famous golf club is having some trouble with his customer attendance. There are days when everyone wants to play golf and the staff are overworked. On other days, for no apparent reason, no one comes to play golf. David's objective is to optimize staff availability by trying to predict when people will play golf. To accomplish that he needs to understand the reason when people decide to play and if there is any explanation for that. He assumes that weather must be an important underlying factor, so he decides to use the weather forecast for the upcoming week. So during two weeks he has been recording:

(a) The outlook, whether it was sunny, overcast or raining.

(b) The temperature

(c) The relative humidity in percent.

(d) Whether it was windy or not.

(e) Whether people attended the golf club on that day.

David compiled this dataset into a table containing 14 rows and 5 columns as shown in Table

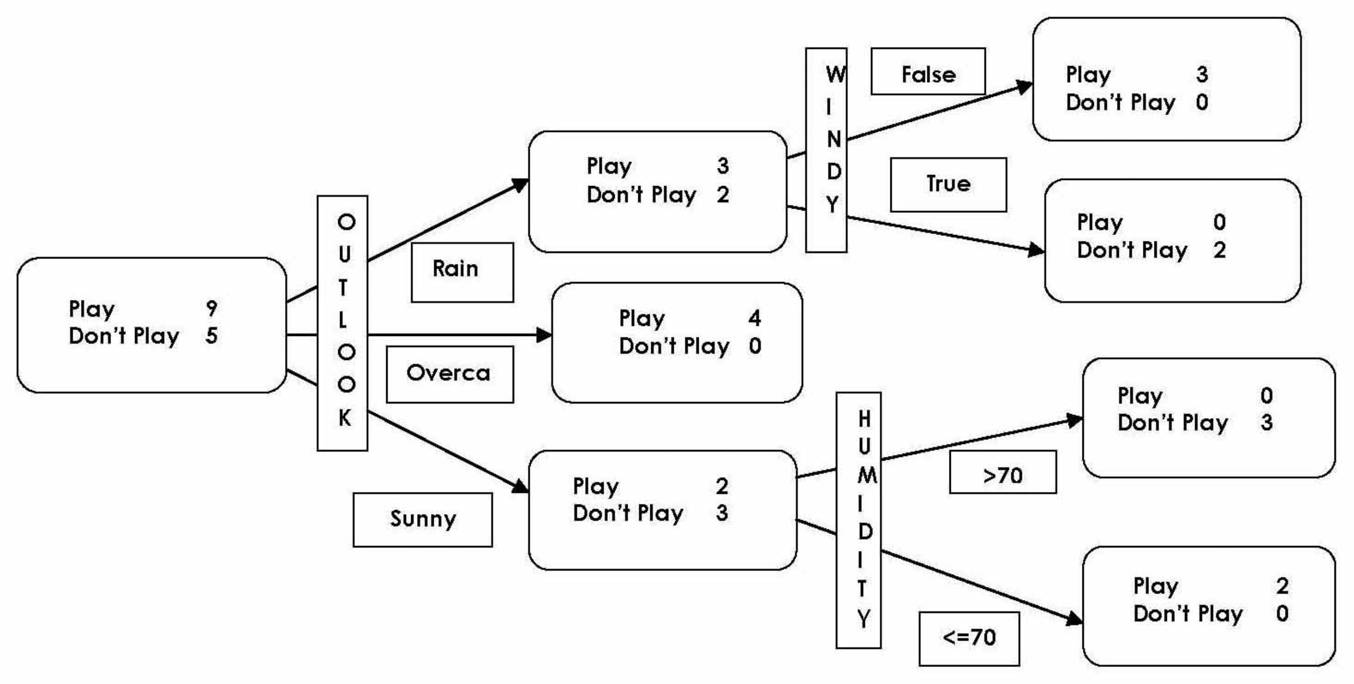
INDEPENDENT VARIABLES				DEPEDENT VARIABLES
OUT LOOK	**TEMPERATURE**	**HUMIDITY**	**WINDY**	**Don't PLAY**
Sunny	80	85	False	Don't Play
Sunny	80	90	True	Pay
Overcast	83	78	False	Play
Rain	70	96	False	Play
Rain	68	80	False	Don't Play
Rain	65	70	True	Play
Overcast	64	65	True	Don't Play
Sunny	72	95	False	Play
Sunny	69	70	False	Play
Rain	75	80	False	Play
Sunny	75	70	True	Play
Overcast	72	90	True	Play
Overcast	81	75	False	Play
Rain	71	80	True	Don't Play

Here the variable is outlook and the dependent variable is play. Three different groups were found:

(a) One that plays golf when the weather is sunny,

(b) One that plays when the weather is cloudy, and

(c) One that plays when it's raining.



David dismisses most of the staff on days that are sunny and humid > 70 or on rainy days that are windy, because almost no one is going to play golf on these days. On days when lot of people will play golf, he hires extra staff. Hence, the decision tree helped david in finding out the most easiest solution.

(e) **Decision Table:** A Decision Table is a table which defining the possible contingencies that may be considered within the program.

The four parts of the decision table are as follows:

(i) **Condition Stub -** lists the comparisons or conditions;

(ii) **Action Stub -** lists the actions;

(iii) **Condition entries -** list in its various columns the possible permutations;

(iv) **Action entries -** lists, in its columns corresponding to the condition entries the actions contingent upon the set of answers to questions of that column.

(f) **Case Tools:** CASE (Computer-Aided-Software Engineering) refers to the automation of anything that humans do to develop systems and support virtually all phases of traditional system development process. These can be used to create internally requirements specifications with graphic generators and using of specifications languages. The various CASE tools are menu generator, screen generator, report generator and code generator.

- **Layout form and Screen Generator:** They are for printed report used to format or paint the desired layouts.
- **Menu Generator:** Menu generator outlines the functions.
- **Report Generator:** It indicate totals, paging, sequencing and control breaks in creating samples of the desired report.
- **Code Generator:** It allows the analyst to generate modular units of source code.

Some of the other features that various CASE products possess are - Repository / Data Dictionary, Computer aided Diagramming Tools; Word Processing; Screen and Reverse Engineering.

(g) **System Components matrix :** It highlights how the basic activities of input, processing, output, storage and controls are accomplished in an information system, and how the use of hardware, software and people resources can convert data resources into information products.

(h) **Data Dictionary:** Each computer record of a data dictionary contains information about a single data item used in a business information system. The information in each record of a Data Dictionary may include the following:

(i) Codes describing the data item's length, data type and range.

(ii) Identity of the source documents used to create the data.

(iii) Names of the computer files storing the data item.

(iv) Identity of individuals/programs permitted to access the data item.

(v) Identity of programs/individuals not permitted to access the data item.

(vi) Names of the computer programs that modify the data item.

For an Auditor, A data dictionary can also help to establish an audit trial because it can identify the input sources of data items, the computer programs that modify particular data items ,and the managerial reports on which data items are output. For the accountants, a data dictionary can also be used to plan the flow of transaction data through the system.

System Specification

At the end of the analysis phase, a document called **System Requirement Specifications (SRS)** is prepared by the system analyst which contain the following:-

- Introduction
- Information Description
- Functional Description
- Behavioral Description
- Validation Criteria
- Appendix

Different Roles Involved in SDLC

(1) Steering Committee: Some of the functions of steering committee are as below :

(i) To provide overall direction

(ii) To be responsible for all cost and timetables.

(iii) To conduct a regular review of progress of the project.

(iv) Taking corrective actions like rescheduling, e-staffing, change in the project objectives etc.

(2) Project Manager: A project manager is responsible for delivery of project with in time and budget.

(3) Project Leader: Project leader views the project position more frequently than a project manager.

(4) System Analysts/Business analysts: System Analysts is a link between the users and the programmers who converts the user requirements in the system requirement.

(5) Module Leader / Team Leader: In developing a financial accounting application - Treasury, Accounts payable, Accounts receivable can be identified as separate modules and can be assigned to different module leaders.

(6) Programmer / Coder / Developer: Programmers converts design into programs by coding using programming language.

(7) Database Administrator (DBA): The DBA handles multiple projects and ensures the integrity and security of information stored in the database. The Inclusion of new data elements is done only with the approval of the database administrator.

(8) Quality Assurance: This team sets the standards for development, and checks compliance with these standards on a periodic basis.

(9) Tester: Tester is one who tests programs and subprograms as per the plan given by the module / project leaders and prepare test reports.

(10) Domain Specialist: Domain Specialist help the project team in developing an application which is new to project team.

5.5 SYSTEM DESIGN

This is the third stage of SDLC. Its objective is to designing of an Information System and must be such that which best satisfies the user / managerial requirements.

Activities: Key design phase activities include determining of the processing steps and computation rules for the new solution and it also involves in preparing the program specifications for the various types of requirements. System design involves first logical design and then the physical construction of a system.

Once the detailed design is completed, the design is then distributed to the system developers for coding. The design phase involves following steps:

(i) Architectural Design;

(ii) Design of the Data / Information Flow;

(iii) Design of the Database;

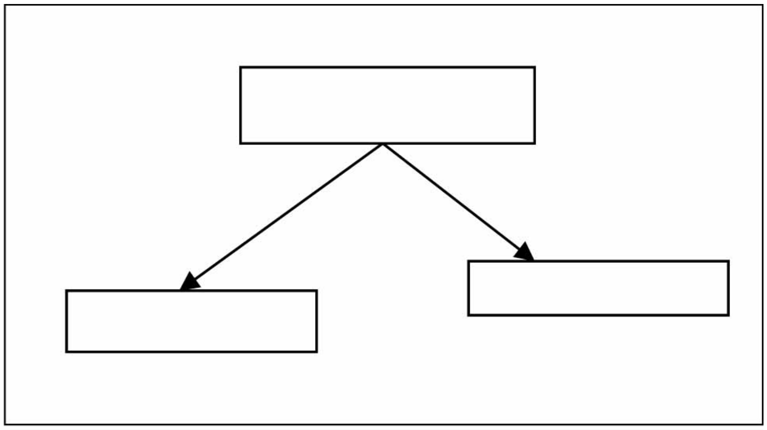
(iv) Design of the User-interface;

(v) Physical Design; and

(vi) Design and acquisition of the hardware/system software platform.

Architectural Design

The architectural design is made with the help of a tool called Functional decomposition. It has three elements - Module, Connection, and Couple. The module is represented by a box and connection between them by arrows. Couple is data element that moves from one module to another and is shown by an arrow.



Design of Data / Information Flow

In designing the data / information flow for the proposed system, the inputs that are required are - existing data / information flows, problems with the present system, and objective of the new system.

Design of Database

The design of the database involves four major activities -

(1) Conceptual Modeling

(2) Data Modeling

(3) Storage Structure Design

(4) Physical Layout Design

Design of User-Interface

Design of user-interface involves determining the ways in which users will interact with a system. While designing the user-interface the points that needs to be considered are source documents to capture data, output reports etc.

Design of Hardware /System Software Platform

The new hardware/system software platform required to support the application system will have to be designed because different and old hardware and software may not be able to communicate with each other.

Designing System Outputs and Inputs

Major factors to be considered in designing User Inputs:

Various issues that should be considered while designing systems input are briefly discussed below:

Input design consists of developing specifications and procedures for data preparation, developing steps which are necessary to put transactions data into a usable form for processing, and data-entry. Important factors to be considered in the input design :

(a) **Content:** The system designer has to prepare new documents for collecting the information which are needed to generate user output.

(b) **Timeliness:** In data processing, it is very important that data is inputted to computer in time because outputs cannot be produced until certain inputs are available.

(c) **Media:** Media is just a device by which data is entered in the system and includes magnetic tapes, magnetic disks, key-boards, optical character recognition and voice input etc.

(d) **Format:** After the data contents and media requirements are determined, input formats are to be considered. The type and length of each data field as well as any other special characteristics must be defined.

(e) **Input volume:** Input volume refers to the amount of data that has to be entered in the computer system at any one time. In many real-time transaction processing systems, input volume is light. In batch-oriented transaction processing systems, input volume could be heavy which involve thousands of records and also more than it.

Important factors which should be considered while designing the user outputs :

These are the important factors which should be considered by the system analyst while designing user outputs.

(a) **Content:** Only the required information should be included in various outputs because too much content can cause managers to waste time in selecting the information that they need. For example -the contents of a weekly report of a sales manager might consist of sales persons and the amount of each product sold by each sales persons.

(b) **Form:** Content can be presented in various forms-quantitative, non-quantitative, text, graphics, video and audio many managers prefer summary information in chart form such as pie chart, line chart, bar chart.

(c) **Output volume:** It is better to use high-speed printer which are fast in case the volume is heavy.

(d) **Timeliness:** Some outputs are required on a regular, periodic basis - perhaps daily, weekly, monthly, at the end of a quarter or annually.

(e) **Media:** A variety of output media are available in the market are- video display, microfilm, magnetic tape/disk and voice output.

(f) **Format:** The manner in which data are physically arranged is referred to as format.

Physical Design

The logical design is transformed into units, which in turn can be decomposed further into implementation units such as programs and modules, these modules are the physical design.

Design Principles

- Design is to be considered as final product.
- The design should be based on the analysis.
- The software functions designed should be directly relevant to business activities.
- The design should follow standards laid down.
- The design should be modular.

Modularity

A module is a manageable unit containing data and instructions to perform a well-defined task. Modularity is measured by two parameters: **Cohesion** and **Coupling**. Cohesion refers to the manner in which elements within a module are linked. Coupling is a measure of the interconnection between modules. In a good modular design, cohesion will be high and coupling will be low.

System Manual

A system manual is an output of the system design that describes the task to be performed by the system with complete layouts and flow charts. It contains:

(a) **General description of the existing system:** It describes the general structure of the existing system from top management to the bottom management.

(b) **Flow of the existing system:** It describes the input, processing and output of the data to be flow at various levels of organisation's structure.

(c) **Outputs of the existing system:** The documents produced by existing system are listed.

(d) **General description of the new system:** A brief justification for the changes is specified.

(e) **Flow of the new system:** It defines the flow of the system from and to the computer operation and within the computer department.

(f) **Output Layouts:** It describes the user interface or layouts for the user that is used for better communication in near future.

(g) **Output distribution:** The output distribution is summarized.

(h) **Input layouts:** The inputs to the new system are described as well as a complete layouts of the input documents, input disks or tapes are described.

(i) **Input responsibility:** The source of each input document is indicated and thus the user department is responsible for each item on the input documents.

(j) **Macro Logic:** It defines the logic of the internal flows as to be defined by system analysts.

(k) **Controls:** This shall include type of controls, and the method in which it will be operated.

5.6 SYSTEM ACQUISITION AND DEVELOPMENT OF SOFTWARE

Acquisition Standards:

Acquisition standards must focus on -

(a) Ensuring security, reliability, and functionality already built into a product.

(b) Ensuring managers to acquire products compatible with existing systems.

(c) Including invitations-to-tender and request-for-proposals should be made. Invitations-to-tender involve soliciting bids from vendors when acquiring hardware or integrated systems of hardware and software.

(d) Establishing acquisition standards to ensure functional, security, and operational requirements to be accurately identified and clearly detailed in request-for-proposals.

Advantages of Pre-written Application Packages: The advantages of using pre-written application packages are summarized below:

(a) **Rapid implementation:** Just after purchasing application packages are readily available but software developed in-house may take months or even years.

(b) **Low risk:** Organizations know the cost and its price as the application package is available in finished but in With in-house developed software, there is an uncertainty with regard to both the quality of the final product and its final cost.

(c) **Quality:** Due to high expertise of the firms engaged in application package, developments can provide better software. In contrast, in-house programmers often have to work over a wide range of application areas and they may not be possessing expertise for undertaking proposed software development.

(d) **Cost:** A pre-written application package generally costs less than an in-house developed package. In addition, many hidden costs are faced by organisations that want to develop applications in-house.

Acquiring Systems Components from Vendors

(a) **Hardware Acquisition:** Hardware acquisition is not just buying the machine and paying the vendor for it but it amounts to an enduring alliance with the supplier. Latest possible technology should be acquired. It is said that the more recent the computer, the better its performance.

(b) **Software Acquisition:** Once user output and input designs are finalized, the nature of the application software requirements must be assessed by the systems analyst. At this stage, the system developers must determine whether the application software should be created in-house or acquired from a vendor.

The factors upon which "Make or Buy" decision of an application software depends:

(a) **Availability of skilled manpower:** If sufficient number of programmers is not available, the organization may purchase packages.

(b) **Cost of programming:** If the cost of developing the software is more than the price of pre-written software, the organization may decide to buy the software.

(c) **Suitability of software:** Many times the available software may not be suitable for the particular needs of the organization. Hence, it may be better to develop software in such instances.

(d) **Time frame available for implementation:** If the time available for implementation of the new computerized system is very short, the organization may go for buying the software.

(e) **Availability of sophisticated software:** In many instances, the programs available for purchase are more sophisticated than the organization would probably develop. For example, many of the applications programs are fully integrated with other application programs. This integration forces for purchasing rather than developing programs.

Contracts, Software Licenses and Copyright Violation

Contracts between an organization and a software vendor should be in writing with sufficient detail to provide assurances for performance, source code accessibility, software and data security, and other important issues.

Software license is a license that grants permission to do things with computer software.

What is vendor evaluation?

Once the proposals are received from various vendors for the system, it is the responsibility of the IT Incharge or the committee to select the best product relevant to the requirements/needs of the organization. . In order to facilitate the process, following are the factors contributing to evaluation and validation process of vendors' proposals:

(i) **Performance Rating of the proposed system in relation to its cost:** In this approach, the vendors are provided with the sample data and the task is performed by each vendor. Subsequently representatives of the organization examine the outputs for accuracy, consistency as well as processing efficiency, so, operational efficiency is judged.

(ii) **Cost Benefits of the proposed system:** In this process, the cost benefit analysis is performed in relation to the performance benefits against the Total Cost of Operations.

(iii) Maintainability of the proposed system: It refers to the flexibility and customization scope inbuilt in the pr posed system for effective use in the organization. If the changes occurring due to the federal tax laws and statutory legal requirements, it should be analysed that whether it can be incorporated in the package easily or not.

(iv) Compatibility with Existing Systems: The proposed system has to be operated in integration with other existing systems in the organization so that it forms a part of the Integrated Enterprise System.

- **Vendor Support :** Support of vendors must be provided at the time of training, implementation, testing and back-up systems.

Methods of Validating the Proposals

Large organizations would naturally tend to adopt an objective approach to validate the vendor's proposal. Some of the validation methods are as follows :

(i) Checklists: The various criteria are put in check list in the form of suitable questions against which the responses of the various vendors are validated.

Point Scoring Analysis in Vendor Evaluation

(ii) Point-Scoring Analysis: When performing a point-scoring analysis, the evaluation committee first assigns potential points to each of the evaluation criteria based on its relative importance. After developing these selection criteria, the evaluation committee proceeds to rate each vendor or package, awarding points, as it deems fit. The highest point determines the winner Assuming that in the process of selecting an accounts payable system, an organization finds three independent vendors whose packages appear to satisfy current needs. The given table shows the results of the analysis.

Software Evaluation Criteria	**Possible points**	**Vendor A**	**Vendor B**	**Vendor C**
Dose the software meet all mandatory specifications ?	10	9	8	7
Does the software contain adequate controls?	10	7	9	6
Is the performance (speed, accuracy, reliability etc) ade-quate?	10	8	9	7
Are other user satisfied with the software?	8	6	7	5
Is the software user friendly ?	10	8	8	7
Can the software be demonstrated and test driven?	9	7	8	7
Will the software give an adequate warranty?	8	7	7	7
Is the software flexible and easily maintained?	8	6	6	5
Totals	73	58	62	50

(iii) Public Evaluation Reports: Several consultancy agencies compare and contrast the hardware and software performance for various manufacturers and publish their reports in this regard, which can be used for vendors evaluation.

(iv) Bench marking problem for vendor's proposals: This practical approach is very popular because it can test the functioning of vendors' proposal. Benchmarking problems are oriented towards testing whether a computer offered by the vendor meets the requirements of the task. Benchmarking problems can be applied only if job mix has been clearly specified. The benchmarking problems would comprise long jobs, short jobs, printing jobs, disk jobs, mathematical problems, input and output loads etc.

Benchmarking problems, however, suffer from a couple of disadvantages. It takes considerable time and effort to select problems representative of the job mix.

(v) Test problems: Test problems disregard the actual job mix and are devised to test the true capabilities of the hardware, software or system. For example, test problems may developed to evaluate the time required to translate the source code into the object code, response time required to execute an instruction, etc. The results, achieved by the machine can be compared.

Development: Programming Techniques and Languages

A good coded program should have the following characteristics:

(a) Individuality: The code should be universally used over the entire organization.

(b) Convenience: The code number should be short and simple and consists of digits or alphabets.

(c) Reliability: Poor setting of parameters and hard coding may subsequently could result in the failure of a program.

(d) Robustness: It refers to the process of taking into account all possible inputs and outputs of a program.

(e) Efficiency: It refers to the performance which should not be affected with the increase in input values.

(f) Usability: It refers to a user-friendly interface and easy-to-understand.

(g) Readability: The maintenance of program must be easier.

Stages through which the program has to pass during its development:

The stages are:

(a) Program Analysis

(b) Program design

(c) Program coding

(d) Debug the program

(e) Program documentation

(f) Program maintenance

Program Coding Standards: Coding standards provide, simplicity, efficient utilization of storage and least processing time. At the time of writing the program code the programmer has to strictly follow different syntax like vocabulary, punctuation and grammatical rules available in the language manuals

Programming Language-Programming language are coded in the form of statements. The programming languages commonly used are as follows:

(a) High - level general purpose programming language such as COBOL and C language.

(b) Object oriented languages such as C++, JAVA etc.

(c) Scripting language like JAVAScript, VBScript.

(d) Decision Support or Expert System languages like PROLOG.

Choice of Programming Language

Algorithmic complexities, structure complexity, knowledge of software development staff are the major factors on the basis of which programming language is choiced.

Program Debugging: Debugging is the form of testing activity which refers to correcting programming language syntax and diagnostic errors so that the program compiles cleanly and thus in this process, errors are found and then they are corrected.

Debugging consisting of following four steps.

(a) Inputting the source program to the compiler.

(b) Letting the compiler find errors in the program.

(c) Correcting lines of code that are erroneous.

(d) Resubmitting the corrected source program as input to the compiler.

Program Documentation: Through out the program life cycle, documentation of procedures and instructions for the users should be made. Program documentation must include the following:

(a) A brief narrative description of what the program should do.

(b) A description of the outputs, inputs and processing to be performed by the program.

(c) A deadline for finishing the program.

(d) The identity of the programming language to use and the coding standards to follow.

(e) A description of the system environment into which the program should fit.

(f) A description of the testing required to certify the program for use.

(g) A description of documentation that must be generated for users, maintenance programmers and operational personnel.

Program Maintenance: The requirements of business applications keep on changing and thus call for modification of various programs. The maintenance of the programs is generally done by people called maintenance programmers. The task of understanding the program written by someone and modifying the same is difficult. Therefore, the maintenance people should be involved from the beginning itself.

5.7 SYSTEM TESTING

System testing must be conducted prior to installation of an information system. It involves:

(a) Preparation of realistic test data in accordance with the system test plan,

(b) Processing the test data using the new equipment,

(c) Thorough checking of the results of all system tests,

(d) Reviewing the results with future users, operators and support personnel

The data collected through testing can also provide an indication of the software's reliability and quality. One of the most effective ways to perform system-level testing is to perform parallel operations with the existing system. System level testing is a very good time for training employees in the operation of the Information Systems as well as maintaining it.

Different levels of Testing are as follows:

Unit Testing

A unit is the smallest testable part of an application which may be an individual program, function, procedure, etc. The goal of unit testing is that the individual parts are correct.

There are five categories of tests that a programmer typically performs on a program unit:

- **Functional Tests:** As per this plan programmer checks by inputting the values to see whether the actual result and expected result match. The test plan tests the operating conditions.
- **Performance Tests:** Performance Tests should be designed to verify the response time, the execution time, the throughput in providing the requirements made by users.
- **Stress Tests:** It involves testing beyond normal operational capacity in order to observe the results. These tests are designed to overload a program in various ways. The purpose of a stress test is to determine the limitations of the program.
- **Structural Tests:** Structural Tests are concerned with examining the internal processing logic of a software system, whether the processing is correctly made as per the logic given.
- **Parallel Tests:** In Parallel Tests, the same test data is used in the new and old system and the output results are then compared.

Types of Unit Testing

(a) Static Analysis Testing: Some important Static Analysis Tests are as follows :

- **Desk Check:** Logical syntax errors and deviation from coding standards are checked.
- **Structured walk-through:** The application developer leads other programmers through the text of the program and explanation.
- **Code inspection:** Review is done with formal checklists by formal committee,

(b) Dynamic Analysis Testing

- **Black Box Testing:** The test designer selects valid and invalid inputs and determines the correct output. If a module performs a function which is not supposed to, the black box test does not identify it as it is not concerned with the internal structure. Thus in black box testing, it has no relation with the internal functioning of a system.
- **White Box Testing:** White box testing uses an internal perspective of the system to design test cases based on internal structure. It requires programming skills to identify all paths through the software. After obtaining a clear picture of the internal workings of a product, tests can be conducted to ensure that the internal operation of the product conforms to specifications and all the internal components are adequately exercised.
- **Gray Box Testing:** Gray box testing is a software testing technique that uses a combination of black box testing and white box testing. In gray box testing, the tester applies a limited number of test cases to the internal workings of the software under test. In the remaining part of the gray box testing, one takes a black box approach in applying inputs to the software under test and observing the outputs.

Integration Testing

Integration testing is an activity of software testing in which individual software modules are combined and tested as a group. This is carried out in the following manner:

- **Bottom-up Integration:** It consists of unit testing, followed by sub-system testing, and then testing of the entire system. The disadvantage is that testing of major decision / control points is deferred to a later period. In this testing it starts from the bottom-up and then it tests the entire system.
- **Top-down Integration:** Once the main module testing is complete, stubs are substituted with real modules one by one, and these modules are tested. Stubs are the incomplete portion of a program code that is put under a function in order to push the function .
- **Regression Testing:** As the software change, each time a new module is added as part of integration testing, the software changes. In the context of the integration testing, the regression tests ensure that changes or corrections have not introduced new errors.

System Testing

When the software as a whole is operational, System testing begins. The types of testing that might be carried out are as follows:

- **Recovery Testing:** Recovery testing is the forced failure of the software in a variety of ways to verify that recovery is properly performed.
- **Security Testing:** The six basic security concepts that need to be covered by security testing are - confidentiality, integrity, authentication authorization, availability and non-repudiation.
- **Stress or Volume Testing:** It involves testing beyond normal operational capacity.
- **Performance Testing:** In the computer industry, software performance testing is used to determine the speed or effectiveness of a computer, network, software program or device.

Final Acceptance Testing

Final Acceptance Testing is conducted when the system is just ready for implementation. During this testing, it is ensured that the new system satisfies the quality standards adopted by the business and the system satisfies the users. Thus the final acceptance testing has two major parts:

- **Quality Assurance Testing:** It ensures that the new system satisfies the prescribed quality standards.
- **User Acceptance Testing :** There are two types of the user acceptance testing.
- **Alpha Testing:** It means the system testing which is often performed by the users within the organization.
- **Beta Testing:** This is the second stage, generally performed by the external users such as by experts data entry operators.

Systems Implementation

System Implementation include the conversion of old system into the new system.

The activities involved in System Implementation are as follows:

- Conversion of data to the new system files.
- Training of end users.
- Completion of user documentation.
- System changeover.
- Evaluation of the system a regular intervals.

Activities during Implementation Stage

(1) Equipment Installation

(2) Training Personnel

(3) System implementation and conversion strategies

Various steps that should be taken for successful Installation of the equimnerrt during the implementation phase:

Following steps should be taken for successful installation of the equipment:

(1) Site preparation: An appropriate location must he found to provide an operating environment for the equipment that will meet the vendor's temperature, humidity and dust control specifications. The electric lines should be checked to ensure that they are free of static or power fluctuation The site-layout should allow sufficient space for moving the equipment in and setting it for normal operation.

(2) Equipment installation: The equipment must be physically installed by the manufacturer, connected to the power source and wired to communication lines, if required.

(3) Equipment check out: The equipment must be turned on for testing under normal operating conditions, the implementation team should devise and run extensive tests of its own to ensure that equipments are in proper working condition.

Training Personnel

A system can succeed or fail depending on the way it is operated and used. When a new system is acquired which often involves new hardware and software, both users and computer professionals generally need some type of training.

Training Systems Operators: Their training must ensure that they are able to handle all possible operations, both routine and extra ordinary. As part of their training, operators should be given both a trouble-shooting list that identifies possible problems and remedies for them, as well as the names and telephone numbers of individuals to contact when unexpected or unusual problems arise.

User Training: users must be instructed first how to operate the equipment. Users should be trained on data handling activities such as editing data, formulating inquiries and deleting records of the data.

System Implementation & Conversion Strategies:

Four types of implementation strategies are as follows:

(a) Direct Implementation / Abrupt change-over: Conversion by direct change over means that on a specified date the old system is dropped and the new system is put into use . The users have no possibility of using the old system other than the new one. Adaptation is a necessity. The disadvantage is that as the old system is dropped and new system is put to use, there is no adequate way to compare new results with old ones.

(b) Phased implementation: If each phase is successful then the next phase is started, eventually leading to the final phase when the new system fully replaces the old one. The advantage is that. It allows users to get involved with the system gradually. The disadvantage is that It takes too long to get the new system in place.

(c) Pilot implementation: With this strategy, the new system replaces the old one in one operation but only on a small scale, it might be tried out in one branch of the company or in one location. When one operation is sucessfully completed, other conversions are done for other operations. Each module is thoroughly tested before being used. Users become familiar with each module as it becomes operational.

(d) Parallel running implementation : The old system remains fully operational while the new systems come online, the old and the new system are both used alongside each other .If all goes well, the old system is stopped and new system carries on. The advantage is that there is a possibility of checking new data against old data in order to catch any errors in the processing of the new system. The disadvantage is that Cost of running two systems at the same time is high. The workload of employees during conversion is almost doubled.

Activities involved in conversion

Activities involved in conversion: These activities are classified as follows:

(a) Procedure conversion: Operating procedures should be completely documented for the new system. Brief meetings must be held when changes are taking place in order to inform all operating employees of any changes initiated.

(b) File conversion: Because large files of information must be converted from one medium to another. In order for the conversion to be as accurate as possible, file conversion programs must be thoroughly tested. Adequate controls, such as record counts and control totals, should be the required output of the conversion program.

(c) System conversion: A cutoff point is established so that data base and other data requirements can be updated to the cutoff point. All transactions initiated after this time are processed on the new system. Consideration should be given to operating the old system for some more time to permit checking and balancing the total results of both systems.

(d) Scheduling personnel and equipment: Some programs might be operational while others will be in various stages of compiling and testing. Schedules should be set up by the system manager in conduction with departmental managers of operational units.

(e) Alternative plans in case of equipment failure: Alternative-processing plans must be implemented in case of equipment failure. Priorities must be given to those jobs critical to an organization, such as billing, payroll, and inventory. Critical jobs can be performed manually until the equipment is set right.

Post Implementation Review

Evaluation of the new system: The final step of the system implementation is evaluation. Evaluation provides the feedback necessary to assess the value of information and the performance of personnel and technology included in the newly designed system.

There are two basic areas of information systems that should be evaluated. The first area is concerned with whether the newly developed system is operating properly. The other area is concerned with whether the user is satisfied with the information system with regard to the reports supplied by it.

Development evaluation: Evaluation of the development process is primarily concerned with whether the system was developed on schedule and within budget.

Operation evaluation: The evaluation of the information system's operation pertains to whether the hardware, software and personnel are capable to perform their duties and they do actually perform.

Operation evaluation answers such questions:

(1) Are all transactions processed on time?

(2) Are all values computed accurately?

(3) Is the system easy to work with and understand?

(4) Is terminal response time within acceptable limits?

(5) Are reports processed on time?

(6) Is there adequate storage capacity for data?

Information evaluation: The extent to which information provided by the system is supportive to decision making is the area of concern in evaluating the system. User satisfaction can be used as a measure to evaluate the information provided by an information system. If management is generally satisfied with an information system, it is assumed that the system is meeting the requirements of the organization.

5.8 SYSTEM MAINTENANCE

System maintenance involves modifying reports ,adding new reports ,changing calculations to update system.

Maintenance can be categorized in the following two ways :

(1) Scheduled maintenance: Scheduled maintenance is anticipated .For example, the implementation of a new inventory coding scheme can be planned in advance. The system should be evaluated periodically to ensure that it is operating properly and is still workable for the organization.

(2) Rescue maintenance: Rescue maintenance refers to previously undetected malfunctions or such sudden changes that were not anticipated but require immediate solution. Rescue maintenance is unplanned .thus a system that is properly developed and tested should have few occasions of rescue maintenance.

As System increase and expand, systems maintenance places increasing demands on programmers time.

Some other maintenance which can be done are :

(i) Corrective maintenance: The need for corrective maintenance is usually initiated by bug reports drawn up by the end users.

(ii) Adaptive maintenance: Adaptive maintenance consists of adapting software to changes in the environment, such as change in business rule, government policies,

(iii) Perfective maintenance: Perfective maintenance mainly deals with accommodating to new or changed user requirements and concerns functional enhancements to the system and activities to increase the system's performance or to enhance its user interface.

(iv) Preventive maintenance: Preventive maintenance concerns with the activities aimed at increasing the system's maintainability.

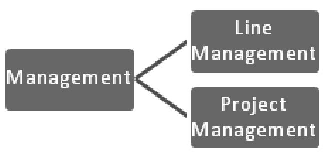
Operation Manuals

Operation Manuals : A user's guide, also commonly known as an Operation Manual, is a document intended to give assistance to people using a particular system.

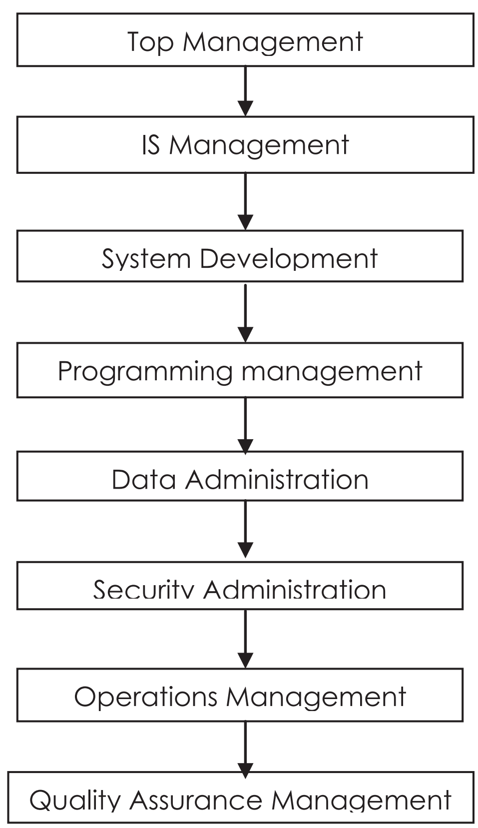
The section of an operation manual after include the following :

- A cover page, a title page and copyright page;
- A preface, containing details of related documents and information on how to navigate the user guide;
- A contents page;
- A guide on how to use at least the main functions of the system;
- A troubleshooting section detailing possible errors or problems that may occur, along with how to fix them;
- A FAQ (Frequently Asked Questions);

Organizational Structure of it Department

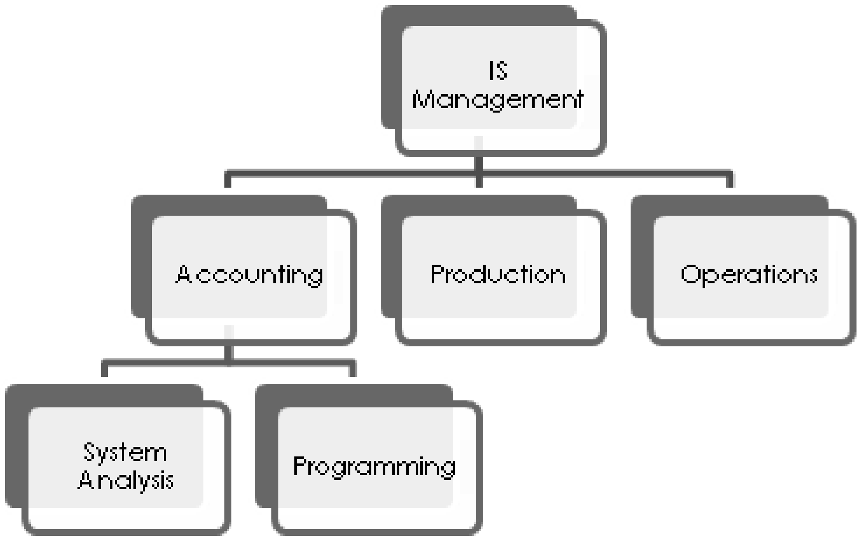


Line Management Structure : Several levels of management subsystems have been identified.



Several levels of management subsystems

Project Management Structure: In project management, project requests are submitted to and prioritized by the steering committee.



Roles performed by IS Manager

Duties and Responsibilities :

The structure of an IT Department is divided into two main areas of activity:

(a) Information processing.

(b) System development and enhancement.

Information processing is concerned with the operational aspects and include-computer operations, system programming etc. System development is concerned with the development, acquisition and maintenance of computer application systems and performs systems analysis and programming functions.

- **Data entry :** The data entry supervisor is responsible for ensuring whether the data is authorized, accurate and complete when entered into the system.
- **File Library:** Managing the organizations library of machine readable files involve 3 functions:
  (1) Files must be used only for the purposes intended.
  (2) The storage media used for files must be maintained in correct working order.
  (3) A file backup strategy and file retention strategy must be implemented.

The file librarian is responsible for recording, issuing, receiving and safeguarding all programs and data files that are maintained on computer tapes or disks.

(i) **Security Administration :** The security administrator in a data processing organization is responsible for matters of physical security.

(ii) **Conducting a Security program :** A security program is a series of ongoing, regular, periodic evaluations conducted to ensure that the physical facilities of an Information system are safe-guarded adequately.

5.9 ER-ENTITY RELATIONSHIP DIAGRAM

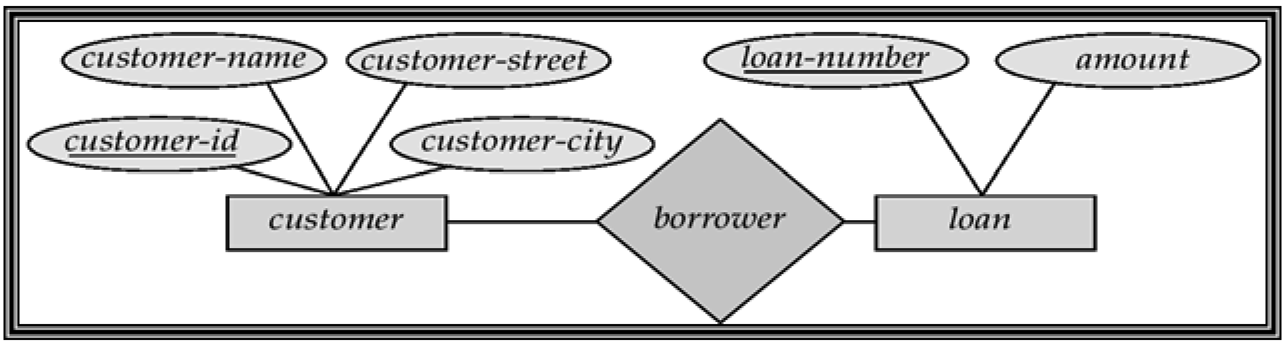
- Major components of ER diagram
- Practices

1976 proposed by Peter Chen. ER diagram is widely used in database design. It represent conceptual level of a database system.

Basic Concepts

- Entity set – an abstraction of similar things, e.g. cars, students
    - An entity set contains many entities
- Attributes: common properties of the entities in a entity sets
- Relationship – specify the relations among entities from two or more entity sets

Example



Relationship

A relationship may be thought as a set as well

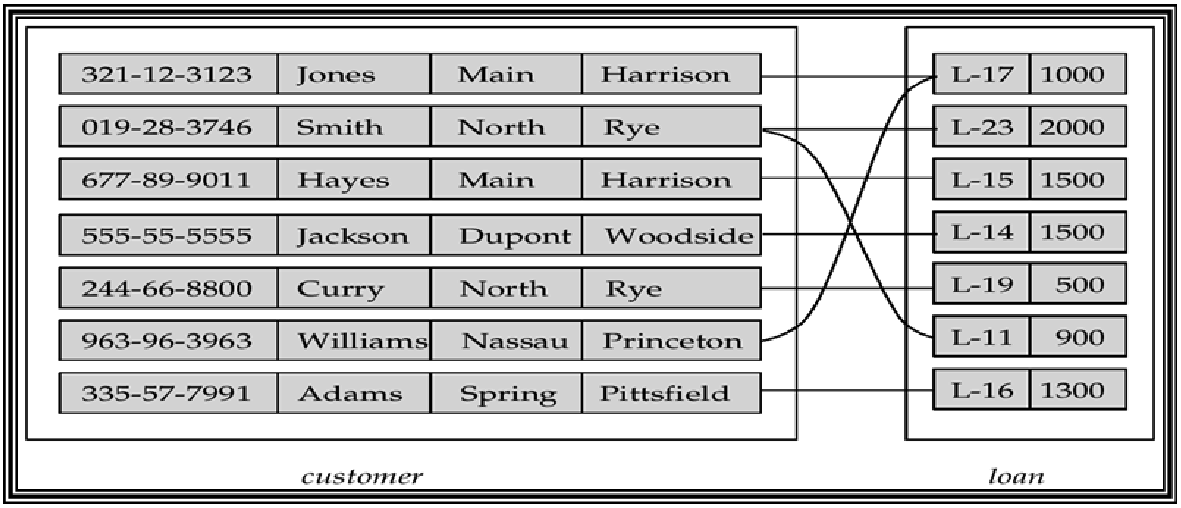
- For binary relationship, it enumerates the pairs of entities that relate to each other
- For example, entity set *M* = *{Mike, Jack, Tom}* entity set *F* = *{Mary, Kate}*. The relationship set *married* between M and F may be {<Mike,Mary>,<Tom, Kate>}
- A *relationship* set is a mathematical relation among $n \geq 2$ entities, each taken from entity sets

$$\{(e_1, e_2, \ldots e_n) \mid e_1 \in E_1, e_2 \in E_2, \ldots, e_n \in E_n\}$$

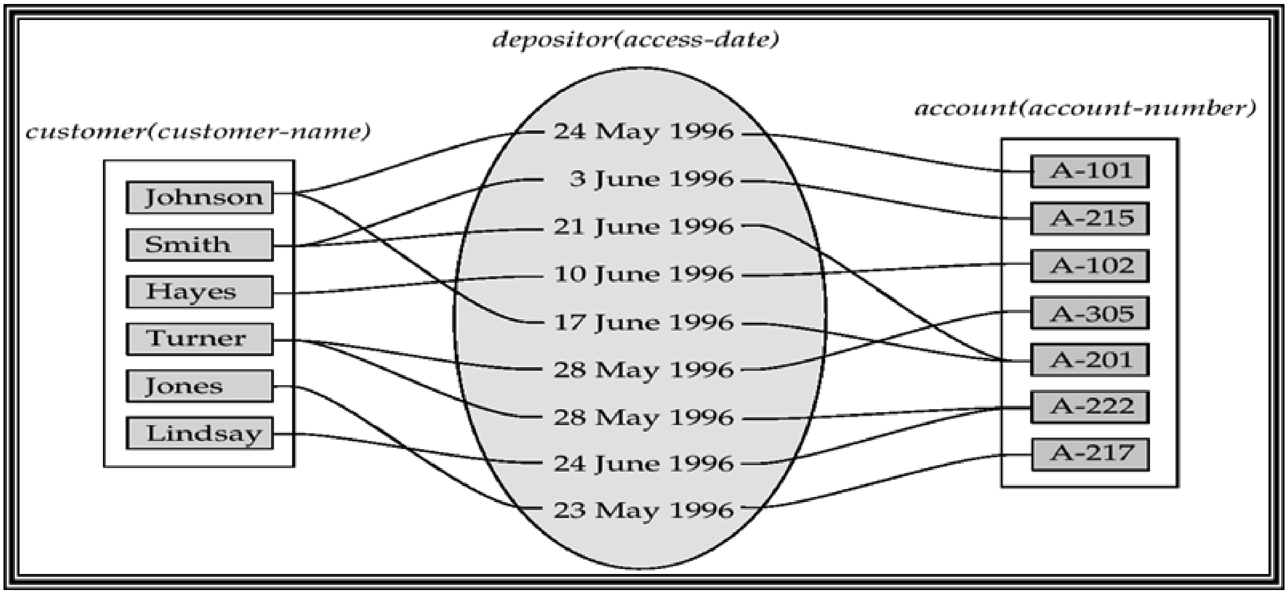
where $(e_1, e_2, \ldots, e_n)$ is a relationship

- Example:

(Hayes, A-102) $\in$ *depositor*



Attribute of a Relationship Set



Entity Relationship Models

- Mandatory Relationships
- Optional Relationships
- Many-to-Many Relationships
- One-to-Many Relationships
- One-to-One Relationships
- Recursive Relationships

Relationship

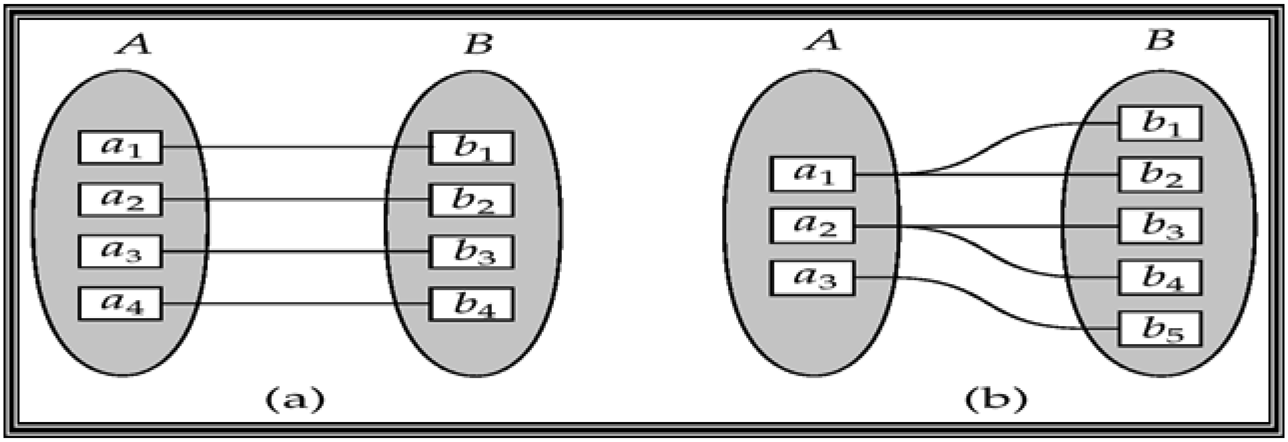
The degree of a relationship = the number of entity sets that participate in the relationship

- Mostly binary relationships
- Sometimes more

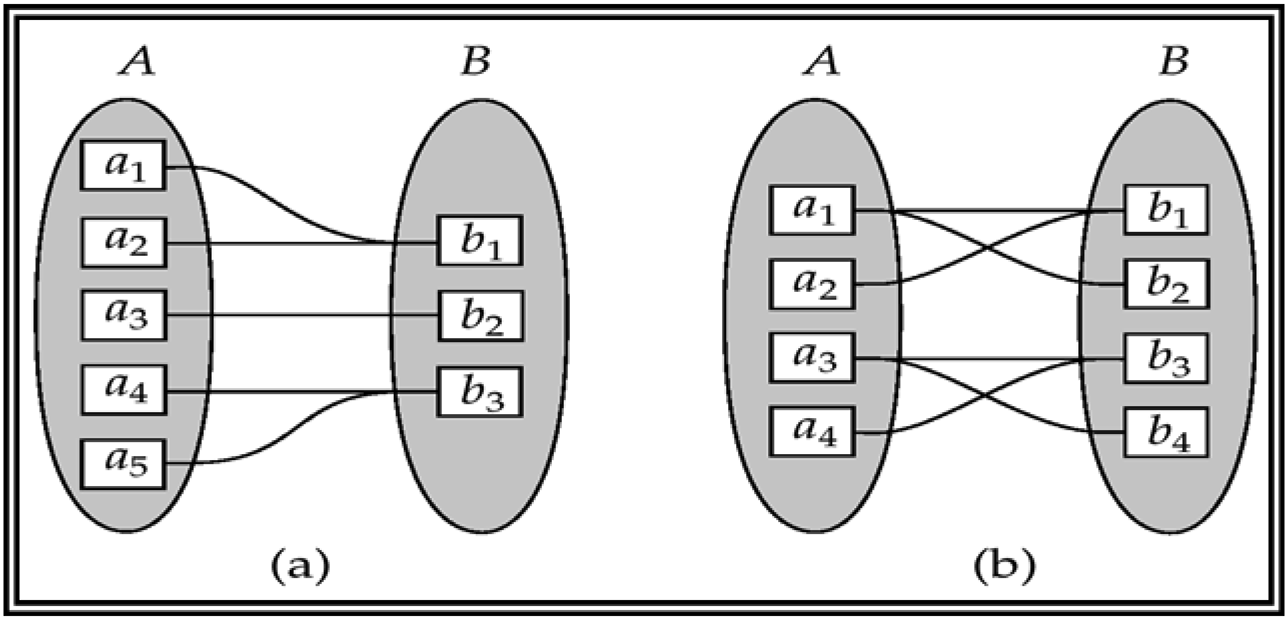
Mapping cardinality of a relationship

- 1 –1
- 1 – many
- many – 1
- Many-many

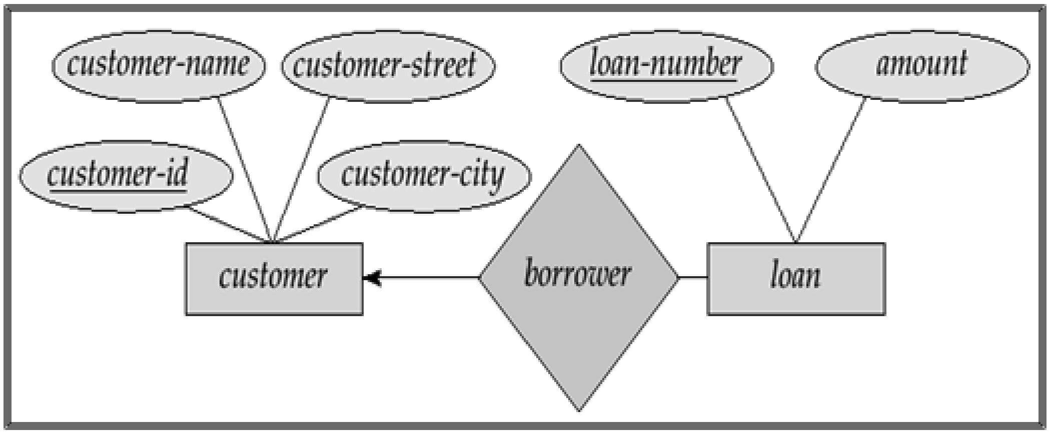
One-One and One-Many



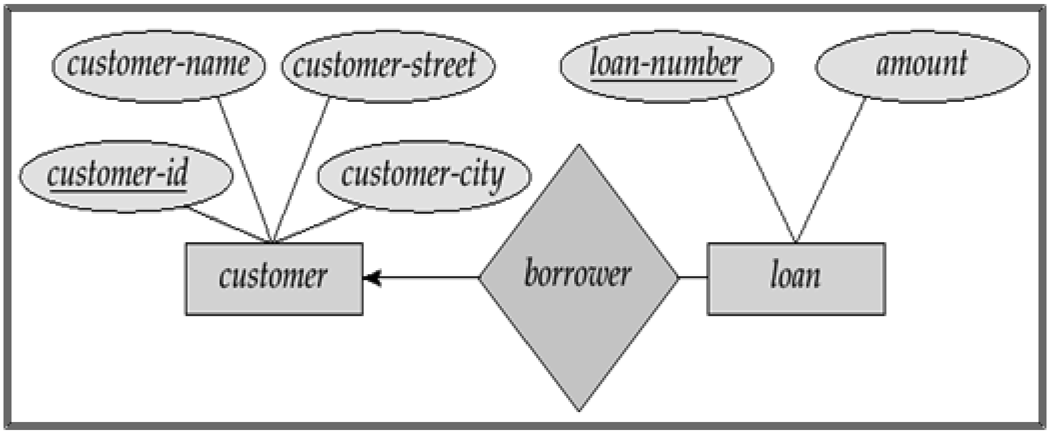
Many-one and many-many



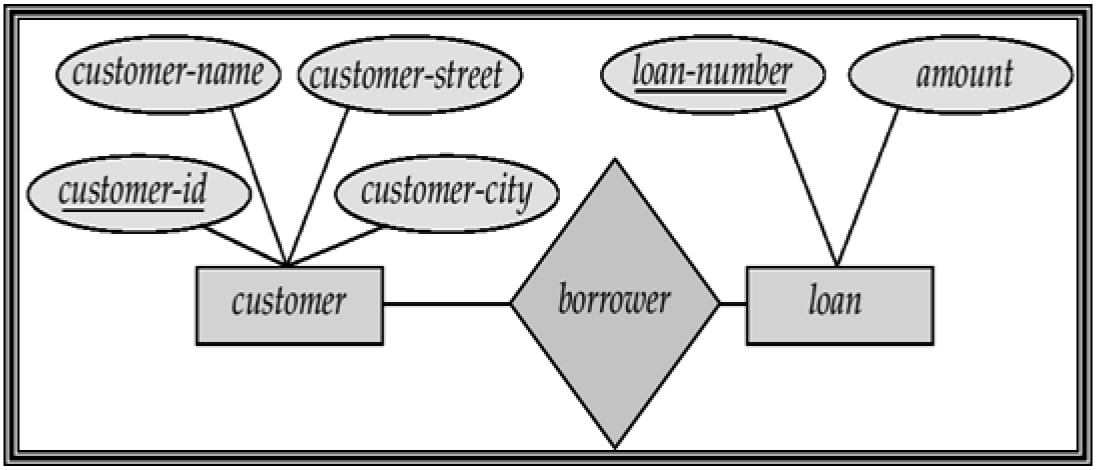
1- **many**



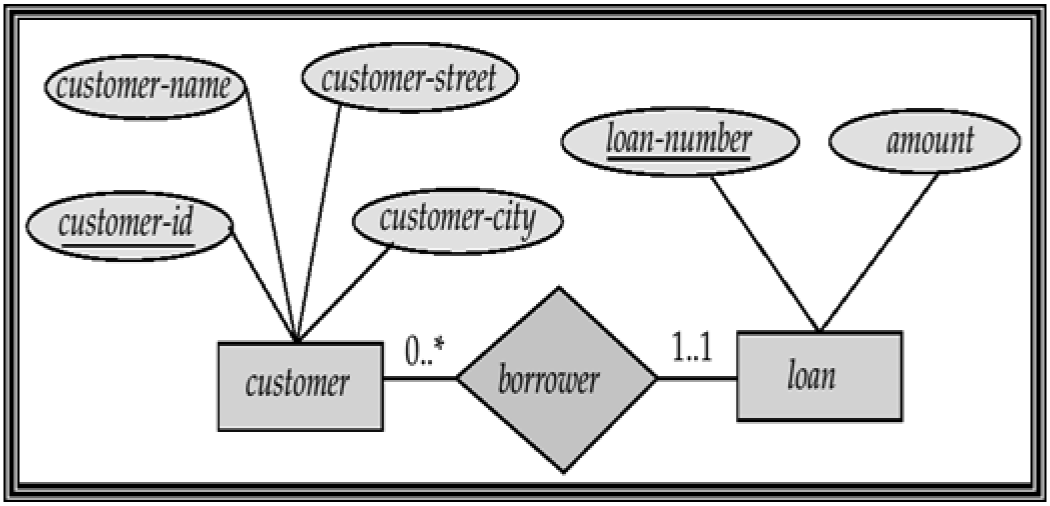
Many – 1



Many – many



Alternative Cardinality Specification



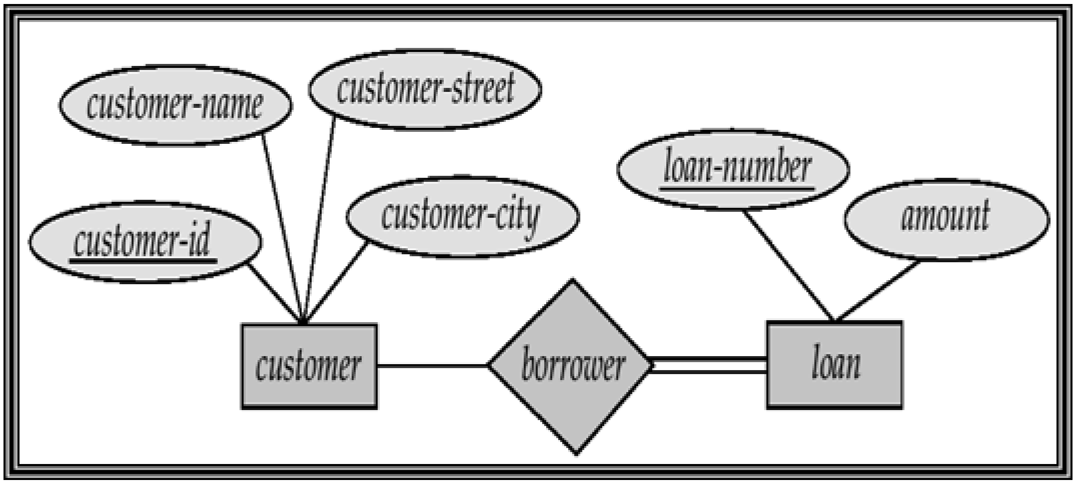
Note on Mapping Cardinality

- Both many and 1 include 0
- Meaning some entity may not participate in the relationship

Total Participation

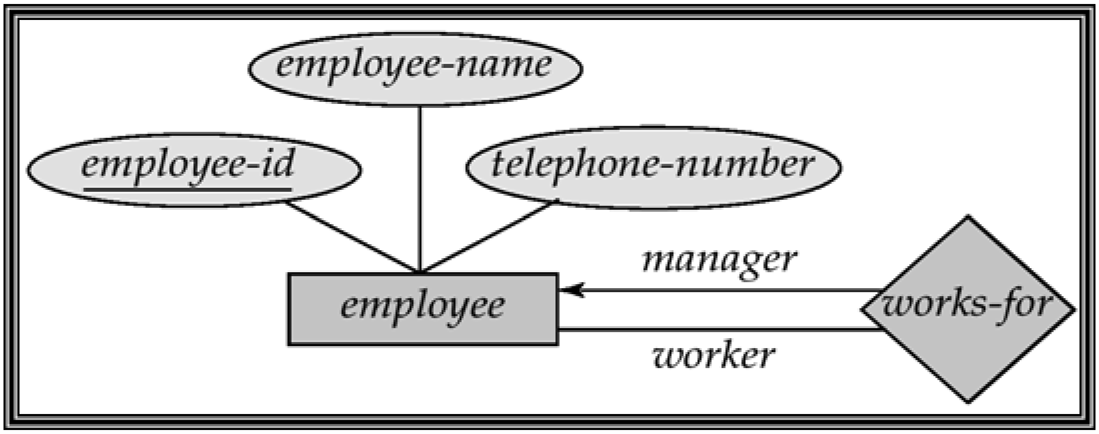
When we require all entities to participate in the relationship (total participation), we use double lines to specify

Every loan has to have at least one customer



Self Relationship

- Sometimes entities in a entity set may relate to other entities in the same set. Thus self relationship
- Here employees mange some other employees
- The labels "manger" and "worker" are called *roles* the self relationship



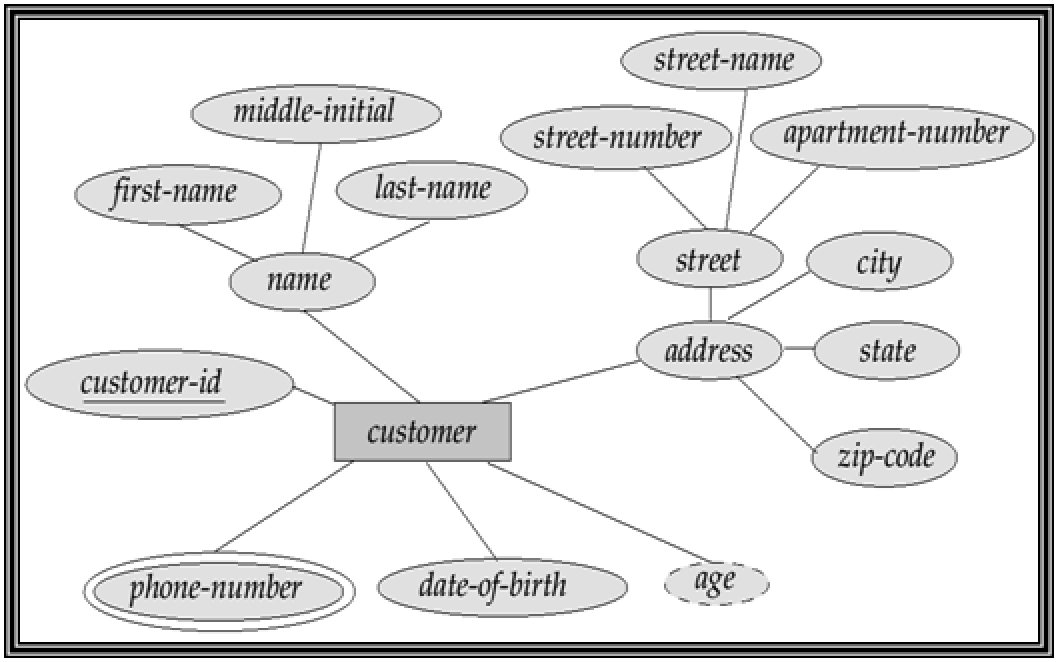
More examples on self-relationship

- People to people
  - Parent – children
  - Manager – employee
  - Husband – wife
- Word to word
  - Root – synonym

Attributes

- Both entity sets and relationships can have attributes
- Attributes may be
  - Composite
  - Multi-valued (double ellipse)
  - Derive (dashed ellipse)

Another Example

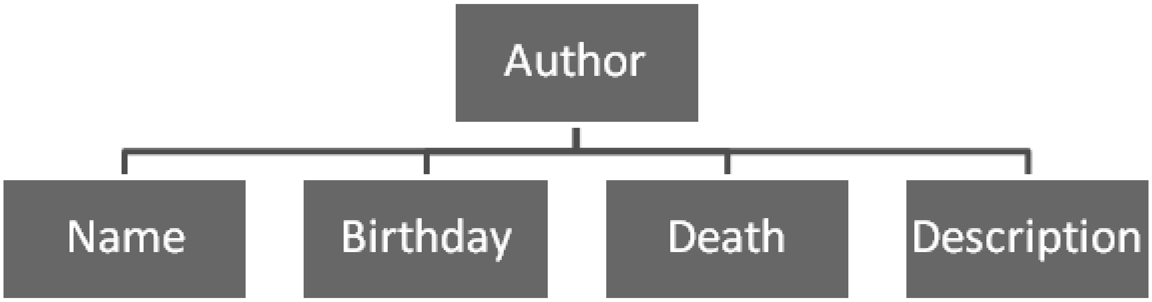


Keys

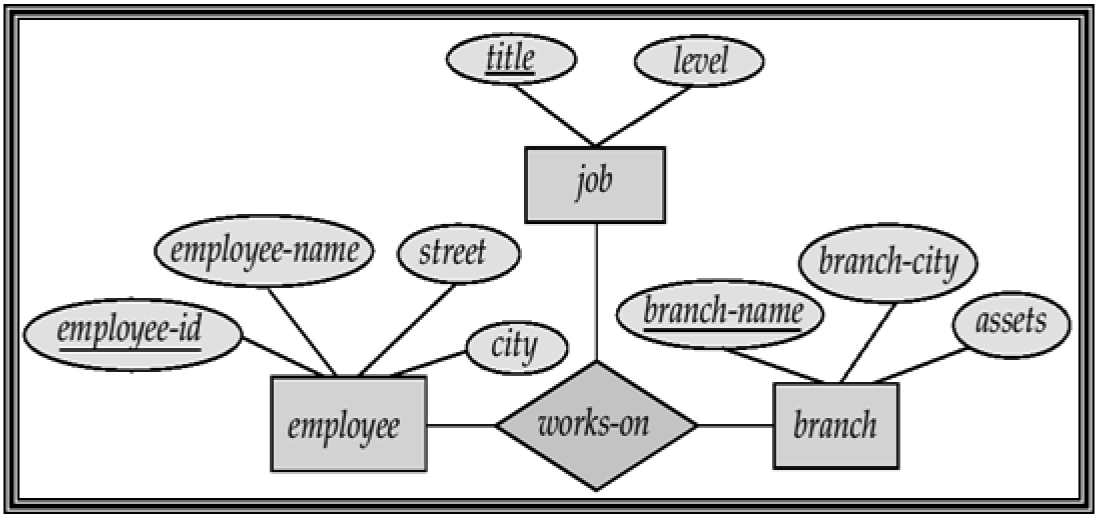
- A *super key* of an entity set is a set of one or more attributes whose values uniquely determine each entity.
- A *candidate key* of an entity set is a minimal super key
- Although several candidate keys may exist, one of the candidate keys is selected to be the *primary key*.

Key Examples

- Suggest super keys for the following entity?
- What are the candidate keys?
- Primary key?



Ternary Relationship



Can We Decompose a Ternary Relationship?

- Some relationships that appear to be non-binary may be better represented using binary relationships
  - E.g. A ternary relationship *parents*, relating a child to his/her father and mother, is best replaced by two binary relationships, *father* and *mother*
    - Using two binary relationships allows partial information (e.g. only mother being know)
  - But there are some relationships that are naturally non-binary

E.g. *works-on, why?*

Converting Ternary to binary

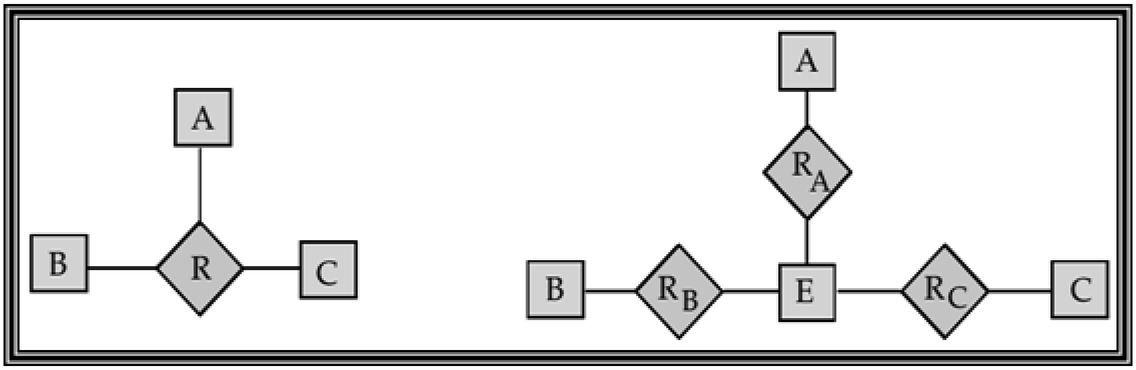
- In general, any non-binary relationship can be represented using binary relationships by creating an artificial entity set.
  - Replace *R* between entity sets A, B and C by an entity set *E*, and three relationship sets:

    1. R_A, relating *E* and *A* 2. R_B, relating *E* and *B*

    3. R_C, relating *E* and *C*
  - Create a special identifying attribute for *E*
  - Add any attributes of *R* to *E*
  - For each relationship (a_i, b_i, c_i) in *R,* create

    1. a new entity e_i in the entity set *E* 2. add (e_i, a_i) to R_A

    3. add (e_i, b_i) to R_B 4. add (e_i, c_i) to R_C



Design an ER Diagram

- Design a database for an on-line reservation system for microscopes in material science lab
- There are two types of users: microscope administrators and microscope end users
- Each microscope is located in a specific lab
- Each request is assigned to an administrator who can authorize or deny the request
- Using of some microscope requires the presence of an administrator
- Time is divided into 1 hour slots. Each reservation can only take one or more time slots

Weak Entity Set

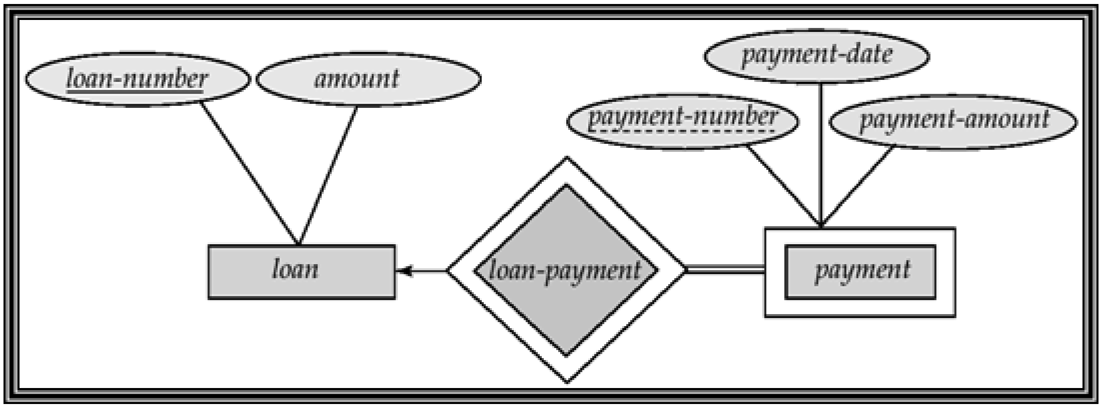
- Some entity sets in real world naturally depend on some other entity set
  - They can be uniquely identified only if combined with another entity set
- Example:
  - section1, section2, … become unique only if you put them into a context, e.g. csce4350

Weak Entity Set Notations

Double rectangles for weak entity set

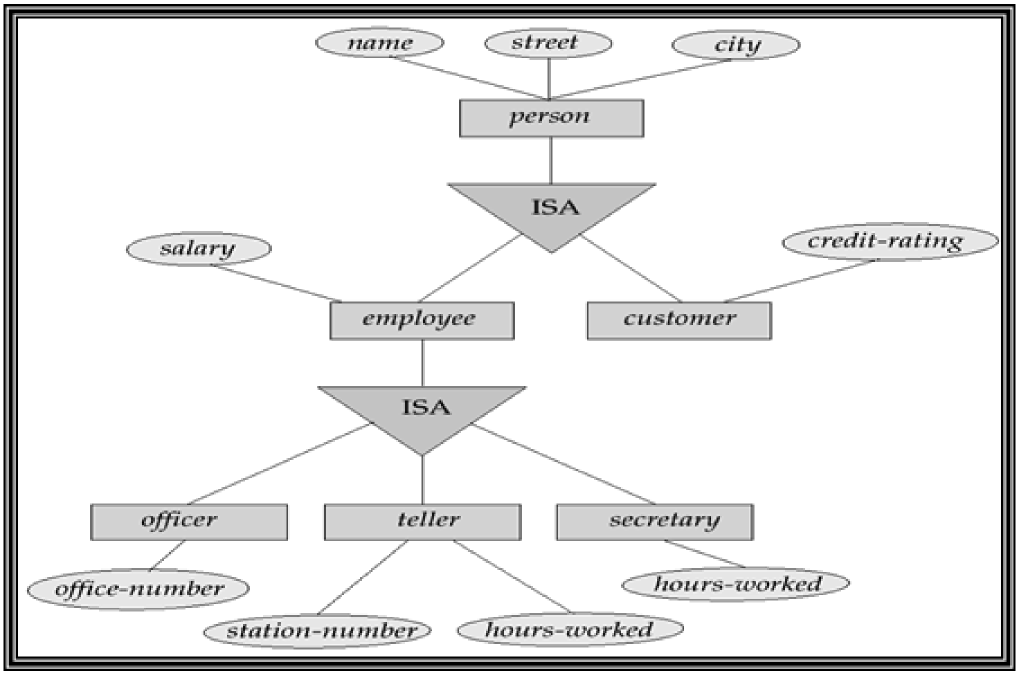
Double diamond for weak entity relationship

Dashed underscore for discriminator



Specialization

- A lower-level entity set inherits all the attributes and relationship participation of the higher-level entity set to which it is linked.
- A lower-level entity set may have additional attributes and participate in additional relationships



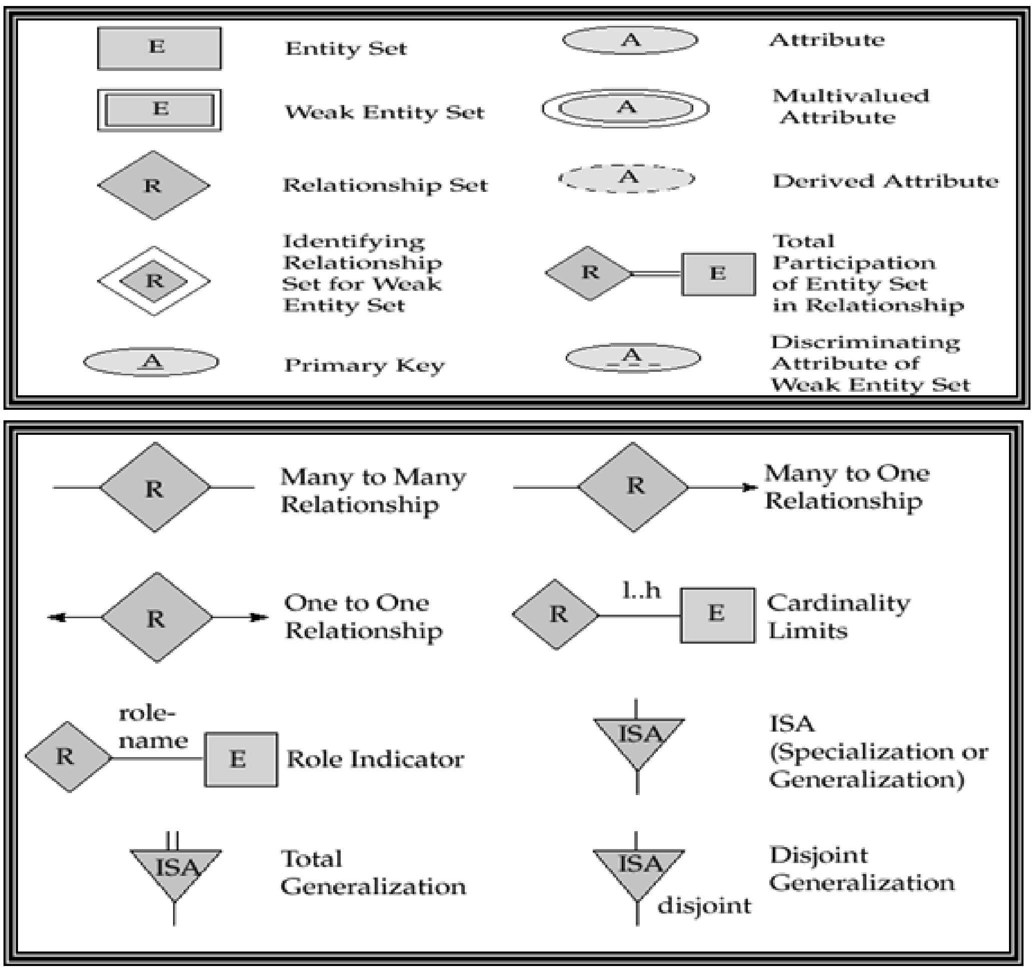
- Disjoint
- Completeness constraint (use double lines)
  - **total** : an entity must belong to one of the lower-level entity sets
  - **partial**: an entity need not belong to one of the lower-level entity sets

Design Considerations

- Use of entity sets vs. attributes

- Whether we want to keep additional information
- Use of entity sets vs. relationship sets
  - Actions among entities are usually represented by relationships
- Binary versus *n*-ary relationship sets
  - N-nary relationships are usually more natural for actions among entity sets
- Weak entity set vs. strong entity set
- Generalization

Notations



Best Practice Guide for ER Design

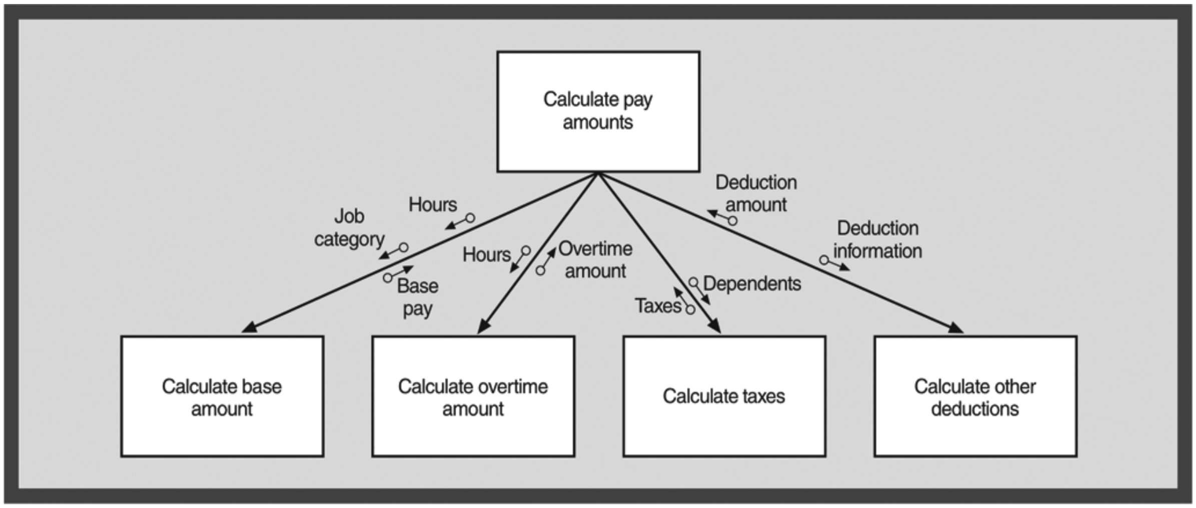
- Use of entity sets vs. attributes
- Use of entity sets vs. relationship sets
- Binary versus *n*-ary relationship sets
  - Weak entity set vs. strong entity set - Choose the natural one
- Generalization
  - If specialized entities need to keep additional information and participate in additional relationships

5.10 STRUCTURE CHARTS

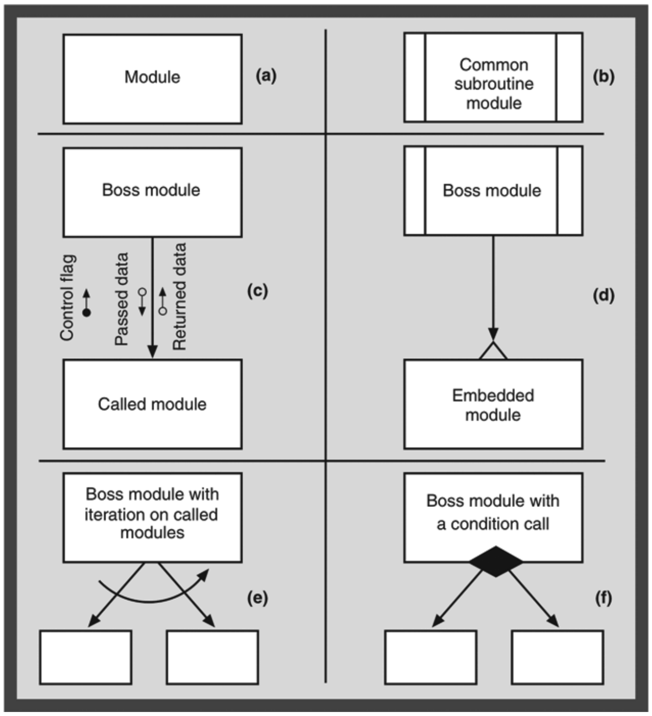
Structure Charts

- Describes functions and sub-functions of each part of system
- Shows relationships between modules of a computer program
- Simple and direct organization
  - ☐ Each module performs a specific function
  - ☐ Each layer in a program performs specific activities
- Chart is tree-like with root module and branches

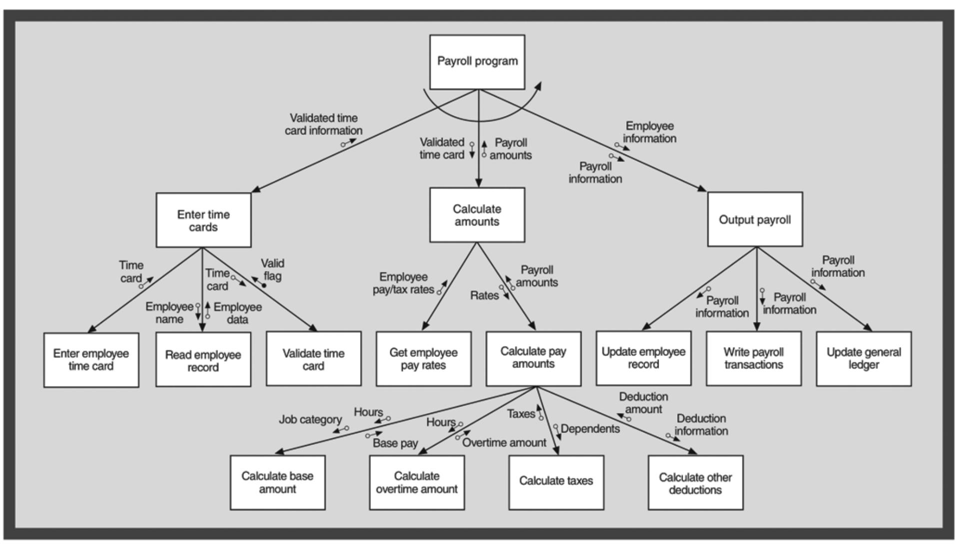
A Simple Structure Chart for the Calculate Pay Amounts Module



Structure Chart Symbols



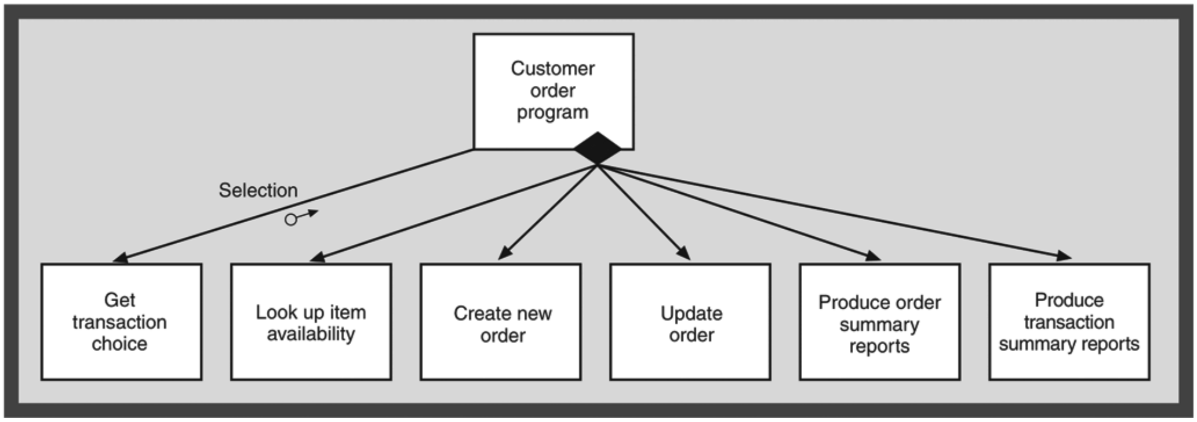
Structure Chart for Entire Payroll Program



Developing a Structure Chart

- Transaction analysis
  - Uses system flow chart and event table inputs
  - Upper-level modules developed first
  - Identifies each transaction supported by program
- Transform analysis
  - Uses DFD fragments for inputs
  - Computer program "transforms" inputs into outputs
  - Charts have input, calculate, and output sub-trees

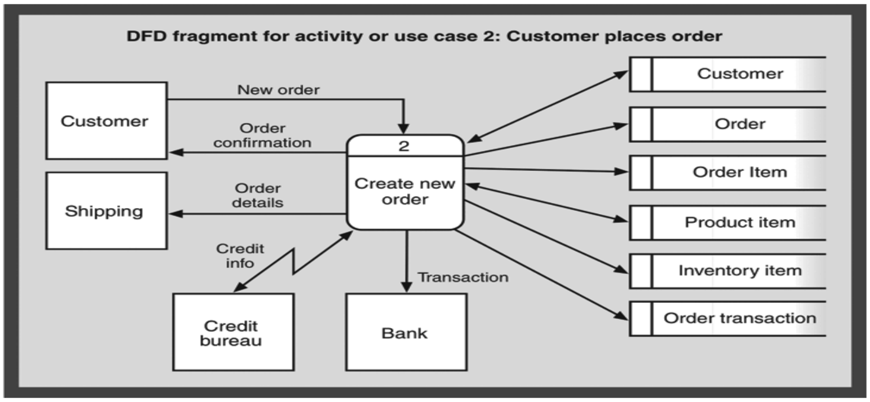
High-Level Structure Chart for the Order-Entry Subsystem after Transaction Analysis



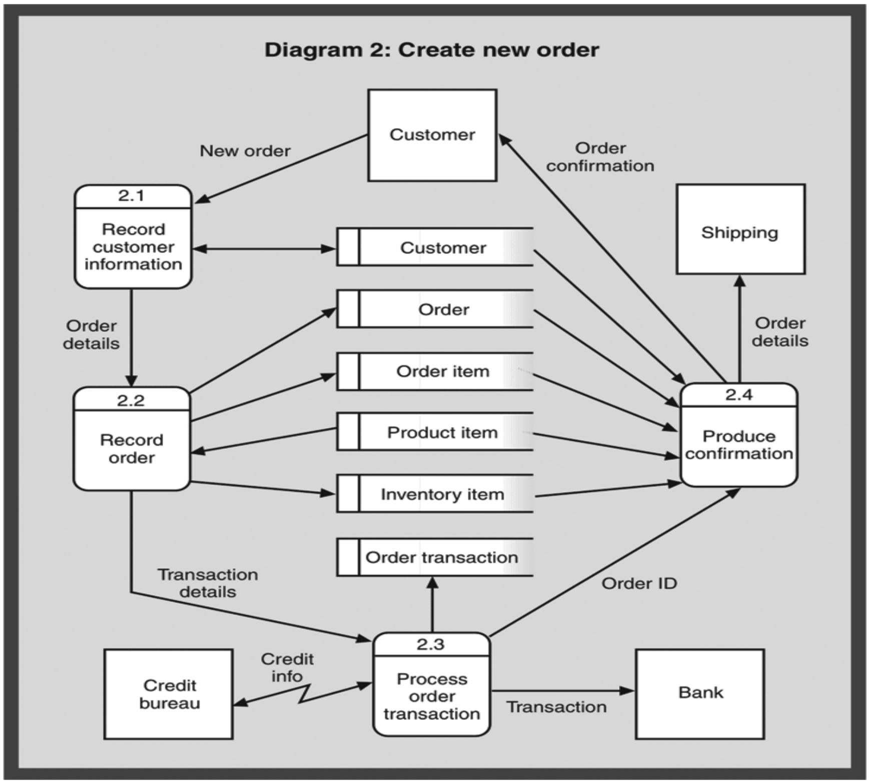
Steps to Create a Structure Chart from a DFD Fragment

- Determine primary information flow
  - Main stream of data transformed from some input form to output form
- Find process that represents most fundamental change from input to output
- Redraw DFD with inputs to left and outputs to right – central transform process goes in middle
- Generate first draft of structure chart based on redrawn data flow

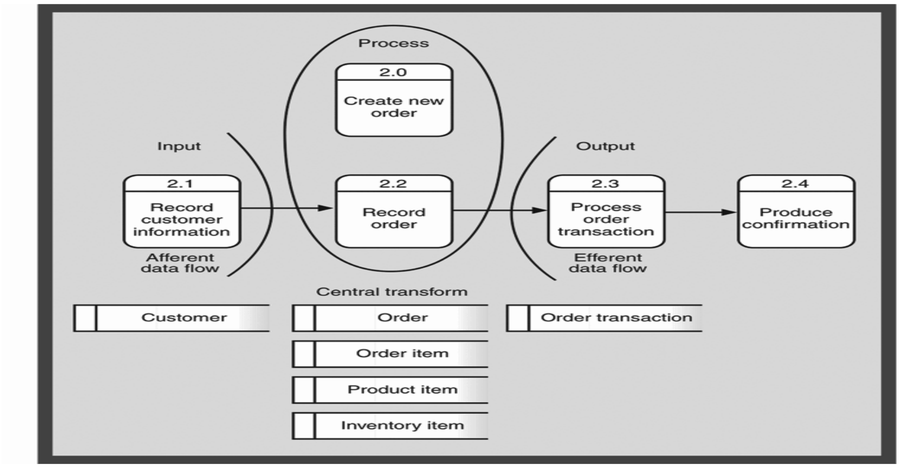
The *Create New Order* DFD Fragment



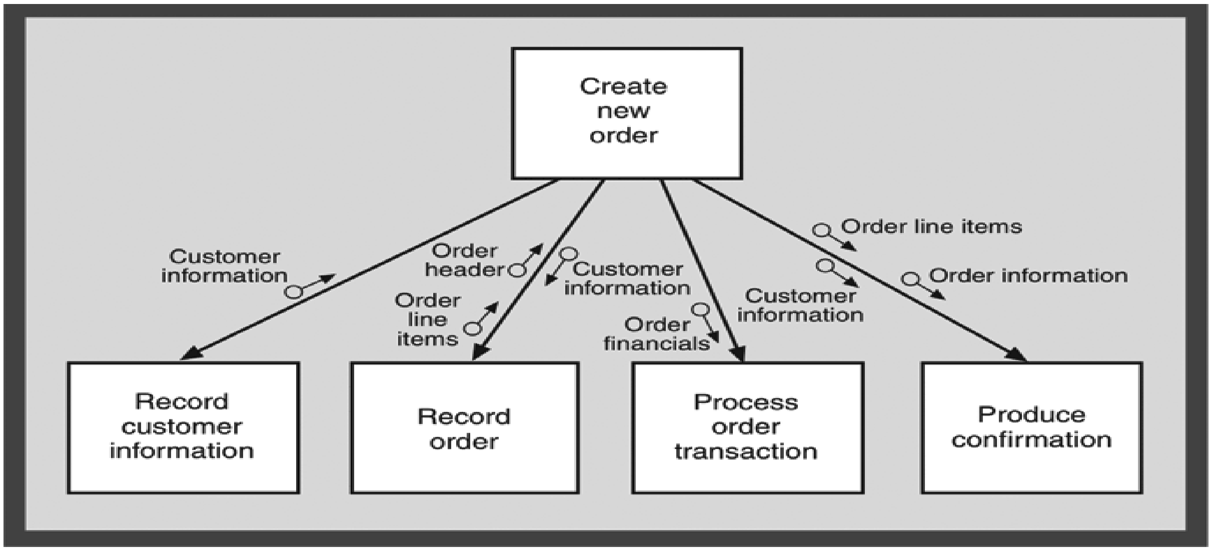
Decomposed DFD for *Create New Order*



Rearranged Create New Order DFD

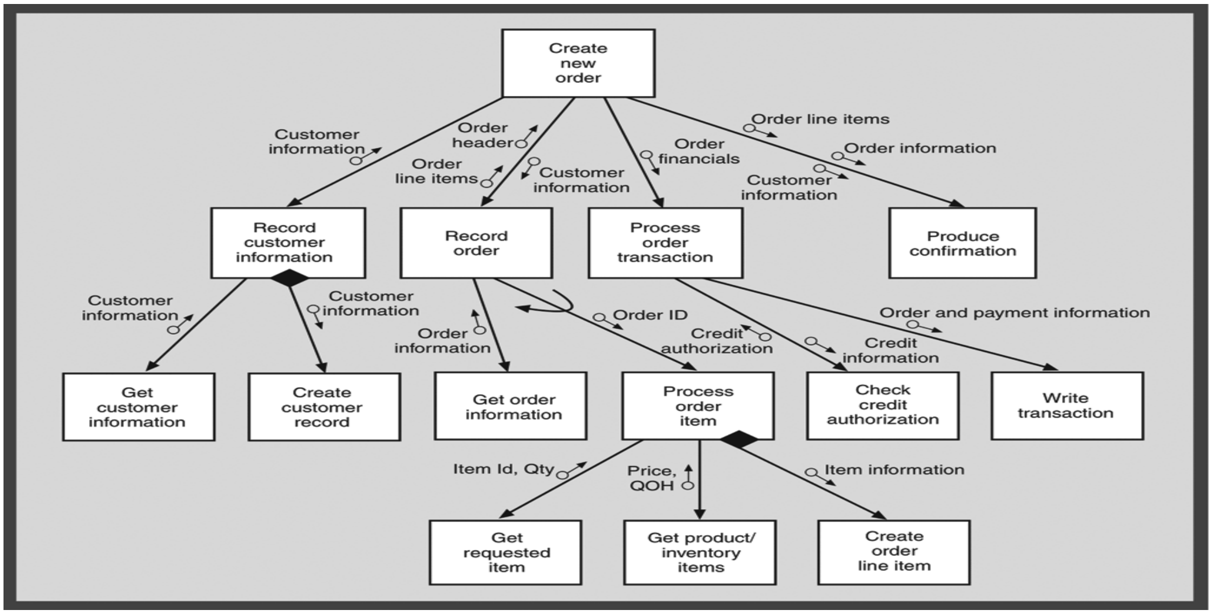


First Draft of the Structure Chart for Create New Order (Figure 10-14)

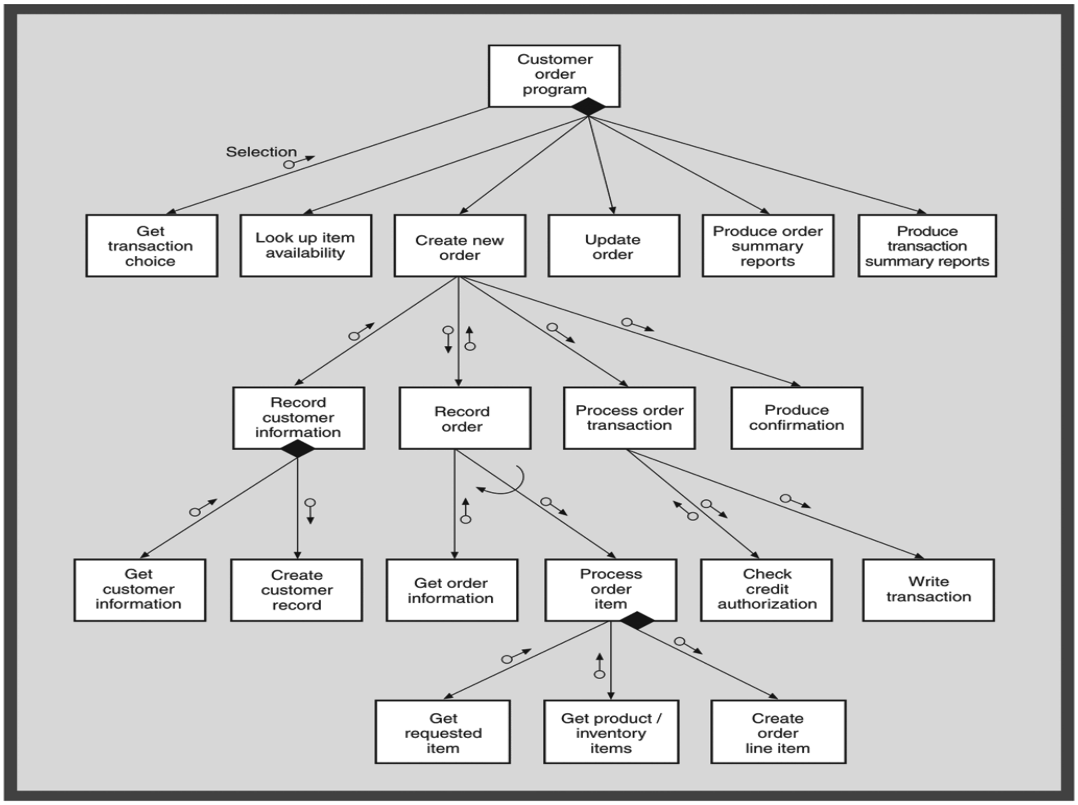


- **Add other modules**
  - Get input data via user-interface screens
  - Read from and write to data storage
  - Write output data or reports
- **Add logic from structured English or decision tables**
- **Make final refinements to structure chart based on quality control concepts**

The Structure Chart for the Create New Order Program (Figure 10-15)



Combination of Structure Charts: Transaction and Transform Analysis



Evaluating the Quality of a Structure Chart

- Module coupling
  - Measure of how module is connected to other modules in program
  - Goal is to be loosely coupled (independent)
- Module cohesion
  - Measure of internal strength of module
  - Module performs one defined task
  - Goal is to be highly cohesive

Module Algorithm Design—Pseudocode

- Describes internal logic of software modules
- Variation of structured English that is closer to programming code
- Syntax should mirror development language
- Three types of control statements used in structured programming
  - Sequence – sequence of executable statements
  - Decision – if-then-else logic
  - Iteration – do-until or do-while

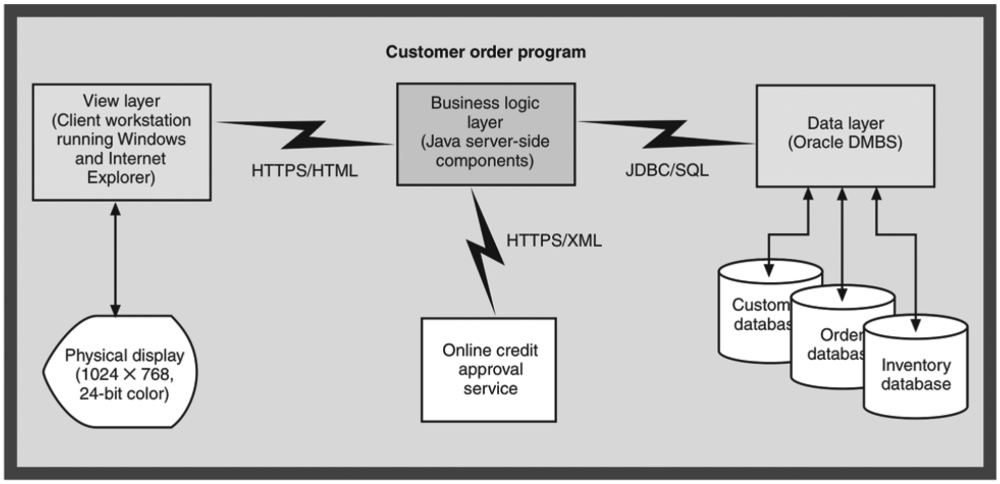
Integrating Structured Application Design with Other Design Tasks

- Structure chart must be modified or enhanced to integrate design of user interface and database
  - Are additional modules needed?
  - Does pseudocode in modules need modification?
  - Are additional data couples needed to pass data?
- Structure charts and system flowcharts must correspond to planned network architecture
  - Required protocols, capacity, and security

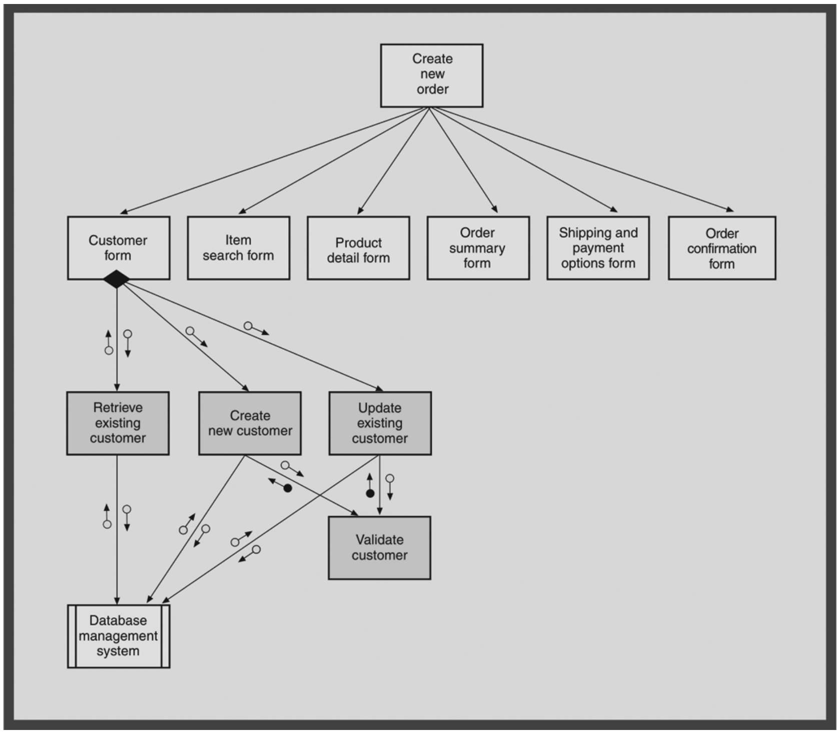
Three-Layer Design

- Three-layer architecture
  - View layer, business logic layer, and data layer
- Structure charts and system flowcharts describe design decisions and software structuring
- Employs multiple programs for user interface, business logic, and data access modules
- Modules in different layers communicate over real-time links using well-defined protocols

System Flowchart Showing Three-Layer Architecture for Customer Order



Structure Chart Showing Three-Layer Architecture for Create New Order (Figure 10-20)



Structure Chart vs. Flow Chart

We are all familiar with the flow chart representation of a program. Flow chart is a convenient technique to represent the flow of control in a program. A structure chart differs from a flow chart in three principal ways:

- It is usually difficult to identify the different modules of the software from its flow chart representation.
- Data interchange among different modules is not represented in a flow chart.
- Sequential ordering of tasks inherent in a flow chart is suppressed in a structure chart.

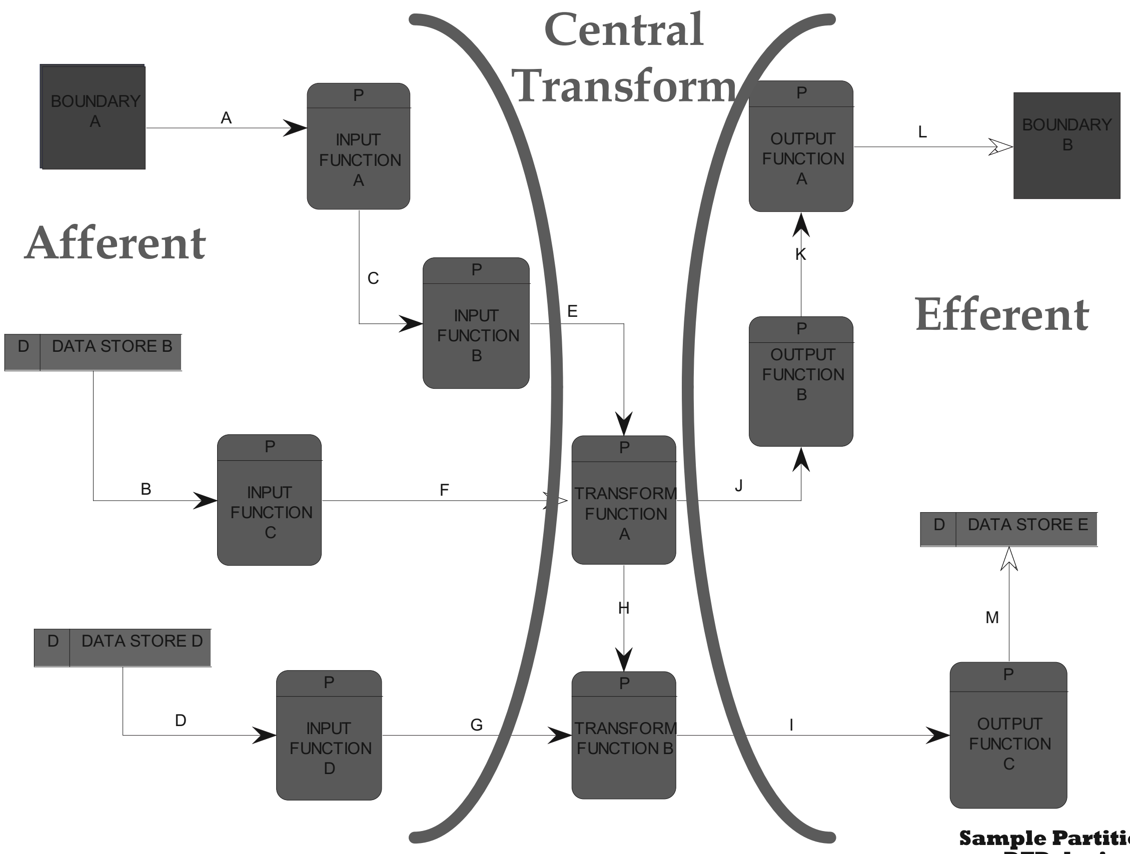
5.11 TRANSFORM AND TRANSACTION ANALYSIS

Transform Analysis

One approach used to derive a program structure chart from program DFD is transform analysis.

Transform analysis is an examination of the DFD to divide the processes into those that perform input and editing, those that do processing or data transformation (e.g., calculations), and those that do output.

- The portion consisting of processes that perform input and editing is called the **afferent**.
- The portion consisting of processes that do actual processing or transformations of data is called the **central transform**.
- The portion consisting of processes that do output is called the **efferent**.



Sample Partitioned DFD during Transform Analysis

Transform Analysis

The strategy for identifying the afferent, central transform, and efferent portions of a begins by first tracing the sequence of processing for each input.

- There may be several sequences of processing.
- A sequence of processing for a given input may actually split to follow different paths.

Once sequence paths have been identified, each sequence path is examined to identify process along that path that are afferent processes.

The steps are as follows:

Step 1 - Beginning with the input data flow, the data flow is traced through the sequence until it reaches a process that does processing (transformation of data) or an output function.

Step 2 - Beginning with an output data flow from a path, the data flow is traced backwards through connected processes until a transformation processes is reached (or a data flow is encountered that first represents output).

Step 3 - All other processes are then considered to be part of the central transform.

Once the DFD has been partitioned, a structure chart can be created that communicates the modular design of the program.

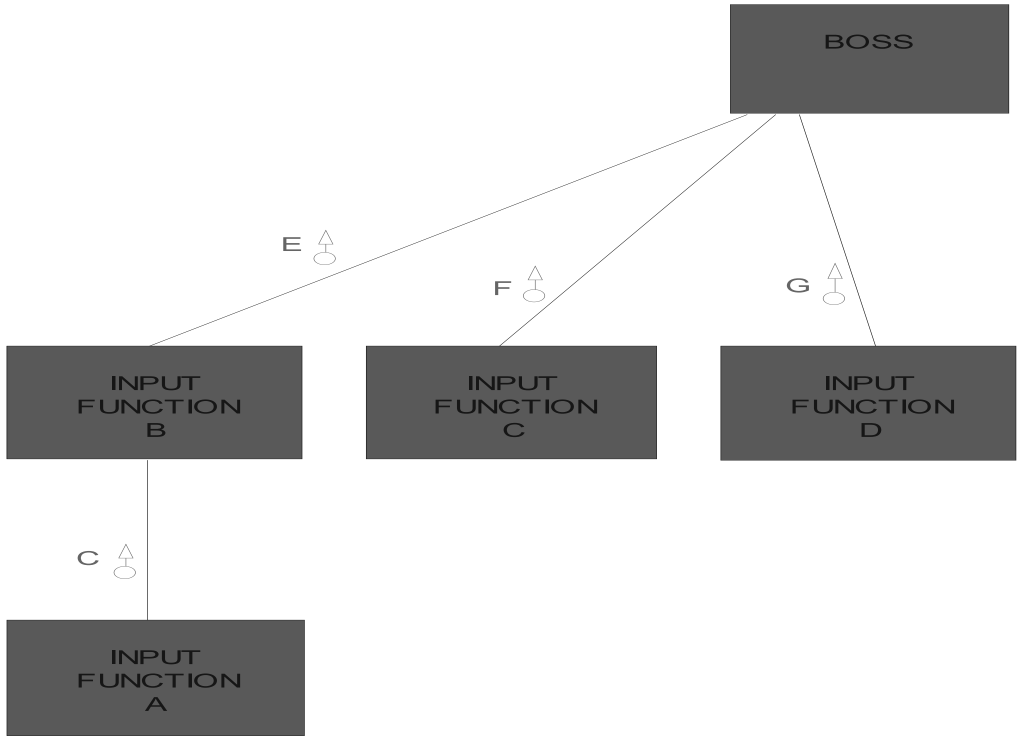
Step 1 - Create a process that will serve as a "commander and chief" of all other modules.

This module manages or coordinates the execution of the other program modules.

Step 2 - The last process encountered in a path that identifies afferent processes becomes a second-level module on the structure charts.

Step 3 - Beneath that module should be a module that corresponds to its preceding process on the DFD.

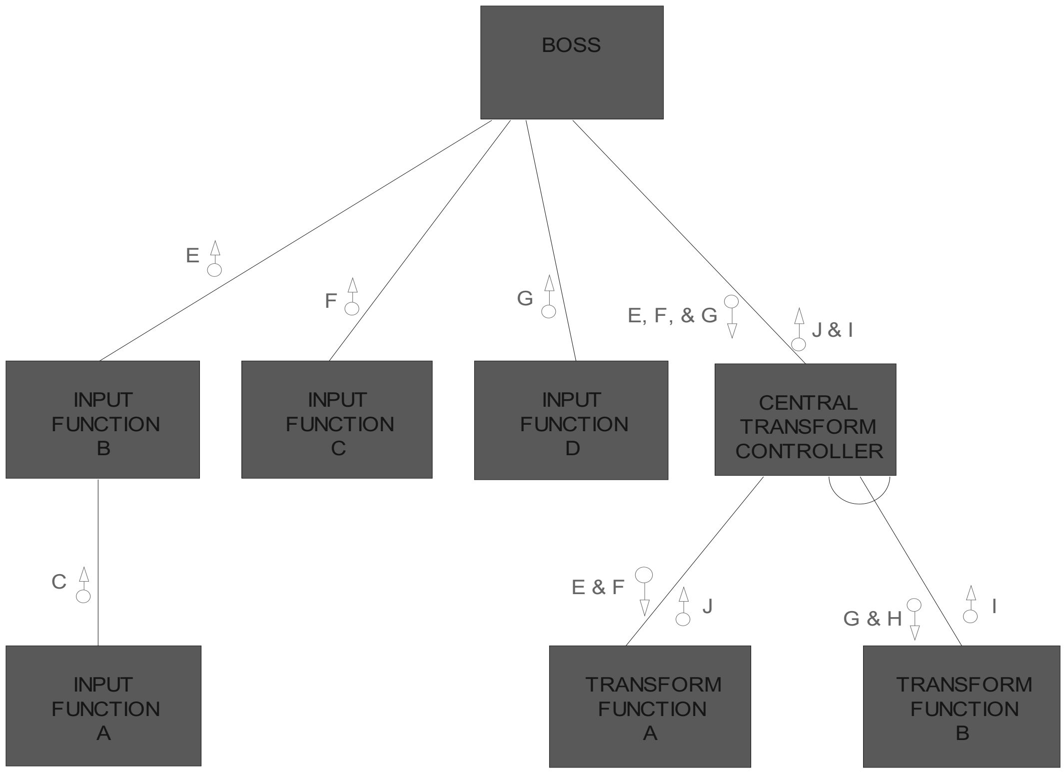
This would continue until all afferent processes in the sequence path are included on the structure chart.



Step 4 - If there is only one transformation process, it should appear as a single module directly beneath the boss module.

- Otherwise, a coordinating module for the transformation processes should be created and located directly above the transformation process.

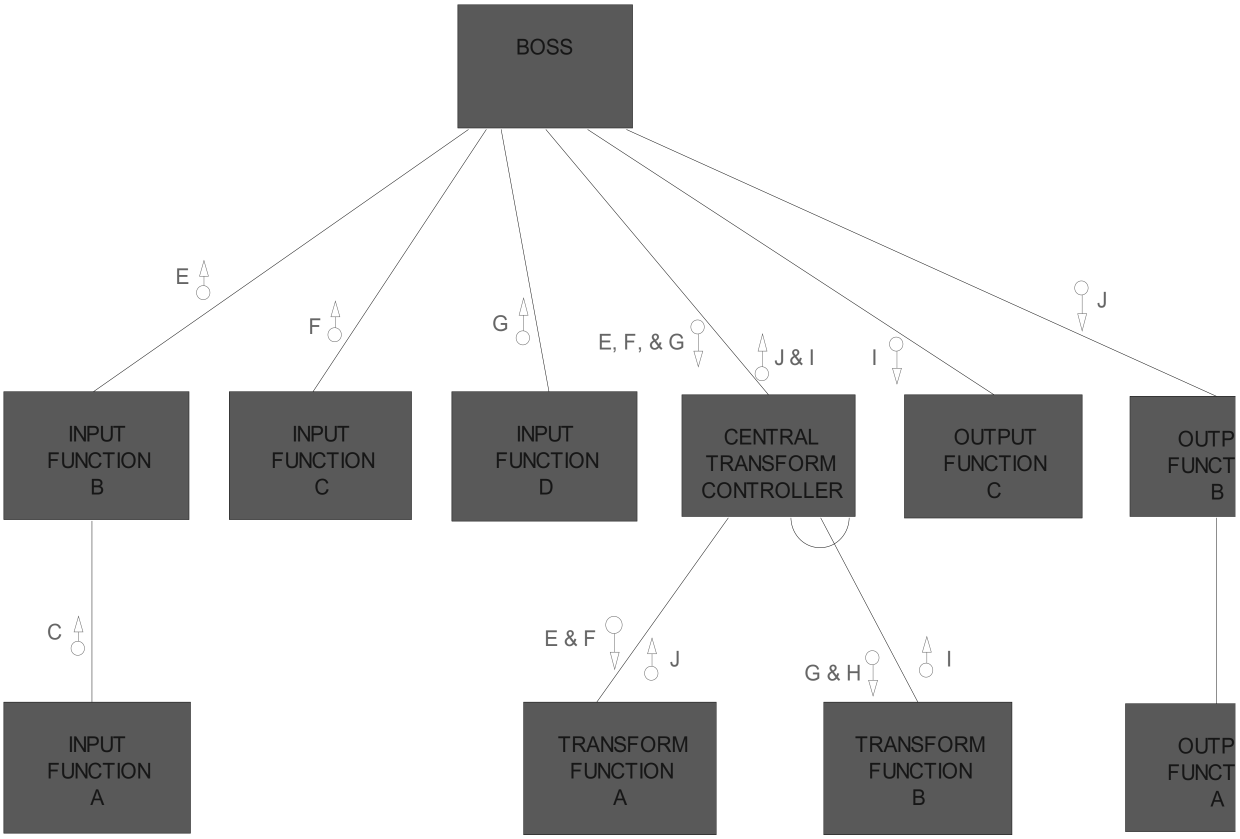
- **Step 5** - A module per transformation process on the DFD should be located directly beneath the controller module.



Step 6 - The last process encountered in a path that identifies efferent processes becomes a second-level module on the structure chart.

Step 7 - Beneath the module (in step 6) should be a module that corresponds to the succeeding process appearing on the sequence path.

Likewise any process immediately following that process would appear as a module beneath it on the structure chart.



Transaction Analysis

An alternative structured design strategy for developing structure charts is called transaction analysis.

Transaction analysis is the examination of the DFD to identify processes that represent transaction centers.

A **transaction center** is a process that does not do actual transformation upon the incoming data (data flow); rather, it serves to route the data to two or more processes.

— You can think of a transaction center as a traffic cop that directs traffic flow.

— Such processes are usually easy to recognize on a DFD, because they usually appear as a process containing a single incoming data flow to two or more other processes.

Difference between Transaction Analysis and Transform Analysis

The primary difference between transaction analysis and transform analysis is that transaction analysis recognizes that modules can be organized around the transaction center rather than a transform center.

Study Note - 6

DATABASE MANAGEMENT SYSTEM

This Study Note includes

6.1 DATABASES AND DATABASE USERS

Databases and database systems have become an essential component of everyday life in modern society. In the course of a day, most of us encounter several activities that involve some interaction with a database. For example, if we go to the bank to deposit or withdraw funds; if we make a hotel or airline reservation; if we access a computerized library catalog to search for a bibliographic item; or if we order a magazine subscription from a publisher, chances are that our activities will involve someone accessing a database. Even purchasing items from a supermarket nowadays in many cases involves an automatic update of the database that keeps the inventory of supermarket items.

The above interactions are examples of what we may call **traditional database applications**, where most of the information that is stored and accessed is either textual or numeric. In the past few years, advances in technology have been leading to exciting new applications of database systems. **Multimedia databases** can now store pictures, video clips, and sound messages. **Geographic information systems (GIS)** can store and analyze maps, weather data, and satellite images. **Data warehouses** and **on-line analytical processing (OLAP)** systems are used in many companies to extract and analyze useful information from very large databases for decision making. **Real-time** and **active database** technology is used in controlling industrial and manufacturing processes and database search techniques are being applied to the World Wide Web to improve the search for information that is needed by users browsing through the Internet.

To understand the fundamentals of database technology, however, we must start from the basics of traditional database applications.

Introduction

Databases and database technology are having a major impact on the growing use of computers. It is fair to say that databases play a critical role in almost all areas where computers are used, including business, engineering, medicine, law, education, and library science, to name a few. The word database is in such common use that we must begin by defining a database. Our initial definition is quite general.

A **database** is a collection of related data (We will use the word data in both singular and plural, as is common in database literature; context will determine whether it is singular or plural. In standard English, data is used only for plural; datum is used for singular). By **data**, we mean known facts that can be recorded and that have implicit meaning. For example, consider the names, telephone numbers, and addresses of the people you know. You may have recorded this data in an indexed address book, or you may have stored it on a diskette, using a personal computer and software such as DBASE IV or V, Microsoft ACCESS, or EXCEL. This is a collection of related data with an implicit meaning and hence is a database.

The preceding definition of database is quite general; for example, we may consider the collection of words that make up this page of text to be related data and hence to constitute a database. However, the common use of the term database is usually more restricted. A database has the following implicit properties:

- A database represents some aspect of the real world, sometimes called the **miniworld** or the **Universe of Discourse (UoD)**. Changes to the miniworld are reflected in the database.
- A database is a logically coherent collection of data with some inherent meaning. A random assortment of data cannot correctly be referred to as a database.
- A database is designed, built, and populated with data for a specific purpose. It has an intended group of users and some preconceived applications in which these users are interested.

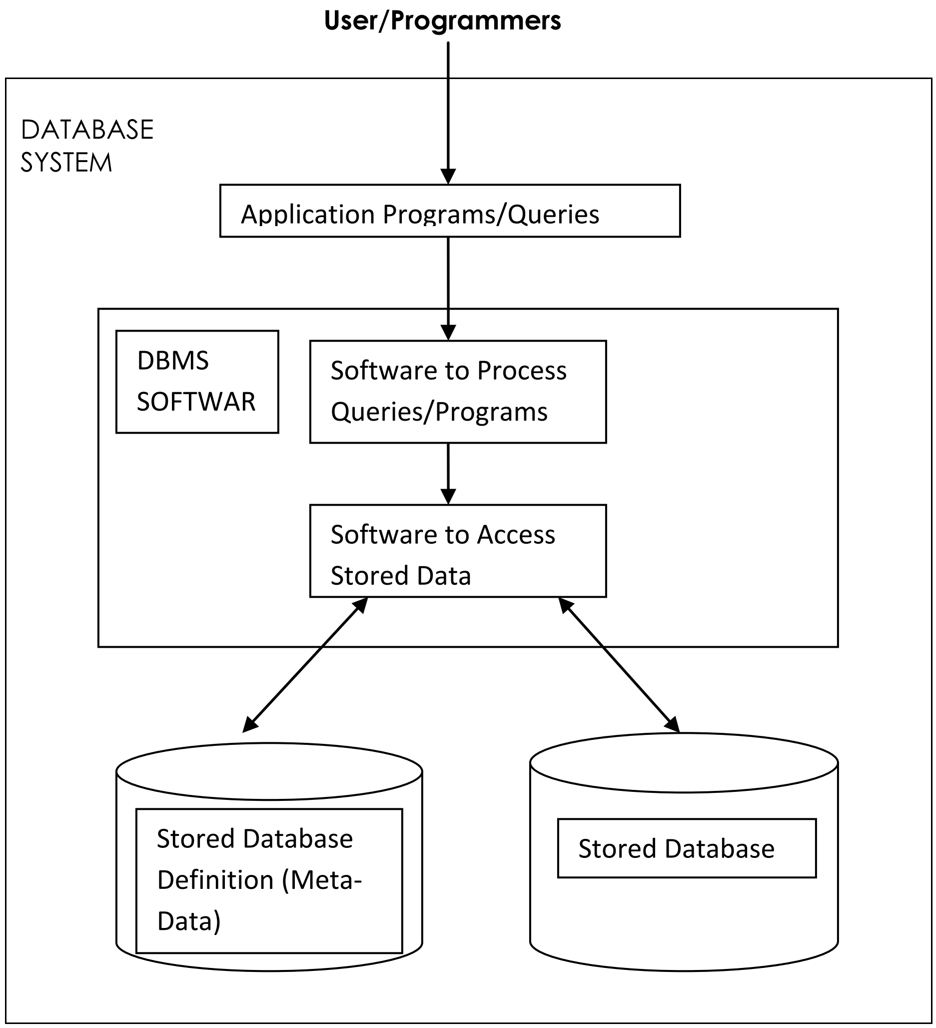
In other words, a database has some source from which data are derived, some degree of interaction with events in the real world, and an audience that is actively interested in the contents of the database.

A database can be of any size and of varying complexity. For example, the list of names and addresses referred to earlier may consist of only a few hundred records, each with a simple structure. On the other hand, the card catalog of a large library may contain half a million cards stored under different categories—by primary author's last name, by subject, by book title—with each category organized in alphabetic order. A database of even greater size and complexity is maintained by the Internal Revenue Service to keep track of the tax forms filed by U.S. taxpayers. If we assume that there are 100 million taxpayers and if each taxpayer files an average of five forms with approximately 200 characters of information per form, we would get a database of $100 \times (10^6) \times 200 \times 5$ characters (bytes) of information. If the IRS keeps the past three returns for each taxpayer in addition to the current return, we would get a database of $4 \times (10^{11})$ bytes (400 gigabytes). This huge amount of information must be organized and managed so that users can search for, retrieve, and update the data as needed.

A database may be generated and maintained manually or it may be computerized. The library card catalog is an example of a database that may be created and maintained manually. A computerized database may be created and maintained either by a group of application programs written specifically for that task or by a database management system.

A **database management system (DBMS)** is a collection of programs that enables users to create and maintain a database. The DBMS is hence a general-purpose software system that facilitates the processes of defining, constructing, and manipulating databases for various applications. Defining a database involves specifying the data types, structures, and constraints for the data to be stored in the database. Constructing the database is the process, of storing the data itself on some storage medium that is controlled by the DBMS. Manipulating a database includes such functions as querying the database to retrieve specific data, updating the database to reflect changes in the miniworld, and generating reports from the data.

It is not necessary to use general-purpose DBMS software to implement a computerized database. We could write our own set of programs to create and maintain the database, in effect creating our own special-purpose DBMS software. In either case—whether we use a general-purpose DBMS or not—we usually have to employ a considerable amount of software to manipulate the database. We will call the database and DBMS software together a database system.



Fg. 1: A simplified database system environment, illustrating the concepts and terminology already discussed

An Example

Let us consider an example that most readers may be familiar with: a UNIVERSITY database for maintaining information concerning students, courses, and grades in a university environment. **Fig. 2** shows the database structure and a few sample data for such a database. The database is organized as five files, each of which stores data records of the same type. (At a conceptual level, a file is a collection of records that may or may not be ordered). The STUDENT file stores data on each student; the COURSE file stores data on each course; the SECTION file stores data on each section of a course; the GRADE_REPORT file stores the grades that students receive in the various sections they have completed; and the PREREQUISITE file stores the prerequisites of each course.

To define this database, we must specify the structure of the records of each file by specifying the different types of **data elements** to be stored in each record. In **Fig. 2,** STUDENT record includes data to represent the student's Name, StudentNumber, Class (freshman or 1, sophomore or 2, . . .), and Major (MATH, computer science or CS, . . .); each COURSE record includes data to represent the CourseName, CourseNumber, CreditHours, and Department (the department that offers the course); and so on. We must also specify a data type for each data element within a record. For example, we can specify that Name of STUDENT is a string of alphabetic characters, StudentNumber of STUDENT is an integer, and Grade of GRADE_REPORT is a single character from the set {A, B, C, D, F, I}. We may also use a coding scheme to represent a data item. For example, in **Fig. 2** we represent the Class of a STUDENT as 1 for freshman, 2 for sophomore, 3 for junior, 4 for senior, and 5 for graduate student.

STUDENT	Name	Student Number	Class	Major	
	Smith	17	1	CS	
	Brown	8	2	CS	
COURSE	Course Name	Course Number	Credit Hours	Department	
	Intro to Computer Science	CS1310	4	CS	
	Data Structures	CS3320	4	CS	
	Discrete Mathematics	MATH2410	3	MATH	
	Database	CS3380	3	CS	
SECTION	Section identifier	Course Number	Semester	Year	Instructor
	85	MATH2410	Fall	98	King
	92	CS1310	Fall	98	Anderson
	102	CS3320	Spring	99	Knuth
	112	MATH2410	Fail	99	Chang
	119	CS1310	Fall	99	Anderson
	135	CS3380	Fall	99	Stone
GRADE_REPORT	Student Number	Section identifier	Grade		
	17	112	B		
	17	119	C		
	8	85	A		
	8	92	A		
	8	102	B		
	8	135	A		
PREREQUISITE	Course Number	Prerequisite Number			
	CS3380	CS3320			
	CS3380	MATH2410			
	CS3320	CS1310			

Fig. 2: An example of a database that stores student records and their grades

To construct the UNIVERSITY database, we store data to represent each student, course, section, grade report, and prerequisite as a record in the appropriate file. Notice that records in the various files may be related. For example, the record for "Smith" in the STUDENT file is related to two records in the GRADE_REPORT file that specify Smith's grades in two sections. Similarly, each record in the PREREQUISITE file relates two course records: one representing the course and the other representing the prerequisite. Most medium-size and large databases include many types of records and have many relationships among the records.

Database manipulation involves querying and updating. Examples of queries are "retrieve the transcript—a list of all courses and grades—of Smith"; "list the names of students who took the section of the Database course offered in fall 1999 and their grades in that section"; and "what are the prerequisites of the Database course?" Examples of updates are "change the class of Smith to Sophomore"; "create a new section for the Database course for this semester"; and "enter a grade of A for Smith in the Database section of last semester." These informal queries and updates must be specified precisely in the database system language before they can be processed.

Characteristics of the Database Approach

A number of characteristics distinguish the database approach from the traditional approach of programming with files. In traditional **file processing**, each user defines and implements the files needed for a specific application as part of programming the application. For example, one user, the grade reporting office, may keep a file on students and their grades. Programs to print a student's transcript and to enter new grades into the file are implemented. A second user, the accounting office, may keep track of students' fees and their payments. Although both users are interested in data about students, each user maintains separate files—and programs to manipulate these files-—because each requires some data not available from the other user's files. This redundancy in defining and storing data results in wasted storage space and in redundant efforts to maintain common data up-to-date.

In the database approach, a single repository of data is maintained that is defined once and then is accessed by various users. The main characteristics of the database approach versus the file-processing approach are the following.

Self-Describing Nature of a Database System

A fundamental characteristic of the database approach is that the database system contains not only the database itself but also a complete definition or description of the database structure and constraints. This definition is stored in the system **catalog**, which contains information such as the structure of each file, the type and storage format of each data item, and various constraints on the data. The information stored in the catalog is called **meta-data**, and it describes the structure of the primary database. (**Fig. 1**)

The catalog is used by the DBMS software and also by database users who need information about the database structure. A general purpose DBMS software package is not written for a specific database application, and hence it must refer to the catalog to know the structure of the files in a specific database, such as the type and format of data it will access. The DBMS software must work equally well with any number of database applications—for example, a university database, a banking database, or a company database—as long as the database definition is stored in the catalog.

In traditional file processing, data definition is typically part of the application programs themselves. Hence, these programs are constrained to work with only one specific database, whose structure is declared in the application programs. For example, a PASCAL program may have record structures declared in it; a C^{++} program may have "struct" or "class" declarations; and a COBOL program has Data Division statements to define its files. Whereas file-processing software can access only specific databases, DBMS software can access diverse databases by extracting the database definitions from the catalog and then using these definitions.

Shown in **Fig. 2**, the DBMS stores in the catalog the definitions of all the files shown. Whenever a request is made to access, say, the Name of a STUDENT record, the DBMS software refers to the catalog to determine the structure of the STUDENT file and the position and size of the Name data item within a STUDENT record. By contrast, in a typical file-processing application, the file structure and, in the extreme case, the exact location of Name within a STUDENT record are already coded within each program that accesses this data item.

Insulation between Programs and Data, and Data Abstraction

In traditional file processing, the structure of data files is embedded in the access programs, so any changes to the structure of a file may require changing all programs that access this file. By contrast, DBMS access programs do not require such changes in most cases. The structure of data files is stored in the DBMS catalog separately from the access programs. We call this property **program-data independence**. For example, a file access program may be written in such a way that it can access only STUDENT records of the structure shown in **Fig. 3**. If we want to add another piece of data to each STUDENT record, say the Birthdate, such a program will no longer work and must be changed. By contrast, in a DBMS environment, we just need to change the description of STUDENT records in the catalog to reflect the inclusion of the new data item Birthdate; no programs are changed. The next time a DBMS program refers to the catalog, the new structure of STUDENT records will be accessed and used.

In object-oriented and object-relational databases, users can define operations on data as part of the database definitions. An **operation** (also called a function) is specified in two parts. The interface (or signature) of an operation includes the operation name and the data types of its arguments (or parameters). The implementation

Data Item Name	Starting Position in record	Length in Characters (bytes)
Name	1	30
StudentNumber	31	4
Class	35	4
Major	39	4

Fig. 3: Internal storage format for a STUDENT record

(or method) of the operation is specified separately and can be changed without affecting the interface. User application programs can operate on the data by invoking these operations through their names and arguments, regardless of how the operations are implemented. This may be termed **program-operation independence**.

The characteristic that allows program-data independence and program-operation independence is called **data abstraction**. A DBMS provides users with a **conceptual representation** of data that does not include many of the details of how the data is stored or how the operations are implemented. Informally, a **data model** is a type of data abstraction that is used to provide this conceptual representation. The data model uses logical concepts, such as objects, their properties, and their interrelationships, that may be easier for most users to understand than computer storage concepts, Hence, the data model hides storage and implementation details that are not of interest to most database users.

For example, consider again **Fig. 2**. The internal implementation of a file maybe defined by its record length—the number of characters (bytes) in each record—and each data item may be specified by its starting byte within a record and its length in bytes. The STUDENT record would thus be represented as shown in **Fig. 3**. But a typical database user is not concerned with the location of each data item within a record or its length; rather the concern is that, when a reference is made to Name of STUDENT, the correct value is returned.

In the database approach, the detailed structure and organization of each file are stored in the catalog. Database users refer to the conceptual representation of the files, and the DBMS extracts the details of file storage from the catalog when these are needed by the DBMS software. Many data models can be used to provide this data abstraction to database users. With the recent trend toward object-oriented and object-relational databases, abstraction is carried one level further to include not only the data structure but also the operations on the data. These operations provide an abstraction of miniworld activities commonly understood by the users. For example, an operation CALCULATE_GPA can be applied to a student object to calculate the grade point average. Such operations can be invoked by the user queries or programs without the user knowing the details of how they are internally implemented. In that sense, an abstraction of the miniworld activity is made available to the user as an **abstract operation**.

Support of Multiple Views of the Data

A database typically has many users, each of whom may require a different perspective or view of the database. A view may be a subset of the database or it may contain virtual data that is derived from the database files but is not explicitly stored. Some users may not need to be aware of whether the data they refer to is stored or derived. A multiuser DBMS whose users have a variety of applications must provide facilities for defining multiple views.

(a)

TRANSCRIPT	StudentName	Student Transcript				
		CourseNumber	Grade	Semester	Year	SectionId
	Smith	CS1310	C	Fall	99	119
		MATH2410	B	Fall	99	112
	Brown	MATH2410	A	Fall	98	85
		CS1310	A	Fall	98	92
		CS3320	B	Spring	99	102
		CS3380	A	Fall	99	135

(b)

PREREQUISITES	CourseName	CourseNumber	Prerequisites
	Database	CS3380	CS3320
			MATH2410
	Data Structures	CS3320	CS1310

Fig. 4: Two views derived from the example database shown previously (a) The student transcript view, (b) The course prerequisite view.

For example, one user of the database of Fig. 2 may be interested only in the transcript of each student; the view for this user is shown in Fig. 4(a). A second user, who is interested only in checking that students have taken all the prerequisites of each course they register for, may require the view shown in Fig. 4(b).

Sharing of Data and Multiuser Transaction Processing

A multiuser DBMS, as its name implies, must allow multiple users to access the database at the same time. This is essential if data for multiple applications is to be integrated and maintained in a single database. The DBMS must include **concurrency control** software to ensure that several users trying to update the same data do so in a controlled manner so that the result of the updates is correct. For example, when several reservation clerks try to assign a seat on an airline flight, the DBMS should ensure that each seat can be accessed by only one clerk at a time for assignment to a passenger. These types of applications are generally called **on-line transaction processing (OLTP)** applications. A fundamental role of multiuser DBMS software is to ensure that concurrent transactions operate correctly.

The preceding characteristics are most important in distinguishing a DBMS from traditional file-processing software.

Actors on the Scene

For a small personal database, such as the list of addresses, one person typically defines, constructs, and manipulates the database. However, many persons are involved in the design, use, and maintenance of a large database with a few hundred users. In this section we identify the people whose jobs involve the day-to-day use of a large database; we call them the "**actors on the scene**." There are people who may be called "workers behind the scene"—those who work to maintain the database system environment, but who are not actively interested in the database itself.

Database Administrators

In any organization where many persons use the same resources, there is a need for a chief administrator to oversee and manage these resources. In a database environment, the primary resource is the database itself and the secondary resource is the DBMS and related software. Administering these resources is the responsibility of the **database administrator** (DBA). The DBA is responsible for authorizing access to the database, for coordinating and monitoring its use, and for acquiring software and hardware resources as needed. The DBA is accountable for problems such as breach-of security or poor system response time. In large organizations, the DBA is assisted by a staff that helps carry out these functions.

Database Designers

Database designers are responsible for identifying the data to be stored in the database and for choosing appropriate structures to represent and store this data. These tasks are mostly undertaken before the database is actually implemented and populated with data. It is the responsibility of database designers to communicate with all prospective database users, in order to understand their requirements, and to come up with a design that meets these requirements. In many cases, the designers are on the staff of the DBA and may be assigned other staff responsibilities after the database design is completed. Database designers typically interact with each potential group of users and develop a view of the database that meets the data and processing requirements of this group. These views are then analyzed and integrated with the views of other user groups. The final database design must be capable of supporting the requirements of all user groups.

End Users

End users are the people whose jobs require access to the database for querying, updating, and generating reports; the database primarily exists for their use. There are several categories of end users:

- **Casual end users** occasionally access the database, but they may need different information each time. They use a sophisticated database query language to specify their requests and are typically middle- or high-level managers or other occasional browsers.
- **Naive or parametric end users** make up a sizable portion of database end users; Their main job function revolves around constantly querying and updating the database, using standard types of queries and updates—called **canned transactions**—that have been carefully programmed and tested. The tasks that such users perform are varied:
  - Bank tellers check account balances and post withdrawals and deposits.
  - Reservation clerks for airlines, hotels, and car rental companies check availability for a given request and make reservations.
  - Clerks at receiving stations for courier mail enter package identifications via bar codes and descriptive information through buttons to update a central database of received and in-transit packages.
- **Sophisticated end users** include engineers, scientists, business analysts, and others who thoroughly familiarize themselves with the facilities of the DBMS so as to implement their applications to meet their complex requirements.
- **Stand-alone users** maintain personal databases by using ready-made program packages that provide easy-to-use menu- or graphics-based interfaces. An example is the user of a tax package that stores a variety of personal financial data for tax purposes.

A typical DBMS provides multiple facilities to access a database. Naive end users need to learn very little about the facilities provided by the DBMS; they have to understand only the types of standard transactions designed and implemented for their use. Casual users learn only a few facilities that they may use repeatedly. Sophisticated users try to learn most of the DBMS facilities in order to achieve their complex requirements. Standalone users typically become very proficient in using a specific software package.

System Analysts and Application Programmers (Software Engineers)

System analysts determine the requirements of end users, especially naive and parametric end users, and develop specifications for canned transactions that meet these requirements. **Application programmers** implement these specifications as programs; then they test, debug, document and maintain these canned transactions. Such analysts and programmers (nowadays called **software engineers**) should be familiar with the full range of capabilities provided by the DBMS to accomplish their tasks.

Workers behind the Scene

In addition to those who design, use, and administer a database, others are associated with the design, development, and operation of the DBMS software and system environment. These persons are typically not interested in the database itself. We call them the "workers behind the scene," and they include the following categories.

- **DBMS system designers and implementers** are persons who design and implement the DBMS modules and interfaces as a software package. A DBMS is a complex software system that consists of many components or **modules**, including modules for implementing the catalog, query language, interface processors, data access, concurrency control, recovery, and security. The DBMS must interface with other system software, such as the operating system and compilers for various programming languages.
- **Tool developers** include persons who design and implement tools—the software packages that facilitate database system design and use, and help improve performance. Tools are optional packages that are often purchased separately. They include packages for database design, performance monitoring, natural language or graphical interfaces, prototyping, simulation, and test data generation. In many cases, independent software vendors develop and market these tools.
- **Operators and maintenance personnel** are the system administration personnel who are responsible for the actual running and maintenance of the hardware and software environment for the database system.

Although the above categories of workers behind the scene are instrumental in making the database system available to end users, they typically do not use the database for their own purposes.

Advantages of Using a DBMS

In this section we discuss some of the advantages of using a DBMS and the capabilities that a good DBMS should possess. The DBA must utilize these capabilities to accomplish a variety of objectives related to the design, administration, and use of a large multiuser database.

- **Controlling Redundancy**

  In traditional software development utilizing file processing, every user group maintains its own files for handling its data-processing applications. For example, consider the UNIVERSITY database example given before; here, two groups of users might be the course registration personnel and the accounting office. In the traditional approach, each group independently keeps files on students. The accounting office also keeps data on registration and related billing information, whereas the registration office keeps track of student courses and grades. Much of the data is stored twice: once in the files of each user group. Additional user groups may further duplicate some or all of the same data in their own files.

  This **redundancy** in storing the same data multiple times leads to several problems. First, there is the need to perform a single logical update—such as entering data on a new student—multiple times: once for each file where student data is recorded. This leads to duplication of effort. Second, storage space is wasted when the same data is stored repeatedly, and this problem may be serious for large databases. Third, files that represent the same data may become inconsistent. This may happen because an update is applied to some of the files but not to others. Even if an update—such as adding a new student—is applied to all the appropriate files, the data concerning the student may still be inconsistent since the updates are applied independently by each user group. For example, one user group may enter a student's birthdate erroneously as JAN-19-1974, whereas the other user groups may enter the correct value of JAN-29-1974.

(a)

GRADE_REPORT	Student Number	Student Name	Section Identifier	Course Number	Grade
	17	Smith	112	MATH2410	B
	17	Smith	119	CS1310	c
	8	Brown	85	MATH2410	A
	8	Brown	92	CS1310	A
	8	Brown	102	CS3320	B
	8	Brown	135	CS3380	A

(b)

GRADE_REPORT	Student Number	Student Name	Section Identifier	Course Number	Grade
	17	Brown	112	MATH2410	B

Fig. 5: The redundant storage of data items, (a) Controlled redundancy: Including Student-Name and CourseNumber in the CRADE_REPORT file, (b) Uncontrolled redundancy: A GRADE_REPORT record that is inconsistent with the STUDENT records in Fig. 5, because the Name of student number 17 is Smith, not Brown.

In the database approach, the views of different user groups are integrated during database design. For consistency, we should have a database design that stores each logical data item—such as a student's name or birth date—in only one place in the database. This does not permit inconsistency, and it saves storage space. However, in some cases, **controlled redundancy** may be useful for improving the performance of queries. For example, we may store StudentName and CourseNumber redundantly in a GRADE_REPORT file , because, whenever we retrieve a GRADE_REPORT record, we want to retrieve the student name and course number along with the grade, student number, and section identifier. By placing all the data together, we do not have to search multiple files to collect this data. In such cases, the DBMS should have the capability to control this redundancy so as to prohibit inconsistencies among the files. This may be done by automatically checking that the StudentName-StudentNumber values in any GRADE_REPORT record in Fig. 5(a) match one of the StudentName-StudentNumber values of a STUDENT record (Fig. 2). Similarly, the SectionIdentifier-CourseNumber values in GRADE_REPORT can be checked against SECTION records. Such checks can be specified to the DBMS during database design and automatically enforced by the DBMS whenever the GRADE_REPORT file is updated. Fig. 2(b) shows a GRADE_REPORT record that is inconsistent with the STUDENT file of Fig. 2, which may be entered erroneously if the redundancy is not controlled.

Restricting Unauthorized Access

When multiple users share a database, it is likely that some users will not be authorized to access all information in the database. For example, financial data is often considered confidential, and hence only authorized persons are allowed to access such data. In addition, some users may be permitted only to retrieve data, whereas others are allowed both to retrieve and to update. Hence, the type of access operation—retrieval or update—must also be controlled. Typically, users or user groups are given account numbers protected by passwords, which they can use to gain access to the database. A DBMS should provide a **security and authorization subsystem**, which the DBA uses to create accounts and to specify account restrictions. The DBMS should then enforce these restrictions automatically. Notice that we can apply similar controls to the DBMS software. For example, only the DBA's staff may be allowed to use certain **privileged software**, such as the software for creating new accounts. Similarly, parametric users may be allowed to access the database only through the canned transactions developed for their use.

Providing Persistent Storage for Program Objects and Data Structures

Databases can be used to provide **persistent storage** for program objects and data structures. This is one of the main reasons for the emergence of the **object-oriented database systems**. Programming languages typically have complex data structures, such as record types in PASCAL or class definitions in C++. The values of program variables are discarded once a program terminates, unless the programmer explicitly stores them in permanent files, which often involves converting these complex structures into a format suitable for file storage. When the need arises to read this data once more, the programmer must convert from the file format to the program variable structure. Object-oriented database systems are compatible with programming languages such as C++ and JAVA, and the DBMS software automatically performs any necessary conversions. Hence, a complex object in C++ can be stored permanently in an object-oriented DBMS, such as Object Store or O2 (now called Ardent). Such an object is said to be persistent, since it survives the termination of program execution and can later be directly retrieved by another C++ program.

The persistent storage of program objects and data structures is an important function of database systems. Traditional database systems often suffered from the so-called **impedance mismatch problem**, since the data structures provided by the DBMS were incompatible with the programming language's data structures. Object-oriented database systems typically offer data structure compatibility with one or more object-oriented programming languages.

Permitting Inferencing and Actions Using Rules

Some database systems provide capabilities for defining deduction rules for inferencing new information from the stored database facts. Such systems are called **deductive database systems**. For example, there may be complex rules in the miniworld application for determining when a student is on probation. These can be specified declaratively as rules, which when compiled and maintained by the DBMS can determine all students on probation. In a traditional DBMS, an explicit procedural program code would have to be written to support such applications. But if the miniworld rules change, it is generally more convenient to change the declared deduction rules than to recede procedural programs. More powerful functionality is provided by **active database systems**, which provide active rules that can automatically initiate actions.

Providing Multiple User Interfaces

Because many types of users with varying levels of technical knowledge use a database, a DBMS should provide a variety of user interfaces. These include query languages for casual users; programming language interfaces for application programmers; forms and command codes for parametric users; and menu-driven interfaces and natural language interfaces for stand-alone users. Both forms-style interfaces and menu-driven interfaces are commonly known as **graphical user interfaces (GUIs)**. Many specialized languages and environments exist for specifying GUIs. Capabilities for providing World Wide Web access to a database—or web-enabling a database—are also becoming increasingly common.

Representing Complex Relationships Among Data

A database may include numerous varieties of data that are interrelated in many ways. **Consider the example shown in Fig. 2**. The record for Brown in the student file is related to four records in the GRADE_REPORT file. Similarly, each section record is related to one course record as well as to a number of GRADE_REPORT records-one for each student who completed that section. A DBMS must have the capability to represent a variety of complex relationships among the data as well as to retrieve and update related data easily and efficiently.

Enforcing Integrity Constraints

Most database applications have certain integrity constraints that must hold for the data. A DBMS should provide capabilities for defining and enforcing these constraints. The simplest type of integrity constraint involves specifying a data type for each data item. For example, **Fig. 2**, we may specify that the value of the Class data item within each student record must be an integer between 1 and 5 and that the value of Name must be a string of no more than 30 alphabetic characters. A more complex type of constraint that occurs frequently involves specifying that a record in one file must be related to records in other files. Considering the same example, we can specify that "every section record must be related to a course record." Another type of constraint specifies uniqueness on data item values, such as "every course record must have a unique value for CourseNumber." These constraints are derived from the meaning or **semantics** of the data and of the miniworld it represents. It is the database designers' responsibility to identify integrity constraints during database design. Some constraints can be specified to the DBMS and automatically enforced. Other constraints may have to be checked by update programs or at the time of data entry.

A data item may be entered erroneously and still satisfy the specified integrity constraints. For example, if a student receives a grade of A but a grade of C is entered in the database, the DBMS cannot discover this error automatically, because C is a valid value for the Grade data type. Such data entry errors can only be discovered manually (when the student receives the grade and complains) and corrected later by updating the database. However, a grade of Z can be rejected automatically by the DBMS, because Z is not a valid value for the Grade data type.

Providing Backup and Recovery

A DBMS must provide facilities for recovering from hardware or software failures. The **backup and recovery subsystem** of the DBMS is responsible for recovery. For example, if the computer system fails in the middle of a complex update program, the recovery subsystem is responsible for making sure that the database is restored to the state it was in before the program started executing. Alternatively, the recovery subsystem could ensure that the program is resumed from the point at which it was interrupted so that its full effect is recorded in the database.

Implications of the Database Approach

In addition to the issues discussed in the previous section, there are other implications of using the database approach that can benefit most organizations.

Potential for Enforcing Standards: The database approach permits the DBA to define and enforce standards among database users in a large organization. This facilitates communication and cooperation among various departments, projects, and users within the organization. Standards can be defined for names and formats of data elements, display formats, report structures, terminology, and so on. The DBA can enforce standards in a centralized database environment more easily than in an environment where each user group has control of its own files and software.

Reduced Application Development lime: A prime selling feature of the database approach is that developing a new application—such as the retrieval of certain data from the database for printing a new report—takes very little time. Designing and implementing a new database from scratch may take more time than writing a single specialized file application. However, once a database is up and running, substantially less time is generally required to create new applications using DBMS facilities. Development time using a DBMS is estimated to be one-sixth to one-fourth of that for a traditional file system.

Flexibility: It may be necessary to change the structure of a database as requirements change. For example, a new user group may emerge that needs information not currently in the database. In response, it may be necessary to add a file to the database or to extend the data elements in an existing file. Modern DBMSs allow certain types of changes to the structure of the database without affecting the stored data and the existing application programs.

Availability of Up-to-Date Information: A DBMS makes the database available to all users. As soon as one user's update is applied to the database, all other users can immediately see this update. This availability of up-to-date information is essential for many transaction-processing applications, such as reservation systems or banking databases, and it is made possible by the concurrency control and recovery subsystems of a DBMS.

Economies of Scale: The DBMS approach permits consolidation of data and applications, thus reducing the amount of wasteful overlap between activities of data-processing personnel in different projects or departments. This enables the whole organization to invest in more powerful processors, storage devices, or communication gear, rather than having each department purchase its own (weaker) equipment: This reduces overall costs of operation and management.

When Not to Use a DBMS

In spite of the advantages of using a DBMS, there are a few situations in which such a system may involve unnecessary overhead costs as that would not be incurred in traditional file processing. The overhead costs of using a DBMS are due to the following:

- High initial investment in hardware, software, and training.
- Generality that a DBMS provides for defining and processing data.
- Overhead for providing security, concurrency control, recovery, and integrity functions.

Additional problems may arise if the database designers and DBA do not properly design the database or if the database systems applications are not implemented properly. Hence, it may be more desirable to use regular files under the following circumstances:

- The database and applications are simple, well defined, and not expected to change.
- There are stringent real-time requirements for some programs that may not be met because of DBMS overhead.
- Multiple-user access to data is not required.

Database System Concepts and Architecture

Data Models, Schemas, and Instances

One fundamental characteristic of the database approach is that it provides some level of data abstraction by hiding details of data storage that are not needed by most database users. A **data model**—a collection of concepts that can be used to describe the structure of a database—provides the necessary means to achieve this abstraction (Sometimes the word model is used to denote a specific database description, or schema). By structure of a database we mean the data types, relationships, and constraints that should hold on the data. Most data models also include a set of **basic operations** for specifying retrievals and updates on the database.

In addition to the basic operations provided by the data model, it is becoming more common to include concepts in the data model to specify the **dynamic aspect or behavior** of a database application. This allows the database designer to specify a set of valid **user-defined operations** that are allowed on the database objects (The inclusion of concepts to describe behavior reflects a trend where database design and software design activities are increasingly being combined into a single activity. Traditionally, specifying behavior is associated with software design). An example of a user-defined operation could be COMPUTE_GPA, which can be applied to a STUDENT object. On the other hand, generic operations to insert, delete, modify, or retrieve any kind of object are often included in the basic data model operations. Concepts to specify behavior are fundamental to object-oriented data models but are also being incorporated in more traditional data models by extending these models. For example, object-relational models (relational Model represents database as a collection of relation. Informally, each relation resembles a table of values or to some extent, a "flat" file of records.) extend the traditional relational model to include such concepts, among others.

Categories of Data Models

Many data models have been proposed, and we can categorize them according to the types of concepts they use to describe the database structure. **High-level** or **conceptual data models** provide concepts that are close to the way many users perceive data, whereas **low-level** or **physical data models** provide concepts that describe the details of how data is stored in the computer. Concepts provided by low-level data models are generally meant for computer specialists, not for typical end users. Between these two extremes is a class of **representational** (or **implementation**) **data models**, which provide concepts that may be understood by end users but that are not too far removed from the way data is organized within the computer. Representational data models hide some details of data storage but can be implemented on a computer system in a direct way.

Conceptual data models use concepts such as entities, attributes, and relationships. An entity represents a real-world object or concept, such as an employee or a project that is described in the database. An attribute represents some property of interest that further describes an entity, such as the employee's name or salary. A relationship among two or more entities represents an interaction among the entities; for example, a works-on relationship between an employee and a project, we will present the Entity-Relationship model—a popular high-level conceptual data model.

Representational or implementation data models are the models used most frequently in traditional commercial DBMSs, and they include the widely-used **relational data model**, as well as the so-called legacy data models—the **network** and **hierarchical models**—that have been widely used in the past. Representational data models represent data by using record structures and hence are sometimes called record-based data models.

We can regard **object data models** as a new family of higher-level implementation data models that are closer to conceptual data models. We describe the general characteristics of object databases, together with an overview of two object DBMSs.

The ODMG proposed standard for object databases: Object data models are also frequently utilized as high-level conceptual models, particularly in the software engineering domain.

Physical data models describe how data is stored in the computer by representing information such as record formats, record orderings, and access paths. An **access path** is a structure that makes the search for particular database records efficient.

(The **ODMG object model** is the data model upon which the object definition language and object query language are based. In fact the object model provides the data type, type constructors, and other concepts that can be utilized in the ODL to specify object database schemas.)

Schemas, Instances, and Database State

In any data model it is important to distinguish between the description of the database and the database itself. The description of a database is called the **database schema**, which is specified during database design and is not expected to change frequently. (Schema changes are usually needed as the requirements of the database applications change. Newer database systems include operations for allowing schema changes, although the schema change process is more involved than simple database updates). Most data models have certain conventions for displaying the schemas as diagrams (It is customary in database parlance to use schemas as plural for schema, even though schemata is the proper plural form. The word scheme is sometimes used for schema). A displayed schema is called a **schema diagram**. The diagram displays the structure of each record type but not the actual instances of records. We call each object in the schema—such as STUDENT or COURSE—a **schema construct.**

STUDENT

Name	Student Number	Class	Major

COURSE

Course Name	Course Number	Credit Hours	Department

PREREQUISITE

Course Number	Prerequisite Number

SECTION

Section Identifier	Course Number	Semester	Year	Instructor

GRADE_REPORT

Student Number	Section Identifier	Grade

Fig. 6: Schema diagram for the database of Fig. 2

A schema diagram displays only some aspects of a schema, such as the names of record types and data items, and some types of constraints. Other aspects are not specified in the schema diagram; for example, **Fig. 6** shows neither the data type of neither each data item nor the relationships among the various files. Many types of constraints are not represented in schema diagrams; for example, a constraint such as "students majoring in computer science must take CS1310 before the end of their sophomore year" is quite difficult to represent.

The actual data in a database may change quite frequently; for example, the database shown in **Fig. 2** changes every time we add a student or enter a new grade for a student. The data in the database at a particular moment in time is called a **database state** or **snapshot**. It is also called the current set of **occurrences** or **instances** in the database. In a given database state, each schema construct has its own current set of instances; for example, the STUDENT construct will contain the set of individual student entities (records) as its instances. Many database states can be constructed to correspond to a particular database schema. Every time we insert or delete a record, or change the value of a data item in a record, we change one state of the database into another state.

The distinction between database schema and database state is very important. When we define a new database, we specify its database schema only to the DBMS. At this point, the corresponding database state is the empty state with no data. We get the initial state of the database when the database is first **populated** or **loaded** with the initial data. From then on, every time an update operation is applied to the database, we get another database state. The distinction between database schema and database is very importnat. When we define a new databse we specify its database schema only the DBMS.

At any point in time, the database has a current state.(The current state is also called current snapshot of the database). The DBMS is partly responsible for ensuring that every state of the database is a valid state—that is, a state that satisfies the structure and constraints specified in the schema. Hence, specifying a correct schema to the DBMS is extremely important, and the schema must be designed with the utmost care. The DBMS stores the descriptions of the schema constructs and constraints—also called the **meta-data**—in the DBMS catalog so that DBMS software' can refer to the schema whenever it needs to. The schema is sometimes called the intension, and a database state an **extension** of the schema.

Although, as mentioned earlier, the schema is not supposed to change frequently, it is not uncommon that changes need to be applied to the schema once in a while as the application requirements change. For example, we may decide that another data item needs to be stored for each record in a file, such as adding the DateOfBirth to the STUDENT schema in Fig. 6. This is known as **schema evolution**.

Most modern DBMSs include some operations for schema evolution that can be applied while the database is operational.

DBMS Architecture and Data Independence

Three important characteristics of the database approach, are (1) insulation of programs and data (program-data and program-operation independence); (2) support of multiple user views; and (3) use of a catalog to store the database description (schema). In this section we specify an architecture for database systems, called the **three-schema architecture**, which was proposed to help achieve and visualize these characteristics.

The Three-Schema Architecture

The goal of the three-schema architecture, illustrated **later**, is to separate the user applications and the physical database. In this architecture, schemas can be defined at the following three levels:

1. The **internal level** has an **internal schema**, which describes the physical storage structure of the database. The internal schema uses a physical data model and describes the complete details of data storage and access paths for the database.

2. The **conceptual level** has a **conceptual schema**, which describes the structure of the whole database for a community of users. The conceptual schema hides the details of physical storage structures and concentrates on describing entities, data types, relationships, user operations, and constraints. A high-level data model or an implementation data model can be used at this level.

3. The **external** or **view level** includes a number of **external schemas** or **user views**. Each external schema describes the part of the database that a particular user group is interested in and hides the rest of the database from that user group. A high-level data model or an implementation data model can be used at this level.

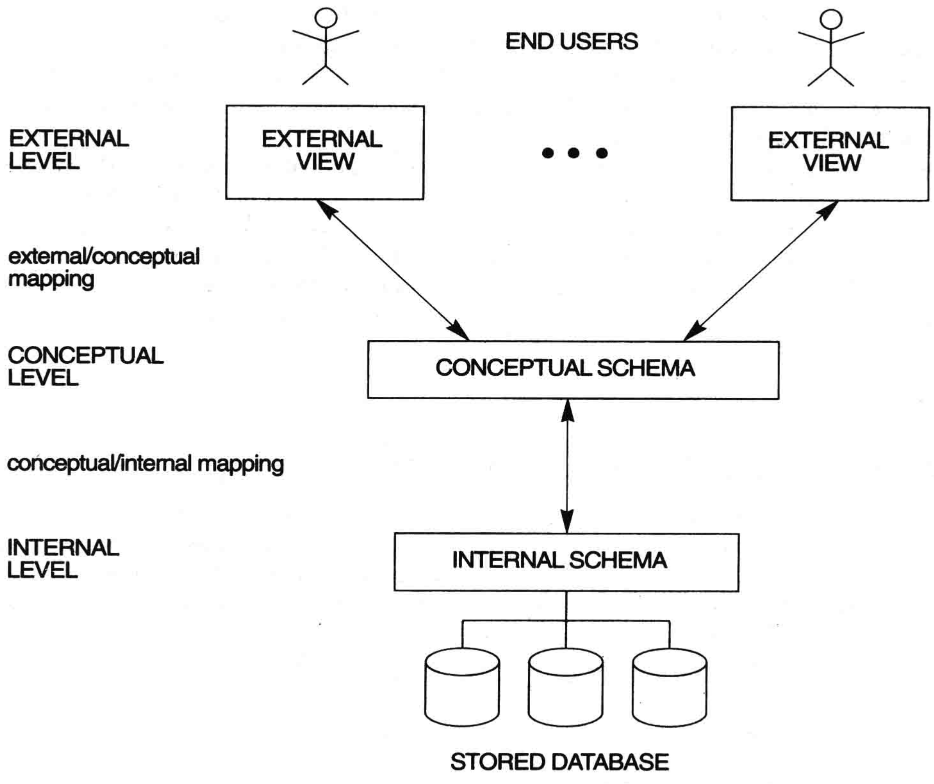


Fig. 7: Illustrating the three-schema architecture

The three-schema architecture is a convenient tool for the user to visualize the schema levels in a database system. Most DBMSs do not separate the three levels completely, but support the three-schema architecture to some extent. Some DBMSs may include physical-level details in the conceptual schema. In most DBMSs that support user views, external schemas are specified in the same data model that describes the conceptual-level information. Some DBMSs allow different data models to be used at the conceptual and external levels.

Notice that the three schemas are only descriptions of data; the only data that actually exists is at the physical level. In a DBMS based on the three-schema architecture, each user group refers only to its own external schema. Hence, the DBMS must transform a request specified on an external schema into a request against the conceptual schema, and then into a request on the internal schema for processing over the stored database. If the request, is a database retrieval, the data extracted from the stored database must be reformatted to match the user's external view. The processes of transforming requests and results between levels are called **mappings**. These mappings may be time-consuming, so some DBMSs:—especially those that are meant to support small databases—do not support external views. Even in such systems, however, a certain amount of mapping is necessary to transform requests between the conceptual and internal levels.

Data Independence

The three-schema architecture can be used to explain the concept of data independence, which can be defined as the capacity to change the schema at one level of a database system without having to change the schema at the next higher level. We can define two types of data independence:

1. **Logical data independence** is the capacity to change the conceptual schema without having to change external schemas or application programs. We may change the conceptual schema to expand the database (by adding a record type or data item), or to reduce the database (by removing a record type or data item). In the latter case, external schemas that refer only to the remaining data should not be affected. For example, the external schema of Fig. 4(a) should not be affected by changing the GRAD_REPORT file shown in Fig. 2 into the one shown in Fig. 5(a). Only the view definition and the mappings need be changed in a DBMS that supports logical data independence. Application programs that reference the external schema constructs must work as before, after the conceptual schema undergoes a logical reorganization. Changes to constraints can be applied also to the conceptual schema without affecting the external schemas or application programs.

2. **Physical data independence** is the capacity to change the internal schema without having to change the conceptual (or external) schemas. Changes to the internal schema may be needed because some physical files had to be reorganized—for example, by creating additional access structures—to improve the performance of retrieval or update. If the same data as before remains in the database, we should not have to change the conceptual schema. For example, providing an access path to improve retrieval of SECTION records (**Fig. 2**) by Semester and Year should not require a query such as "list all sections offered in fall 1998" to be changed, although the query would be executed more efficiently by the DBMS by utilizing the new access path.

Whenever we have a multiple-level DBMS, its catalog must be expanded to include information on how to map requests and data among the various levels. The DBMS uses additional software to accomplish these mappings by referring to the mapping information in the catalog. Data independence is accomplished because, when the schema is changed at some level, the schema at the next higher level remains unchanged; only the mapping between the two levels is changed. Hence, application programs referring to the higher-level schema need not be changed.

The three-schema architecture can make it easier to achieve true data independence, both physical and logical. However, the two levels of mappings create an overhead during compilation or execution of a query or program, leading to inefficiencies in the DBMS. Because of this, few DBMSs have implemented the full three-schema architecture.

Database Languages and Interfaces

(A) DBMS Languages

Once the design of a database is completed and a DBMS is chosen to implement the database, the first order of the day is to specify conceptual and internal schemas for the database and any mappings between the two. In many DBMSs where no strict separation of levels is maintained, one language, called the **data definition language** (DDL), is used by the DBA and by database designers to define both schemas. The DBMS will have a DDL compiler whose function is to process DDL statements in order to identify descriptions of the schema constructs and to store the schema description in the DBMS catalog.

In DBMSs where a clear separation is maintained between the conceptual and internal levels, the DDL is used to specify the conceptual schema only. Another language, the **storage definition language** (SDL), is used to specify the internal schema. The mappings between the two schemas may be specified in either one of these languages. For a true three-schema architecture, we would need a third language, the **view definition language** (VDL), to specify user views and their mappings to the conceptual schema, but in most DBMSs the DDL is used to define both conceptual and external schemas.

Once the database schemas are compiled and the database is populated with data, users must have some means to manipulate the database. Typical manipulations include retrieval, insertion, deletion, and modification of the data. The DBMS provides a **data manipulation language** (DML) for these purposes.

In current DBMSs, the preceding types of languages are usually not considered distinct languages; rather, a comprehensive integrated language is used that includes constructs for conceptual schema definition, view definition, and data manipulation. Storage definition is typically kept separate, since it is used for defining physical storage structures to fine-tune the performance of the database system, and it is usually utilized by the DBA staff. A typical example of a comprehensive database language is the SQL relational database language, which represents a combination of DDL, VDL, and DML, as well as statements for constraint specification and schema evolution. The SDL was a component in earlier versions of SQL but has been removed from the language to keep it at the conceptual and external levels only.

There are two main types of DMLs. A **high-level** or **nonprocedural DML** can be used on its own to specify complex database operations in a concise manner. Many DBMSs allow high-level DML statements either to be entered interactively from a terminal (or monitor) or to be embedded in a general-purpose programming language. In the latter case, DML statements must be identified within the program so that they can be extracted by a pfe-compiler and processed by the DBMS. A **low-level** or **procedural DML** must be embedded in a general-purpose programming language. This type of DML typically retrieves individual records or objects from the database and processes each separately.

Hence, it needs to use programming language constructs, such as looping, to retrieve and process each record from a set of records. Low-level DMLs are also called **record-at-a-time** DMLs because of this property. High-level DMLs, such as SQL, can specify and retrieve many records in a single DML statement and are hence called **set-at-a-time** or **set-oriented DMLs**. A query in a high-level DML often specifies which data to retrieve rather than how to retrieve it; hence, such languages are also called **declarative**.

Whenever DML commands, whether high-level or low-level, are embedded in a general-purpose programming language, that language is called the host language and the DML is called the **data sublanguage**(In object databases, the host and data sublanguages typically form one integrated language—for example, C++ with some extensions to support database functionality. Some relational systems also provide integrated languages—for example, ORACLE'S PL/SQL).On the other hand, a high-level DML used in a stand-alone interactive manner is called a **query language**. In general, both retrieval and update commands of a high-level DML may be used interactively and are hence considered part of the query language.

Casual end users typically use a high-level query language to specify their requests, whereas programmers use the DML in its embedded form. For naive and parametric users, there usually are **user-friendly interfaces** for interacting with the database; these can also be used by casual users or others who do not want to learn the details of a high-level query language. We discuss these types of interfaces next.

(B) DBMS Interfaces

User-friendly interfaces provided by a DBMS may include the following:

Menu-Based Interfaces for Browsing- These interfaces present the user with lists of options, called **menus**, that lead the user through the formulation of a request. Menus do away with the need to memorize the specific commands and syntax of a query language; rather, the query is composed step by step by picking options from a menu that is displayed by the system. Pull-down menus are becoming a very popular technique in window-based user interfaces. They are often used in **browsing interfaces**, which allow a user to look through the contents of a database in an exploratory and unstructured manner.

Forms-Based Interfaces- A forms-based interface displays a **form** to each user. Users can fill out all of the form entries to insert new data, or they fill out only certain entries, in which case the DBMS will retrieve matching data for the remaining entries. Forms are usually designed and programmed for naive users as interfaces to canned transactions. Many DBMSs have **forms specification languages**, special languages that help programmers specify such forms. Some systems have utilities that define a form by letting the end user interactively construct a sample form on the screen.

Graphical User Interfaces- A graphical interface (GUI) typically displays a schema to the user in diagrammatic form. The user can then specify a query by manipulating the diagram. In many cases, GUIs utilize both menus and forms. Most GUIs use a **pointing device**, such as a mouse, to pick certain parts of the displayed schema diagram.

Natural Language Interfaces- These interfaces accept requests written in English or some other language and attempt to "understand" them. A natural language interface usually has its own "schema," which is similar to the database conceptual schema. The natural language interface refers to the words in its schema, as well as to a set of standard words, to interpret the request. If the interpretation is successful, the interface generates a high-level query corresponding to the natural language request and submits it to the DBMS for processing; otherwise, a dialogue is started with the user to clarify the request.

Interfaces for Parametric Users- Parametric users, such as bank tellers, often have a small set of operations that they must perform repeatedly. Systems analysts and programmers design and implement a special interface for a known class of naive users. Usually, a small set of abbreviated commands is included, with the goal of minimizing the number of keystrokes required for each request. For example, function keys in a terminal can be programmed to initiate the various commands. This allows the parametric user to proceed with a minimal number of keystrokes.

Interfaces for the DBA- Most database systems contain privileged commands that can be used only by the DBA's staff. These include commands for creating accounts, setting system parameters, granting account authorization, changing a schema, and reorganizing the storage structures of a database.

The Database System Environment

A DBMS is a complex software system. In this section we discuss the types of software components that constitute a DBMS and the types of computer system software with which the DBMS interacts.

DBMS Component Modules

The typical DBMS components. The database and the DBMS catalog are usually stored on disk. Access to the disk is controlled primarily by the **operating system** (OS), which schedules disk input/output. A higher-level **stored data manager** module of the DBMS controls access to DBMS information that is stored on disk, whether it is part of the database or the catalog. The dotted lines and circles marked **A, B, C, D, and E in Fig. 8** illustrate accesses that are under the control of this stored data manager. The stored data manager may use basic OS services for carrying out low-level data transfer between the disk and computer main storage, but it controls other aspects of data transfer, such as handling buffers in main memory. Once the data is in main memory buffers, it can be processed by other DBMS modules, as well as by application programs.

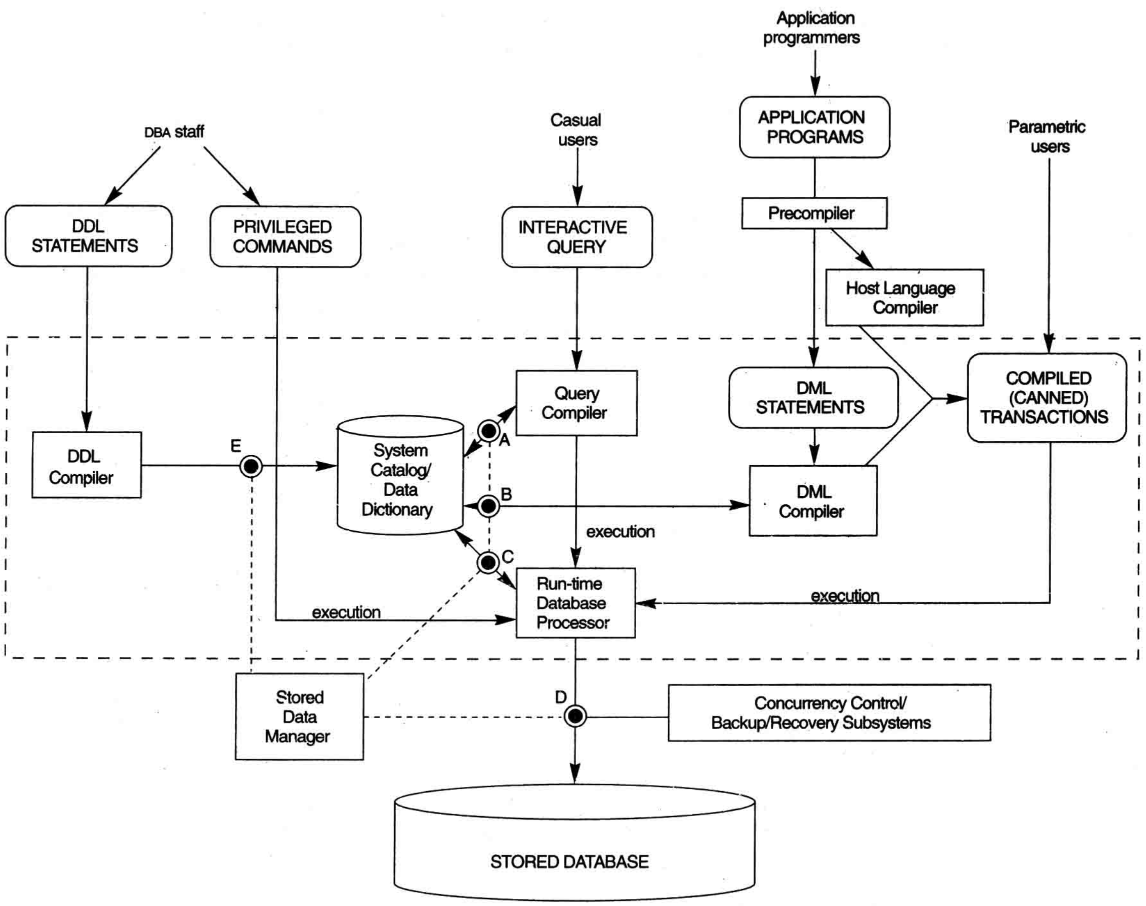


Fig. 8: Typical component modules of a DBMS. Dotted lines show accesses that are under the control of the stored data manager.

The DDL **compiler** processes schema definitions, specified in the DDL, and stores descriptions of the schemas (meta-data) in the DBMS catalog. The catalog includes information such as the names of files, data items, storage details of each file, mapping information among schemas, and constraints, in addition to many other types of information that are needed by the DBMS modules. DBMS software modules then look up the catalog information as needed.

The **run-time database processor** handles database accesses at run time; it receives retrieval or update operations and carries them out on the database. Access to disk goes through the stored data manager. The **query compiler** handles high-level queries that are entered interactively. It parses, analyzes, and compiles or interprets a query by creating database access code, and then generates calls to the run-time processor for executing the code.

The **pre-compiler** extracts DML commands from an application program written in a host programming language. These commands are sent to the **DML compiler** for compilation into object code for database access. The rest of the program is sent to the host language compiler. The object codes for the DML commands and the rest of the program are linked, forming a canned transaction whose executable code includes calls to the runtime database processor. Fig. 8 is not ment to describe a specific DBMS; rather it illustrates typical DBMS Modules.

The DBMS interacts with the operating system when disk accesses—to the database or to the catalog—are needed. If the computer system is shared by many users, the OS will schedule DBMS disk access requests and DBMS processing along with other processes. The DBMS also interfaces with compilers for general-purpose host programming languages. User-friendly interfaces to the DBMS can be provided to help any of the user types to shown in Figures to specify their request.

Database System Utilities

In addition to possessing the software modules just described, most DBMSs have **database utilities** that help the DBA in managing the database system. Common utilities have the following types of functions:

1. **Loading:** A loading utility is used to load existing data files—such as text files or sequential files—into the database. Usually, the current (source) format of the data file and the desired (target) database file structure are specified to the utility, which then automatically reformats the data and stores it in the database. With the proliferation of DBMSs, transferring data from one DBMS to another is becoming common in many organizations. Some vendors are offering products that generate the appropriate loading programs, given the existing source and target database storage descriptions (internal schemas). Such tools are also called **conversion tools**.
2. **Backup:** A backup utility creates a backup copy of the database, usually by dumping the entire database onto tape. The backup copy can be used to restore the database in case of catastrophic failure. Incremental backups are also often used, where only changes since the previous backup are recorded. Incremental backup is more complex but it saves space.
3. **Fife reorganization:** This utility can be used to reorganize a database file into a different file organization to improve performance.
4. **Performance monitoring:** Such a utility monitors database usage and provides statistics to the DBA. The DBA uses the statistics in making decisions such as whether or not to reorganize files to improve performance.

Other utilities may be available for sorting files, handling data compression, monitoring access by users, and performing other functions.

Tools, Application Environments, and Communications Facilities

Other tools are often available to database designers, users, and DBAs. CASE tools(Although CASE stands for Computer Aided Software Engineering, many CASE tools are used primarily for database design) are used in the design phase of database systems. Another tool that can be quite useful in large organizations is an expanded **data dictionary** (or **data repository**) system. In addition to storing catalog information about schemas and constraints, the data dictionary stores other information, such as design decisions, usage standards, application program descriptions, and user information. Such a system is also called an information repository. This information can be accessed directly by users or the DBA when needed. A data dictionary utility is similar to the DBMS catalog, but it includes a wider variety of information and is accessed mainly by users rather than by the DBMS software.

Application development environments, such as the PowerBuilder system, are becoming quite popular. These systems provide an environment for developing database applications and include facilities that help in many facets of database systems, including database design, GUI development, querying and updating, and application program development.

The DBMS also needs to interface with communications software, whose function is to allow users at locations remote from the database system site to access the database through computer terminals, workstations, or their local personal computers. These are connected to the database site through data communications hardware such as phone lines, long-haul networks, local-area networks, or satellite communication devices. Many commercial database systems have communication packages that work with the DBMS. The integrated DBMS and data communications system is called a DB/DC system. In addition, some distributed DBMSs are physically distributed over multiple machines. In this case, communications networks are needed to connect the machines. These are often **local area networks (LANs)** but they can also be other types of networks.

Classification of Database Management Systems

Several criteria are normally used to classify' DBMSs. The first is the data model on which the DBMS is based. The two types of data models used in many current commercial DBMSs are the relational data model and the object data model. Many legacy applications still run on database systems based on the hierarchical and network data models. The relational DBMSs are evolving continuously, and, in particular, have been incorporating many of the concepts that were developed in object databases. This has led to a new class of DBMSs that are being called object-relational DBMSs. We can hence categorize DBMSs based on the data model: relational, object, object-relational, hierarchical, network, and other.

The second criterion used to classify DBMSs is the **number of users** supported by the system. **Single-user systems** support only one user at a time and are mostly used with personal computers. **Multiuser systems**, which include the majority of DBMSs, support multiple users concurrently.

A third criterion is the number of sites over which the database is distributed. A DBMS is centralized if the data is stored at a single computer site. A centralized DBMS can support multiple users, but the DBMS and the database themselves reside totally at a single computer site. A distributed DBMS (DDBMS) can have the actual database and DBMS software distributed over many sites, connected by a computer network. Homogeneous DDBMSs use the same DBMS software at multiple sites. A recent trend is to develop software to access several autonomous preexisting databases stored under heterogeneous DBMSs. This leads to a federated DBMS (or multidatabase system), where the participating DBMSs are loosely coupled and have a degree of local autonomy. Many DDBMSs use a client-server architecture.

A fourth criterion is the cost of the DBMS. The majority, of DBMS packages cost between $10,000 and $100,000. Single-user low-end systems that work with microcomputers cost between $100 and $3000. At the other end, a few elaborate packages cost more than $100,000.

We can also classify a DBMS on the basis of the types of access path options for storing files. One well-known family of DBMSs is based on inverted file structures. Finally, a DBMS can be general-purpose or special-purpose. When performance is a primary, consideration, a special-purpose DBMS can be designed and built for a specific-application; such a system cannot be used for other applications without major changes. Many airline reservations and telephone directory systems developed in the-past are special-purpose DBMSs. These fall into the category of on-line transaction processing (OLTP) systems, which must support a large number of concurrent transactions without imposing excessive delays.

Let us briefly elaborate on the main criterion for classifying DBMSs: the data model. The basic relational data model represents a database as a collection of tables, where each table can be stored as a separate file. Most relational databases use the high-level query language called SQL and support a limited form of user views.

The object data model defines a database in terms of objects, their properties, and their operations. Objects with the same structure and behavior belong to a class, and classes are organized into hierarchies (or acyclic graphs). The operations of each class are specified in terms of predefined procedures called methods. Relational DBMSs have been extending their models to incorporate object database concepts and other capabilities; these systems are referred to as object-relational or extended-relational systems.

The network model represents data as record types and also represents a limited type of 1:N relationship, called a set type.

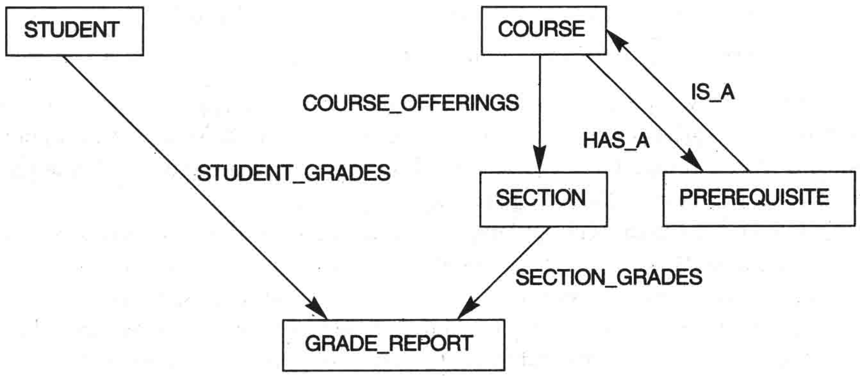


Fig. 9: The schema in the notation of the network data model

The network model, also known as the CODASYL DBTG model,(CODASYL DBTG stands for Data system Language Data Base Task Group,which is the committee that specified the network model and its language.) has an associated record-at-a-time language that must be embedded in a host programming language. The **hierarchical model** represents data as hierarchical tree structures. Each hierarchy represents a number of related records. There is no standard language for the hierarchical model, although most hierarchical DBMSs have record-at-a-time languages.

6.2 RELATIONAL DATA BASE MANAGEMENT SYSTEM

SQL SERVER – Difference Between DBMS and RDBMS

What is difference between DBMS and RDBMS?

DBMS – Data Base Management System

RDBMS – Relational Data Base Management System or Relational DBMS

A DBMS has to be persistent, that is it should be accessible when the program created the data ceases to exist or even the application that created the data restarted. A DBMS also has to provide some uniform methods independent of a specific application for accessing the information that is stored.

RDBMS adds the additional condition that the system supports a tabular structure for the data, with enforced relationships between the tables. This excludes the databases that don't support a tabular structure or don't enforce relationships between tables.

DBMS does not impose any constraints or security with regard to data manipulation it is user or the programmer responsibility to ensure the ACID PROPERTY of the database whereas the RDBMS is more with this regards because RDBMS defines the integrity constraint for the purpose of holding ACID PROPERTY. RDBMS may be or may not be Client Server Database System.

Examples :

DBMS – File System, XML

RDBMS – SQL Server, Oracle

RELATIONAL MODEL CONCEPTS

The Relational model was first introduced by Ted codd of IBM Research in 1970. It became popular due to its simplicity and mathematical foundation.

It may be noted that, the two commercial relational DBMS are ORACLE and Microsoft Access.

The relational model represents the database as a collection of relations. Generally each relation is represented by a table of values.

For example, the database of files shown below is considered to be in the relational model.

Student	Name	Student Number	Major
	Amal	17	CS
	Kamal	18	Cs

Fig: 10

Course	Course Name	Course Number	Department
	Data Structure	CS 131	CS
	Discrete Math	CS 230	Math
	Database	CS 338	CS

Fig: 11

Grade Report	Student Number	Grade
	17	B
	17	C
	8	A
	8	B
	8	A

Fig: 12

It may be noted that each of the above tables is known as relation and the whole database is called relational database.

When a relation is presented as table of values, each row in the table represents a collection of related data values.

In above examples, the first table is called STUDENT because each row represents facts about a particular student entity.

The column names viz. name, student number, major specify the interpretation of the data values in each row. All values in a column are of the same data type.

DOMAINS

The datatype describing the types of values, appearing in each column is called a domain.

A domain D is a set of atomic values. By atomic value, we mean that each value in the domain is not divisible as far as the relational model is concerned.

Some examples:

INDIA – Phone-number: The set of 7 digit phone number valid in India.

PIN-code: The set of valid 6 digit Postal Identification number.

Names: The set of names of person.

Social-security-number: The set of valid 9 digit social security number of U.S.A.

Tuple : In a formal relational model, a row is called a tuple.

Attribute: A column header is called an attribute.

Relation: A table is called a relation. The attributes and tables of a relation STUDENT is given in the Fig. 13.

Attributes

Relation Name

STUDENT	ROLL NO.	SSN	HOME PHONE	ADDRESS	OFF. PHONE	AGE
	Amal	305	5530381	X	Null	19
tuples	Bimal	381	5534561	Y	Null	18
	Kamal	391	5538879	Z	5774988	25
	Nirmal	345	5534579	W	5778988	18

Fig: 13

Relation Schema

A Relation Schema R, denoted by R (A_1, A_2, A_3 .... A_n) is made up for a relation name R and a list of attributes A_1, A_2, ... $A_{n.}$

The degree of a relation is the number of attributes n of its relation schema.

As an example, a relation having degree 6 is shown as under:

STUDENT	Name	Roll No.	Home-Phone	Address	Off-phone	Age
R	A_1	A_2	A_3	A_4	A_5	A_6

A relation (or relation state) r of the relation schema R (A_1, A_2, ... A_n) also denoted by r(R), is a set of n tuples r= {t_1, t_2, ... t_m}. each n-tuples t is an ordered list of n values, t = {v_1, v_2, ... V_n} where each value $v_{i,}$ $1 \le I \le n$, is an element of dom (A_i) or is a special null value.

RELATIONAL MODEL NOTATION

The following notations will be used:

A Relation schema R of degree n is denoted by R (A_1, A_2, A_3 .... A_n).

An n-tuple t in a relation r(R) is denoted by t = {v_1, v_2, ... V_n}, where v_i are the values corresponding to attribute A_i.

The letters Q, R, S denote relation name.

The letters t, u, v denote tuples.

The letters q, r, s denote relation states.

Relational constraints

Various restrictions on data that can be specified on a relational database schema in the term of constraints.

The other types of constraints, called data dependencies (which include functional dependencies and multivalued dependencies), are used mainly for database design by normalization.

Domain constraints: Domain constraints specify that the value of each attribute A must be an atomic value from the domain dom (A). the data types associated with domains typically include standard numeric datatypes for integers (such as short, long) and real numbers (float and double), characters, fixed length strings data types.

CONCEPT OF KEYS – CANDIDATE KEY, PRIMARY KEY, ALTERNATE KEY, FOREIGN KEY

We store tuples or records in a relation for use in future. Sometimes, we may require a particular record, sometimes a group of records and some other times all the records in a relation. But to retrieve a specific record, there must be some identifying characteristics in the record or records to that these can be uniquely separated from a given lot of records. The identifying characteristics may be the sole property of an attribute or a combination of attributes. The data values of an attribute or a group of attributes uniquely identify a tuple in a relation. This attribute or the group of attributes is called a key or a Super Key.

For example, the salesman code numbers represented by the field-name SMCODE in the SALESMAN table may be called a key because any given code number will identify the

(SALESMAN)

SMCODE	SMNAME	CITY	INAME	UNIT PRICE
K 101	AMAL	KOLKATA	BABY OIL	50
D 235	BIMAL	DELHI	BABY POWER	20
P 410	KAMAL	PATNA	BABY CLOTH	60

Fig: 13(a)

Corresponding record without any ambiguity. In the same relation, SMNAME may also be chosen as a key, because there is no duplicate data value against SMNAME and hence of any given name, the corresponding record may be traced in the relation. Also a combination of SMCODE and SMNAME or SMCODE, SMNAME or CITY may also serve as a key or superkey. We require a superkey for which no proper subset is superkey. Such minimal superkeys are called candidate keys. A candidate key is chosen by the database designer as the principal means of identifying entities within an entity set or relation and it is called the primary key. A candidate key which is not the primary key is termed as alternate key. Sometimes, the primary key of a relation appears as a non-key attribute of some other associated relation. Such a nonkey attribute is called a foreign key. For example, in the following BATCH relation, REGN_NO is a foreign key with respect to the relation STUDENT.

STUDENT

ROLL NO	REGN_NO
BA 23	1234
CA 31	1239

Fig: 14

BATCH

REGN_NO	NAME	COURSE	STATUS
1234	Amal	BBA	Passed
1239	Kamal	BCA	Failed

Fig: 15

Key Constraints: A relations defined as a set of tuples. By definition, all elements of a Set are distinct. Hence, all tuples in a relation must also be distinct. This means that no two tuples can have the same combination of values for all their attributes.

Suppose that we denote one such subset of attributes by SK. Then for any two distinet tuples t_1 and t_2 in a relation state r of R.

T1 [SK] ≠ t2 [SK]

SUPERKEY

Any such set of attributes SK is called a Superkey of the relation Schema R. A superkey SK specifies a uniqueness constraint that no two distinct tuples in a state r of R can have the same for SK. Considering Fi.g. 16 STUD {Name, Roll NO, Add., Age} from a Superkey.

STUDENT	NAME	ROLL NO.	ADD.	AGE
	Amal	37	X	11
	Kamal	53	Y	17
	Bimal	64	Z	13

Fig: 16

It may be noted that a key K of a relation Schema R is a Superkey of R with the additional property that removing may attribute A from K leaves a set of attributes K' that is not a Superkey of R. Hence Key is a minimal Superkey.

A Superkey can have redundant attributes, so that a more useful concept is that of a Key.

A Key is a minimal Syperkey. That is, a Superkey from which we cannot remove any attributes still have the uniqueness constraint.

For example the attribute set {REGN_NO} is a key of student because no two tuples can have the same value for REGN_NO.

Any set of attributes that includes REGN_NO.- for example, {REGN_NO}, Name, Age} – is a Superkey. However, the Superkey {REGN_NO, Name, Age} is not a key of student because removing Name or Age or both from the set still leaves us with a Superkey.

CANDIDATE KEY

A relation schema may have more than one key. In this case, each of the keys is called a candidate key.

For Example the CAR relation (Fig. 17) has two candidate keys. License Number and Engine Serial Number.

PRIMARY KEY

It is common to designate one of the candidate keys as the Primary Key. We use the convention that the attributes forming the primary key of a relation schema are underlined.

Car	Licencse Num.	Engine Serial No.	Make	Year
	Delhi ABC	A69874	Maruti	1998
	KOL ADE	B 71310	Maruti	1999

Fig: 17

RATIONAL DATABASE AND RELATIONAL DATABASE SCHEMA

A Relational database usually contains many relatins, with tuples in relations that are related in various ways.

A Relational database schema S is a set of relation Schemas S = $\{R_1, R_2, \ldots\ldots\ldots\ldots\ldots\ldots R_m\}$ and set of Integrity Constraints (IC)

A relational database state (DB) of S is a set of relation states DB = $\{r_1, r_2, r_3, \ldots\ldots\ldots\ldots, r_m\}$ such that each r_i is a state of R_i and such that the r_i relation states satisfy the integrity constraints specified in IC.

Fig. 18 shows a relational database schema that we call COMPANY = {EMPLOYEE, DEPARTMENT, DEPT-LOC, PROJECT, WORKS-ON, DEPENDENT}

EMPLOYEE

NAME	<u>SSN</u>	BDATE	ADDRESS	SEX	SALARY	DNO

DEPARTMENT

DNAME	<u>DNUMBER</u>	MGRSSN

DEPT-LOCATIONS

DNUMBER	DLOCATION

PROJECT

DNAME	DNUMBER	DLOCATION

WORKS-ON

<u>ESSN</u>	<u>PNO</u>	<u>HOURS.</u>

DEPARTMENT

<u>ESSN</u>	<u>DEP. NAME</u>	SEX	BDATE	RELATIONSHIP

Fig: 18

Table 17.11 shows Schema diagram for the COMPANY Relational database schema, the Primary Keys are underlined. A relation database state is called a relational database instance.

EMPLOYEE	NAME	SSN	BDATE	ADDRESS	SEX	SALARY	DNO
	--	--	--	--	--	--	--
	--	--	--	--	--	--	--
	--	--	--	--	--	--	--

Fig: 18

DEPARTMENT	DNAME	DNUMBER	MGRSSN
	--	--	--
	--	--	--
	--	--	--

Fig: 19

Tables show a Relational database state corresponding to the COMPANY schema.

ENTITY INTEGRITY

Entity Integrity constraint states that no primary key value can be null. This is because the Primary Key value is used to identify individual tuples in a relation Null values for the Primary Key implies that we cannot identify some tuples.

REFERENTIAL INTEGRITY CONSTRAINT

Key constraints and entity integrity constraints are specified on individual relations. The Referential Integrity Constraints are specified between two relations and is used to maintain the consistency among tuples of the two relations.

Informally, the Referential Integrity Constraint states that a tuple in one relation that refers to another relation must refer to an existing tuple in that relation.

For examole, the attribute DNO of EMPLOYEES gives the department number for which each employee works, hence its value in every EMPLOYEE tuple must match the DNUMBER value of some tuple in the Department relation.

EMPLOYEE	NAME					DNO
	Kamal	--	--	--	--	5
	Hassan	--	--	--	--	5
	Suman	--	--	--	--	4
	Bimal					1

DEPARTMENT	DNAME	DNUMBER	MGRSSN
	Research	5	--
	Administration	4	--
	Quarter	1	--

Fig: 20

FOREIGN KEY

The conditions for a foreign key, given below, specify a referential integrity constraint between the two Relation Schema R_1 and R_2.

A set of attributes FK in a relation Schema R_1 is a foreign key of R_1 that refers relation R_2 if it satisfies the following two rules:

(1) The attributes FK have same domain (S) as the primary key attributes PK of R_2; the attributes FK are said to reference or refer to relation.

(2) A value of FK in tuple t_1 of the current state r_1 (R_1) either, occurs as a value of PK for some tuple t_2 in the current State r_2 (R_2). Hence

$$\boxed{T_1 \text{ [FK]} = t_2 \text{ [PK]}}$$

R_1 is called the referencing relation and R_2 is called the referenced relation.

Referential Integrity constraints

EMPLOYEE

NAME	SSN	BDATE	ADD	SEX	SALARY	DNUMBER

DEPARTMENT

DNAME	DNUMBER	MGRSSN

Fig: 21

Here DNO depends on DNUMBER and MGSSN depends on SSN.

RELATIONAL ALGEBRA

Relational algebra is a collection of operations to generate new relations after manipulating relations. The operations are based on two groups of logical entities called operators. One group consists of the traditional set operators; namely, UNION, INTERSECTION, DEFFERENCE and CARTESIAN PRODUCT and the other group contains special relational operators named SELECTION, PROJECTION, JOIN and DIVISION. The operators act on relations. The relations are called operand.

TRADITIONAL SET OPERATORS

These operators other than the Cartesian product always operate on operands of same degree. These are UNION, INTERESECTION and DIFFERENCE operations. These operations can take place between two relations having the same degree and the i=1 to degree.

UNION

The union operator is denoted by the word UNION or the symbol U and it acts on two relations to generate a new relation containing all tuples of the relations except the duplicate ones. This implies that the new relation will have tuples which will belong to either the first relation or the second or both.

Thus the result of this operation, denoted by RUS, is a relation what includes all tuples those are either in R or in S or in R and S. duplicate tuples are eliminated.

For example, let X and Y be two relations as shown below:

Relation X

Batch-No	**COURSE**
1	BA
2	BSC
3	BCA
4	BCOM

Fig: 22

Relation Y

Batch-No	**COURSE**
1	BA
2	BSC
3	BCA
4	BCOM
5	MA
6	MSC

Fig: 23

Then, XUY will be a relation as shown below:

(X U Y)

Batch-No	COURSE
1	BA
2	BSC
3	BCA
4	BCOM
5	MA
6	MSC

Fig: 24

INTERSECTION

The intersection operator is denoted by the word INTERESECT or the symbol ∩ and it acts on two relations to generate another relation consisting of only the common tuples between the two.

The result of this operation, denoted by R ∩ S includes all tuples that are in both R and S.

Example: Let X and Y be two relations as shown below:

Relation X

REGN_NO	NAME	OCCUPATION
ABC 123	AMAL	SERIVICE
ABC 124	KAMAL	STUDENT
ABC 125	BIMAL	STUDENT
ABC 129	RITA	SERVICE
ABC 130	SITA	BUSINESS
ABC 131	GITA	STUDENT

Fig: 25

Relation Y

REGN_NO	NAME	OCCUPATION
ABC 124	KAMAL	STUDENT
ABC 125	BIMAL	STUDENT
ABC 131	GITA	STUDENT
ABC 234	MITA	STUDENT
ABC 235	SUMITRA	STUDENT
ABC 236	SUCHITRA	STUDENT

Fig: 26

THE X ∩ Y will be a relation as shown below:

Relation X ∩ Y

REGN_NO	NAME	OCCUPATION
ABC 124	KAMAL	STUDENT
ABC 125	BIMAL	STUDENT
ABC 131	GITA	STUDENT

Fig: 27

DIFFERENCE

The difference operator is denoted by the symbol '-' (or minus) and it operates on two relations to yiled a third relation that comprises all tuples belonging to the relations preceding the operator and not to the relation following it.

The result of this operation denoted by R-S, includes all tuples present in R.

For example: Let X and Y be as in Fig. 25 and Fig. 26. Then X-Y will produce the following relation.

Relation X - Y

REGN_NO	NAME	OCCUPATION
ABC 123	AMAL	SERVICE
ABC 129	RITA	SERVICE
ABC 130	SITA	BUSINESS

Fig: 28

It is seen that X ∩ Y represents X-(X-Y) operation.

EXTENDED CARTESIAN PRODUCT

the Extended Cartesian product of two relations is denoted by the operator ¥ and it produces a third relation containing all possible tuples that may be formed by concatenating the attributes of the relations.

Let A and B be relations of degree n1 and n2, respectively. Then A x B, the Cartesian product of A and B is the set of (n1 + n2) – tuples whose first n1 attribute values form a tuple in A and the last n2 attribute values from a tuple in B. if the cardinality of the relations be C1 and C2 then the cardinality of the resulting relation will be n1 x n2.

Example: Let the relations A and B be as shown in figure below:

Relation A

NAMES
AMAL
KAMAL
BIMAL

Fig: 29

Relation B

HOBBIES
BOOK COLLECTION
STAMP COLLECTION
COIN COLLECTION

Fig: 30

The A x B yields the following relation:

Relation A x B

NAMES	HOBBIES
AMAL	BOOK COLLECTION
AMAL	STAMP COLLECTION
AMAL	COIN COLLECTION
KAMA	BOOK COLLECTION
KAMA	STAMP COLLECTION
KAMAL	COIN COLLECTION
BIMAL	BOOK COLLECTION
BIMAL	STAMP COLLECTION
BIMAL	COIN COLLECTION

Fig: 31

SPECIAL RELATION OPERATORS

Selection: The selection operator operates upon a relation to generate another relation. The tuples of relation form a horizontal subset of the operand relation which satisfies a given condition. The operator is denoted by stating the relation name, followed by the keyword WHERE, followed by a conditional expression involving the following:

(i) Operands which are constant values or component numbers

(ii) The comparison operators <, =, >, <=, ! = and >=

(iii) The logical operators ^ (and; V (or), and ¬ (not).

The greek letter σ (sigma) is also used to denote the selection operation.

Examples: Consider the relation X in Fig. 25 and the relation Z below.

Relation Z

REGN_NO.	COURSE	FEES_PAID
ABC 123	BA	700
ABC 124	BSC	1000
ABC 125	BSC	900
ABC 129	BA	500
ABC 130	BSC	950

Fig: 32

Then the selection operation yields new relations as illustrated below:

Selection operation 1.

X WHERE OCCUPATION = 'SERVICE'

Alternatively, we can also write σ occupation = 'service' (X)

The New Relation formed is shown in Fig. 33.

REGN_NO.	COURSE	FEES_PAID
ABC 123	AMAL	SERVICE
ABC 129	RITA	SERVICE

Fig: 33

Selection operation 2.

Z WHERE FEES_PAID > 700

Alternatively, σFEES-PAID>700(Z)

Resulting Relation:

REGN_NO.	COURSE	FEES_PAID
ABC 124	BSC	1000
ABC 125	BSC	900
ABC 130	BSC	950

Fig: 34

Selection operation 3.

Z WHERE COURSE = "BSC" AND FEES_PAID = 900

Alternatively, σ course = BSC AND FEES PAID = 900(Z)

New Relation:

REGN_NO.	COURSE	FEES_PAID
ABC 125	BSC	900

Fig: 35

Study Note - 7

MANAGEMENT INFORMATION SYSTEM (MIS) AND INFORMATION ECONOMICS

This Study Note includes

7.1 MANAGEMENT INFORMATION SYSTEM (MIS)

Management Information System (MIS): Decisions are made on many issues that recur regularly and require a certain amount of information. So, the information systems can be developed so that the reports are prepared regularly to support these recurring decisions. MIS is designed to provide accurate, relevant and timely information to managers at different levels and in different functional areas throughout the organization for decision-making purpose.

Management: A manager may be required to perform following activities in an organization:

(i) Determination of organizational objectives and developing plans to achieve them.

(ii) Securing and organizing the human and physical resources so that these objectives could be accomplished.

(iii) Exercising adequate controls over the functions.

(iv) Monitoring the results to ensure that accomplishments are proceeding according to plan.

Information: Information could be defined as sets of facts, figures and symbols processed for the current decision-making situation.

System: A system is defined as a set of related components, activities, processes and human beings interacting together so as to accomplish some common objectives and thus, MIS can be defined as set of related processes, interacting together to provide processed data to managers at various levels and functional areas for decision making. State and explain any five characteristics of a good Management Information System.

Objectives of MIS

- To provide the managers at all levels with timely and accurate information for control of business activities
- To highlight the critical factors in the operation of the business for appropriate decision making
- To develop a systematic and regular process of communication within the organization on performance in different functional areas
- To use the tools and techniques available under the system for programmed decision making
- To provide best services to customers
- To gain competitive advantage
- To provide information support for business planning for future

Basic Features of an MIS

Management Oriented: The basic aim of MIS is to provide necessary information support to the Management in decision making. Naturally, the design of MIS is framed keeping the consideration of requirement of management of the organization. The management plays the most important role to develop the system specification of MIS to ensure the information need of different levels of management.

Timeliness: One of the most important issues involved in the effectiveness of MIS are flow of information at right time to the user level of management.

Integrated: Disintegrated information from different sub-systems becomes too much clumsy in decision making. Information from different related functional areas is to be integrated to make it meaningful for the users. In today's business environment, the different parameters of business process have a complex equation in an overall impact on the outcome. To understand the combined effect, linking them with the help of different analytical models is essential.

Simplicity: An MIS System should be as simple as possible so that people at operation and users do not feel any hazards. The success of a system lies in the acceptance by operation staff and users. A good amount of planning is required on the part of a MIS designer to make it simple keeping in mind the need of information at different levels of management. The deigning skill of database and analytical models decides the quality of MIS.

Reliability: MIS system should provide most reliable information. For that what is needed the skill in design and efficiency in programming to develop the system. More important is a thorough check of input information, process flow and output reports on regular and routine basis.

Consistency: The input data and output reports must follow some standard norms so that consistency is preserved.

Relevance: Only relevant information flow at different levels of management helps in increasing the effectiveness of MIS. In other words, information of right quantity improves the efficiency of the users in the use of information for their decision making.

Flexibility: MIS should be flexible enough to take care of changes in the environment in the business system.

Implementation of MIS

For establishment of MIS in an organization, the following steps are followed:

Analytical study on information requirement: A joint efforts by systems experts and management experts is required to understand the exact need of information at different levels management and how to assimilate them from data flow from different sources. The anticipated change in the need of information may be kept in mind while planning the design in order to provide sufficient flexibility in the system.

Determine the sources of information: Once the first step is understood, it is to see how to get the required information and their sources. If required, data recording system may be changed at different points so that exact data flow is ensured and the same can be done without much hazards. For the sake of simplicity of the system reorientation in the physical flow of data has to be done.

Establishment of right kind of data processing environment: The important steps involved in MIS designing is arranging the right kind of tools for processing i.e Computer System and infrastructure in terms of software and skilled manpower. The proper scheduling of processing is equally important to ensure smooth flow of information.

Selection of software: One of the important factors of success for MIS is quality of software. Software must fulfill the following criteria

- Compatibility of hardware
- Capable of taking load of data volume
- Have the support of software for required database
- Capable of supporting the communication network
- Satisfy the design specification of system architecture – Central data processing or distributed

Database design: In database design the important issues involved are sub-systems in the organization and the logic of integration. Technical knowledge of database and knowledge of application systems, their control requirements and designing of reports are essential for efficient designing of database.

Support of top management: To ensure the smooth functioning of MIS top management support is required. Top management will support only when they are convinced about the benefit of MIS of the organization and confident of efficient performance of processing and regular reporting. Thus, for support of top management, efficiency of MIS has to be established.

Manpower: Arrangement of right kind of manpower with proper skill is the most consideration for successful operation of the system. Proper planning for training of manpower involved in transaction processing and report generation under an MIS system is required to take care of future development of the system.

Integration of information: At the time of designing the data bases, provision for integration of information from different sub-systems is essential so that comprehensive information flow can be of great use for strategic planning.

Evaluation, maintenance and Control: The effectiveness of an MIS system is evaluated by the capacity of its fulfillment of requirement of information by the management. Evaluation is done by ascertainment of the views of the users. Maintenance is needed to take care of the gaps, if any, for further growth and for regular smooth functioning of the system. Control means establishment of checks for input data, processing and output to ensure correctness of reports. Proper maintenance and control on effective operation of MIS required to ensure protection from hazards and smooth functioning on a routine basis.

Different Approaches for Developing Management Information System

For developing, three different approaches are generally practiced which are given below:

Top Down Approach: Top Down Approach starts from the identification of information requirements of different activities of the organization by the top management in order to have information support in strategic and tactical decision making and designing the information system accordingly. Top Management provides the guidelines for basic objectives, policies and plan for developing these sub-systems. In other words, this approach designs a model of information flow and same model is used in developing all the sub-systems under the MIS.

Each Sub-systems will have different modules and they are collectively integrated to form a sub-system. The approach of integration is same for all sub-systems. The implementation of different sub-systems is done on the basis of broad guidelines of the top management. Integration of all sub-systems is done at the end to form a comprehensive MIS for the organization. The implementation process is very scientific, systematic and simple.

Bottom Up approach: In the Bottom Up Approach, each sub-systems for different functional areas like Payroll, Sales Management, Production Management, Inventory Control System are developed according to the specifications for each sub-systems on the basis of types of input documents, flow of information and output requirements. There is no common approach for system development. Rather, the sub-systems are developed purely on the basis of control information requirements for each sub-systems and guidelines generated by the manager of the respective functional areas.

The next step in the bottom up approach is to integrate the information of these sub-systems for a comprehensive MIS for the organization. This step is a complicated one in this approach. The data base structure of different systems, flow of information and links among them are to be understood thoroughly to have proper integration. Sometimes intermediate databases are created to collect all relevant information from different sub-systems for integration.

Important Characteristics for a Good Management Information System are Briefly Discussed Below:

(a) **Management Oriented:** A good management information system is not necessarily meant for top management only it may also meet the information requirements of middle level or operating levels of management.

(b) **Management directed:** Management should be responsible for setting system specifications well as management should also involve in directing changes when occur.

(c) **Integrated:** It means that all the functional and operational information sub-systems should be integrated together and there must be a capability of generating more meaningful information.

(d) **Common data flows:** It means that common input, processing and output procedures and media should be used. It eliminates data duplication and produces an efficient information system.

(e) **Heavy planning element:** A management information system usually takes 3 to 5 years and sometimes even longer period to get established firmly within a company. It means that MIS designer should keep in view future objectives and requirements of firm's information in mind.

(f) **Computerized:** The use of computer system increases the effectiveness of MIS. It processes the data fast and accurate.

Misconceptions about MIS: Some of the misconceptions about MIS are as follows:

(i) Some people feel that the study of MIS is about the use of computers. This statement is not true.

(ii) More data in reports means more information for managers. This is a misconception. It is not the quantity of data, but, its relevance, which is important to managers in process of decision-making.

(iii) It is a belief that there must be a high degree of accuracy in reporting but, this is not always true. At higher decision levels, great accuracy may not be required. Higher management is concerned with broad decisions on principles and objectives. A fairly correct presentation of relevant data often is adequate for top management decisions.

Pre-requisites of an MIS -

The following are pre-requisites of an effective MIS:

- **Database -** The data in database is organised in such a way that access to the data is improved and redundancy is reduced. Such a database is capable of meeting information requirements of its executives, which is necessary for planning, organising and controlling the operations of the business.
- **Qualified System and Management Staff -** MIS should be managed by qualified officers. The organizational management base should comprise of two categories of officers (i) System and Computer experts and (ii) Management experts
- **Support of Top Management -** A MIS becomes effective only if it receives the full support of top management. To gain the support of top management, the officer should place before them all the supporting facts and state clearly the benefits which will accrue from it to the organization.
- **Control and Maintenance of MIS-** Sometimes users develop their own procedures or shortcut methods to use the system, which reduces its effectiveness. Maintenance is closely related to control.

Constraints in Operating MIS:

Major constraints which come in the way of operating an information system are:

- Non-availability of experts, who can provide a desired direction for installing and operating the system aligning with the objectives of the organization. This problem may be overcome by grooming internal staff. The grooming of staff should be done by proper selection and training.
- Approach adopted by experts for designing and implementing MIS is a non-standardized one. Standadization may be arrived for the organizations in the same industry.
- Non-availability of cooperation from staff is a critical problem. The problem may be solved by educating the staff about the utility of MIS. The task should be carried out by organizing lectures, and explaining the utility of the system. Some persons from staff should also be involved in the development and implementation of the system.
- There is high turnover of experts in MIS. This problem can be handled by creating the better working conditions and paying at least at par with similar organizations.
- There is a difficulty in quantifying the benefits of MIS, the constraints can be resolved by educating the top managers and telling them about the advantages of MIS.

Effects of Using Computer for MIS:

The effects of applying computer technology to Information System are as discussed below:

(a) Increase in speed of processing and retrieval of data: Computer with its fast computational capability and systematic storage of information with random access facility has emerged as an answer to the problems faced in modern days management.

(b) Expansion in the scope of use of information system: System experts in business organizations developed the areas and functions, where computerized MIS could be used to improve the working of the concern. These types of applications are not feasible under the manual system.

(c) Scope of analysis widened: The use of computer can provide multiple type of information accurately and which makes the decision fast.

(d) Complexity of system design and operation increased: The computer manufacturers have developed some important programs software to help the users, which are self explanatory and require minimum system experts.

(e) Integrates the working of different information subsystem: There are number of subsystems like production, material, marketing ,finance, engineering and personnel which are integrated only due to applying computer technology to MIS.

(f) Increases the effectiveness of information systems: Before the existence of computer technology, it was difficult to provide the relevant information to business executives in time even after incurring huge expenses. The use of computer technology has overcome this problem, by providing timely, accurate and desired information for the purpose of decision-making.

(g) More comprehensive information: The use of computer for MIS enabled system expert to provide more comprehensive information to executives on business matters.

Limitations of the Management Information system:

Limitations of the Management Information System are:

- MIS is not a substitute for effective management.
- MIS may not have requisite flexibility to quickly update itself with changing needs of time.
- MIS cannot provide standard information packages suitable for the purpose of every type of decision made by executives.

- MIS takes into account mainly quantitative factors, thus it ignores the non-quantitative factors like morale and attitude of members of the organization.
- MIS is less useful for making non-programmed decisions.

The effectiveness of MIS decreases due to frequent changes in top managements, organisational structure and operational team.

Information Requirements of Management

Management information system is developed to provide the right kind of information for decision making. Information System, to be truly efficient, has to have interlink with different functional management. In no business, a single function operates in seclusion of other functional areas. Rather, they have close links. Unless different functions are seen in totality, strategic decision making for the organization as a whole can not be efficient.

Information Requirement depends on the following factors:

i) Operational Functions

ii) Type of Decision Making

iii) Level of Management

Operational Functions: The information generated in different functions is different and control requirements vary widely. For example, the requirement of information for decision making in production function will not be same as in case of financial function.

Type of Decision Making: Decision making type may be (i) programmed decisions and (ii) Non-programmed decisions.

Programmed decision making refers to those decision making process which are based on some standard set of procedure established by the management and according to scientific principle of management. In case of programmed decision making, supporting information sets and reports are standard, well defined and well structured. Naturally decision making process is simple and based on some guidelines. For example, stores ledger summary and material consumption reports may help in decision making on Inventory control.

Non-programmed decision making refers to those decision making process which does not go by any pre-determined set of guidelines. Normally this type of decision making takes place to handle special business situations with the help of experience, judgement and vision of the decision maker. In case of non-programmed decision making, information are unstructured and external environmental information is a must along with internal information sets. For example, for decision on business policy many non-standard information like technology change, competitors market share etc is required apart from internal information of sales of different products.

Level of Management

Information requirement varies with the level of management and purpose. The levels of management in the order of hierarchy are Top Management, Middle Management and Operational Management. The activities of different levels of management are given below:

Top Management: Top management is concerned with strategic decisions like diversification, technology acquisition, new market exploration, strategic business alliance, takeover, merger etc.

Middle Level: Middle level management is generally involved tactical decision making with the help of performance analysis, budget variance analysis, devising better productivity mechanism and control etc

Operational Management: Operational Management staff are mainly involved in scheduling the activities, keeping track of progress of day-to-day operations and decisions of well structured problems etc.

The characteristics of information naturally varies depending on the functions of different levels of management. They are as given below:

Contents of Reports based on level of management:

Characteristics Information	**Top Management**	**Middle Management**	**Operational Management**
Focus of Planning & Management	Strategic Planning	Resource Management	Day - to - day activities
Boundary	Internal & External	Internal	Internal
Volume	Summary with analysis	Report of Variances	Reports of detailed activities
Integration among functional areas	Highly integrated	Moderately integrated	Restricted to functional area
Comparison with time frame	1 to 5 years	Previous year or month to month	Day - to - day
Support to decision making	Relatively unstructured problems	Moderately structured problems	Structured problems

Level	**Information type**	**Report contents**
Top	Strategic information which are relatively unstructured and complex. Example: • Strategic decision making on production planning, new product, marketing, sales promotion etc. • Planning and Control of different activities of the organization as a whole • Financial Decision making – fund management or resource mobilization • Business policy decision	• Summary results • Comparative figures • Possible analytical presentation • Guideline for alternative options
Middle	Control information which are moderately structured and less complex . Example: • Tactical Planning • Control information for resource use and results like weekly sales of different products • Reasons of variances, if any	• Actual performance summary and variance analysis • Reports on exceptions

Level	**Information type**	**Report contents**
Opera-ting	Supervisory information which are highly structured and simple. Example: • Control on day to day activities like production, sales, purchases, idle time etc • Scheduling the activities	• Detailed reports • Operational results • Maintenance Report

Information need for Strategic Decision making

The primary objective of MIS to derive comprehensive information for effective decision making. The innovations of Information Technology is to reduce time for acquiring, processing and analyzing data to provide real time information. Today, business intelligence mean accumulation of relevant market related real time information. The success of an MIS depends on the evolving right kind of flow of information for business strategic planning in an organization.

Strategic Information System is to provide best information flow to feed the management in the decision making process to sustain organization's competitive advantage. Information System with the power of information technology which ensures high speed communication can provide the best support to build decision making models. The Information System will help the organization in the following ways:

- Re-engineering the business process with fast review the results
- Building Competitive Intelligence through monitoring competitors' performance
- Capturing Market Information on new technology and products
- Market Trend analysis
- Designing products with the help of CAD tools

Critical Success Factors:

- Cost Structure
- Product quality and innovations
- Customers' profile
- Customers Services
- Customers' satisfaction level
- Management development programmes
- Change management and flexibility etc.

External Information set

- Demographic
- Economic
- Technological
- Market measures
- Profit measures
- Industry benchmarks
- Competitors performance etc.

Different types of Reports

Depending on the level of management, different functional areas will require the following information:

Personnel Management

Top-level (Strategic information)

- Skill information (No of persons in a specialized area with experience)
- Long term human resources requirement
- Policies on human resources development etc.

Middle Level (tactical information)

- Deployment pattern in different departments
- Personnel deployment policy
- Performance appraisal etc.

Operational Level (Operational information)

- Performance
- Leave / absentism
- Punctuality etc.

Production Management

Top-level (Strategic information)

- Policy on production – priority of different products etc.
- Yearly and monthly comparative results on production of different items
- Information on new technology
- Information on capacity utilization

Middle Level (tactical information)

- Actual performance with target
- Variance and their causes
- Breakdown and maintenance information

Operational Level (Operational information)

- Performance details
- Preventive maintenance schedule
- Machine performance etc.

Sales Management

Top-level (Strategic information)

- Information on new product or new market
- Information on market share
- Analysis of competitors strategy
- Sales growth or fall

Middle Level (tactical information)

- Actual sales – product wise with targets
- Sales Variance and their causes
- Performance of different sales offices

Operational Level (operational information)

- Sales details – branch wise product wise
- Individuals sales personnel performance
- Sales expenses details

Management Decision making

Today, the managers need information support for decision making. The business activities have become more complex and competition has become more acute. For survival, the decision making process must be accurate and at right time. For this, information base for decision making plays a great role. Development in Information Technology have created a new era in management decision making process. The decision making has become increasingly difficult due to following change in the business environment:

- Increase in the number of alternatives to be evaluated
- Increase in risk in business
- Complex decision making environment
- Time pressure
- High cost of making wrong decisions

Components of Business Information System

Business Information System comprises of:

(i) Transaction Processing System

(ii) Management Information System

(iii) Expert System

(iv) Decision Support System

(v) Executive Information System

Transaction Processing System

Transaction processing refers to the processing of information relating to monetary transactions in the business activities like purchase, sale, payment, receipts etc. It is a computer based processing for different functional areas to generate all required reports for day-to-day use in the organization. The transaction processing system may be disintegrated or integrated. In case disintegrated transaction processing, data are collected from respective functional areas and processed and reports are generated for their use. In case of integrated transaction processing system, an application system which has capability of integrating all functional areas (say, ERP system), transaction processing are interlinked with all data from different system and the reports reflect the impact of integrated information.

Transaction processing may also be in batch mode or may follow on-line or distributed data processing system. Example of transaction processing in an organization:

- Payroll
- Accounts Receivable
- Bank Reconciliation
- Purchase Order Processing
- Sales Order Processing
- Inventory Control
- Job Costing etc.

On-line Transaction Processing (OLTP)

On-line transaction processing is carried in a client/server system. In todays competitive environment, information at right time plays a great role in controlling costs of various resources and providing best possible services to the customers. In other words, business environment has been characterized by growing competition, shrinking cycle time and accelerating pace of technological innovations and companies have to focus on better information management. Better information means right information at right time. OLTP are being adopted in wider scale to have the following advantages:

- It can serve multiple users at a point of time
- Technology serves the facilities to collect information from multi-locations
- High flexibility in information processing etc.

In case of Sales and Distribution System in an organization where transactions take place at different locations on-line transaction processing is followed to carry out the following basic functions:

- Inquiry handling
- Quotation preparation
- Receiving order from customers
- Checking availability of materials / products
- Scheduling delivery
- Monitoring sales transactions
- Invoicing
- Managing Bills Receivables etc.

On-line Analytical Processing (OLAP)

An OLAP software does the analysis of information from data warehouse. The OLAP applications are widely scattered in divergent application area like Finance Management, Sales Analysis. The real test of an OLAP system is inefficient use of data from databases and computational capability of data to develop model establishing the relationship of various parameters. In fact, it provides the services of 'just-in-time' information.

Though OLAP software are found in widely divergent functional areas, they have three common key features which are:

- Multidimensional views of data
- High analytical ability
- 'Just-in-time' information delivery

Rarely a business model limited a fewer than three dimensions. The common dimensions in business environment are organization, line item, time, product, channel, place etc. OLAP system should have the ability to respond the queries from a manager within a specified time. The OLAP software must provide a rich tool kit of powerful capability of analytical ability.

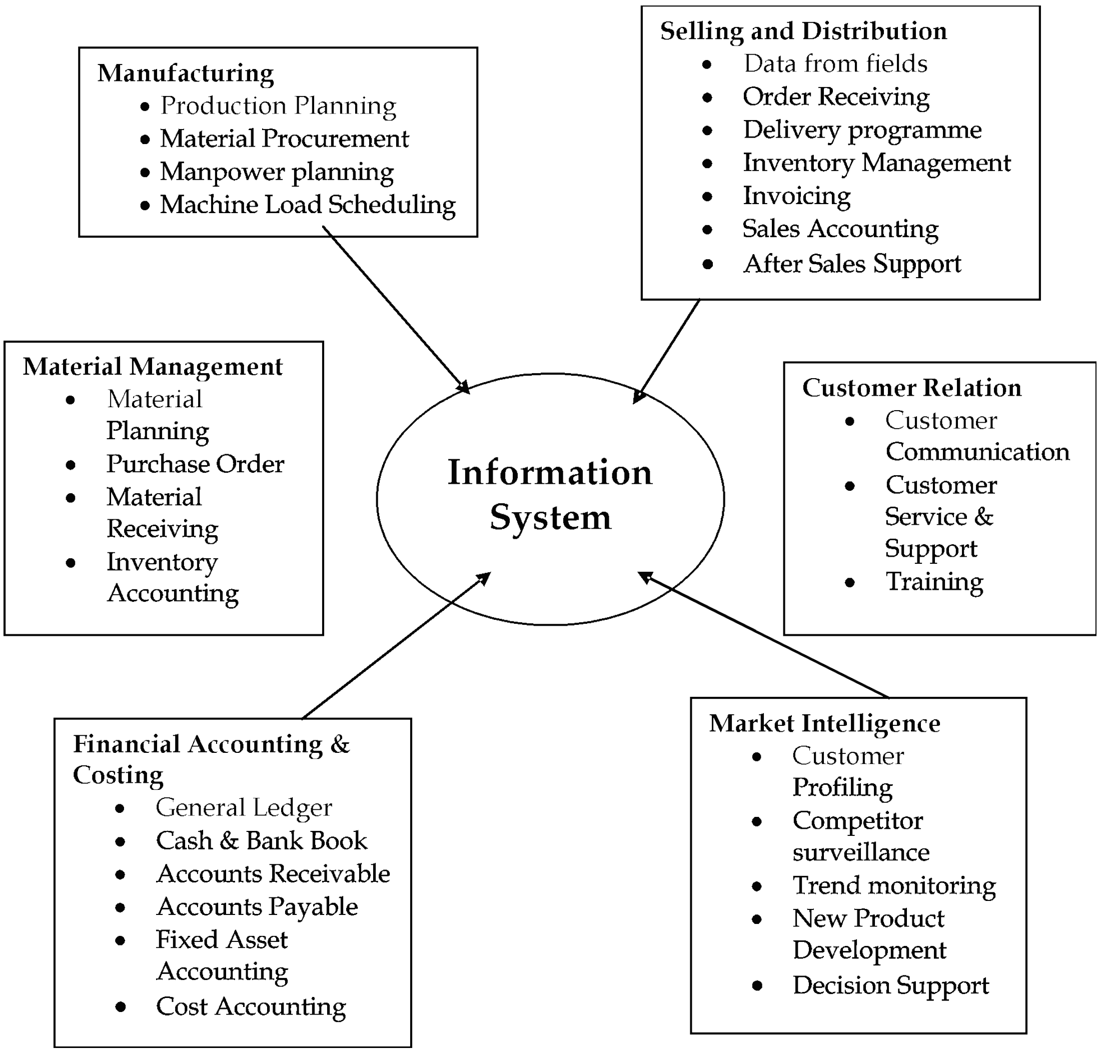
Need for Integration of Information Enterprise-wide

The conventional information systems aim at providing information related to different business functional areas to the respective managers for decision making. The evolution in information system suggest for integration of information of various functional areas enterprise wide for a comprehensive information set for more effective decision making. This is possible only by way of taking care of all transactions related data from different functional areas on-line and integrating them. Today an Enterprise Resource Planning (ERP) system in an organization grasps all business details in real time and integrate them to see activities of various functional areas together so that resources relocation is possible more meaningfully, rationally and cost-effectively.

Today, many organizations world-wide have clearly perceived the advantages of information integration. A good number of large and medium size organizations have implemented ERP system to derive the greater benefits of linking all the functional systems for effective use of information.

The following are the needs of integration of information:

- Information for various inter-related parameters provides clear picture
- Comprehensive review of business situation is possible
- Disjoint information may have serious gaps
- Redundancy of information is avoided by scientific linking
- Cross functional impacts in the business is assessed



Models used for representing the Information

Iconic scale model: It is physical replica of the system based on different scale from original. Iconic models may appear to scale in three dimensions - such as model of a production process, building, car or an aircraft.

Analytical model: It may be a model for a physical system but the model differs from actual system. Example – Map showing water, mountain etc. by different colours.

Mathematical Model: It represents a data set in the form of graph, picture or frictional diagram. It uses highly mathematical or statistical algorithm to interpret data of huge volume with ease. The algorithm varies depending on the complexity of analysis of data sets and the type of analysis.

Analysis of Information

1. Environment Analysis
   - Customers – need, choice, disposable income level
   - Suppliers – Range of product, pricing, after-sales service
   - Competition – pricing policy, quality etc.
   - Trade association – industry trend, technology
   - Government – control, taxes & duties
   - Market – population, demographics etc.
2. Product position analysis
   - Market share and growth
   - Product performance
   - Range of products and level of competition
   - Market trend
   - Technology and possibility of change
3. Cost Benefit Analysis
   - Payback period
   - Net Present Value
   - Internal rate of return
4. Business Planning
   - Operating performance analysis
   - Profitability analysis
   - Market research
   - Product mix selection
   - Budgeting

Information requirement for Product Pricing Strategy

- History of change in price
- Demand for the product
- Graph showing demand and price & quality purchased
- Profitability of products
- Price of substitute products
- Price of similar products etc.

Sources of information

- In-house market database

- Industry statistics
- Market research information
- Feedback from customers
- Trade journals

Executive Information System

An Executive Information System (EIS) is special type MIS meant for top management of an organization. In other words, it is a Decision Support System (DSS) for Executives. Executive decisions are of three types – strategic planning, tactical planning and 'fire-fighting'.

According to CIMA

An Executive Information System (EIS) is a set of procedure designed to allow senior managers to gather and evaluate information relating to the organization and its environment.

Naturally, the EIS takes care the requirement of information depending upon the type of decisions taken at different levels of managers in an organization. In fact, EIS acts as a tool specially designed for different executives to feed their information need in useful formats. A manager can navigate a particular format with some amount of computer skill. The EIS is not only limited to internal data source rather facilities to easy access to common sources of external data is also arranged.

Following are the special features of an EIS:

- It a specially designed tool to feed executives information need.
- It is an easy - to - use and screen based software.
- It provides the executives the facilities of on-line analysis tools like time series analysis, regression analysis etc.
- It is not limited to internal data only. Access to external sources of data is also provided.
- It provides the facilities to connect to internet.
- Information is presented in summary format.
- It is a comprehensive Information System and work in conjunction with DSS.

For an Executive Information System, information requirement varies widely according to the requirement to understand the impact of different variables on the issue. For example, for decision of pricing of a product, information requirement may be summed up as follows:

- Recent history of price changes
- Demand for the product
- Graph showing the relationship between demand and price exhibited by recent results
- Effect of demand of changing price over time
- Prices of substitute products
- Price of similar products
- Cost of sales etc

1. Planned or structure decisions

Decisions made by reference to a pre-determined set of precedents. Based on rutine procedures, techniques and rules. Well structured, time-tested for validity. Judgement & discretion not crucial. Manager arrives at the decision by applying pre-defined rule. Characteristics consistent over time. Need not be simple, may need complex equations.

Non-planned or non-structure decisions:

Made on problem situations which are non-repetitive, unique. Not much information available. Decisions made by reference intuition and experience. No single best way of making decisions. Solution tend to be unique and unusal. Judgement & discretion is crutial.

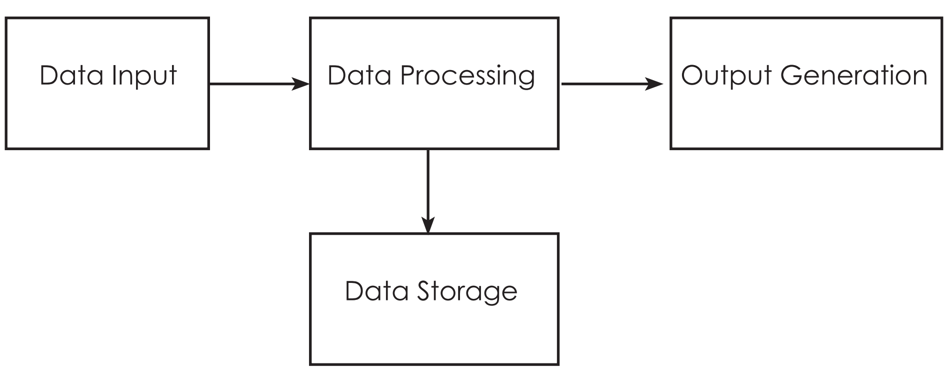
2. Transaction Processing Systems

- an information system designed to process routine business transactions
- seeks time- and cost-efficiency by automating repetitive operations in large volumes
- interfaces with an organization's other information systems, such as IRS, DSS, EIS
- centers around accounting and finance transactions
- e.g, airline reservation systems, order entry/processing systems, bank's account processing systems

The Major Characteristics of TPS

- Large amounts of data are processed.
- The sources of data are mostly internal, and the output is intended mainly for an internal audience.
- The TPS processes information on a regular basis: daily, weekly, monthly, etc.
- Large storage (database) capacity is required.
- High processing speed is needed due to the high volume.
- TPS basically monitors and collects past data.
- Input and output data are structured (i.e., standardized).
- Low computation complexity is usually evident in TPS.
- A high level of accuracy, data integrity, and security is needed.
- High reliability is required.
- Inquiry processing is a must

A Transaction Processing Model

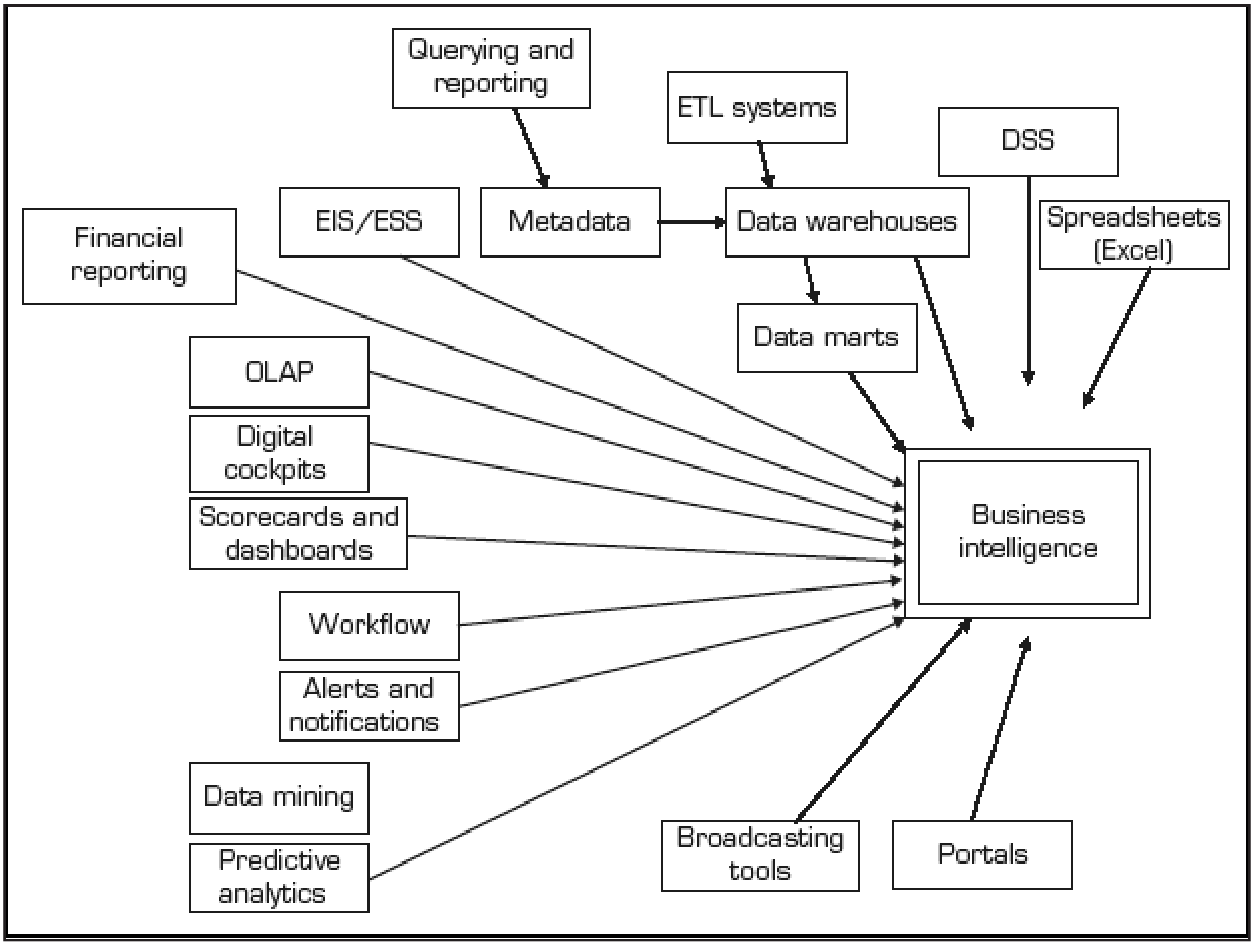


Business Intelligence (BI) – Framework

Business intelligence (BI)

A conceptual framework for decision support. It combines architecture, databases (or data warehouse), analytical tools and applications

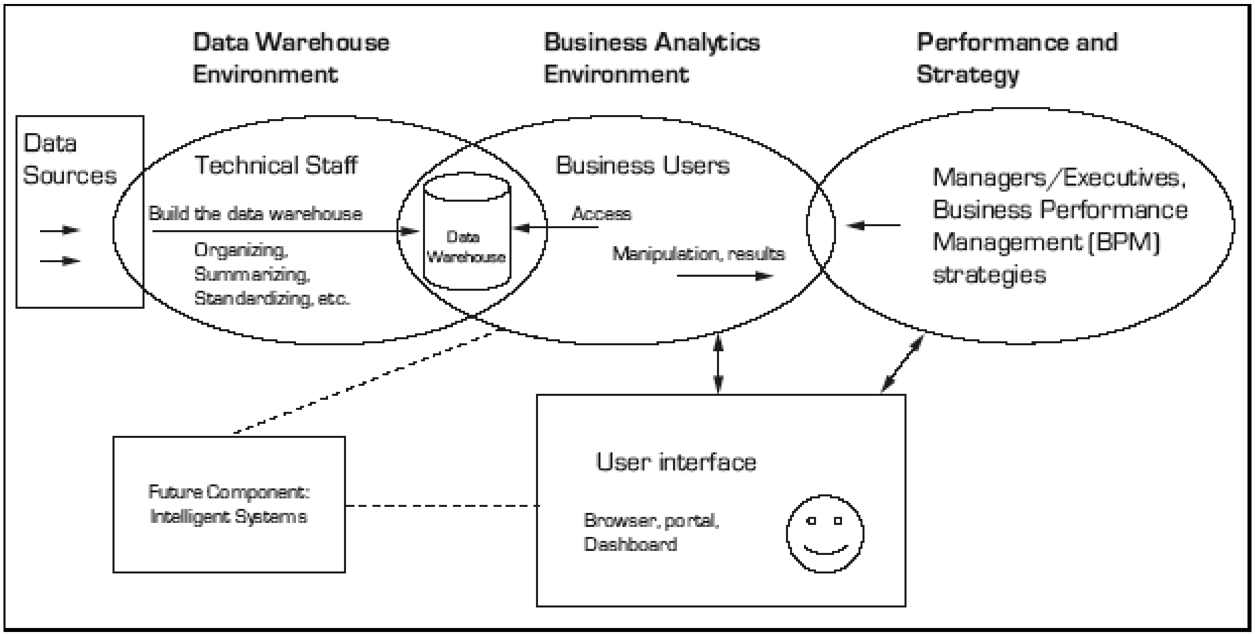
- Remember that we defined *business analytics (BA)* to include the access, reporting, and analysis of data supported by software to drive business performance and decision making
- From our perspective, BA and BI are the essentially the same thing



Evolution of BI

- **The Origins and Drivers of Business Intelligence**
  - Organizations are being compelled to capture, understand, and harness their data to support decision making in order to improve business operations
  - Managers need the *right information* at the *right time* and in the *right place*
- **BI's Architecture and Components**
  - Data Warehouse
  - Business Analytics

* Performance and Strategy
* User Interface



A High Level Architecture for BI

* **BI's Architecture and Components**
  * **Data Warehouse**
    * Data obtained from operational systems needed to support decision making
* **BI's Architecture and Components**
  * **Business Analytics**
    * Create on-demand reports and queries and analyze data (originally called online analytical processing – OLAP)
    * **Automated decision systems**: rule – based
      * App. Case 1.1 – price setting example
    * **Data Mining:** a class of information analysis based on databases that looks for hidden patterns in a collection of data which can be used to predict future behavior
* **BI's Architecture and Components**
  * **business (or corporate) performance management (BPM)**

A component of BI based on the *balanced scorecard* methodology, which is a framework for defining, implementing, and managing an enterprise's business strategy by linking objectives with factual measures

* **BI's Architecture and Components**
* **User Interface: Dashboards and Other Information Broadcasting Tools**
  * **Dashboards**

A visual presentation of critical data for executives to view. It allows executives to see hot spots in seconds and explore the situation

- Examples of dashboards and scorecards:

http://www.idashboards.com/?gclid=CIDDrpLR05QCFQNaFQodSWDQkQ

Benefits of BI

- Time savings
- Single version of truth
- Improved strategies and plans
- Improved tactical decisions
- More efficient processes
- Cost savings
- Faster, more accurate reporting
- Improved decision making
- Improved customer service
- Increased revenue

Many benefits are intangible

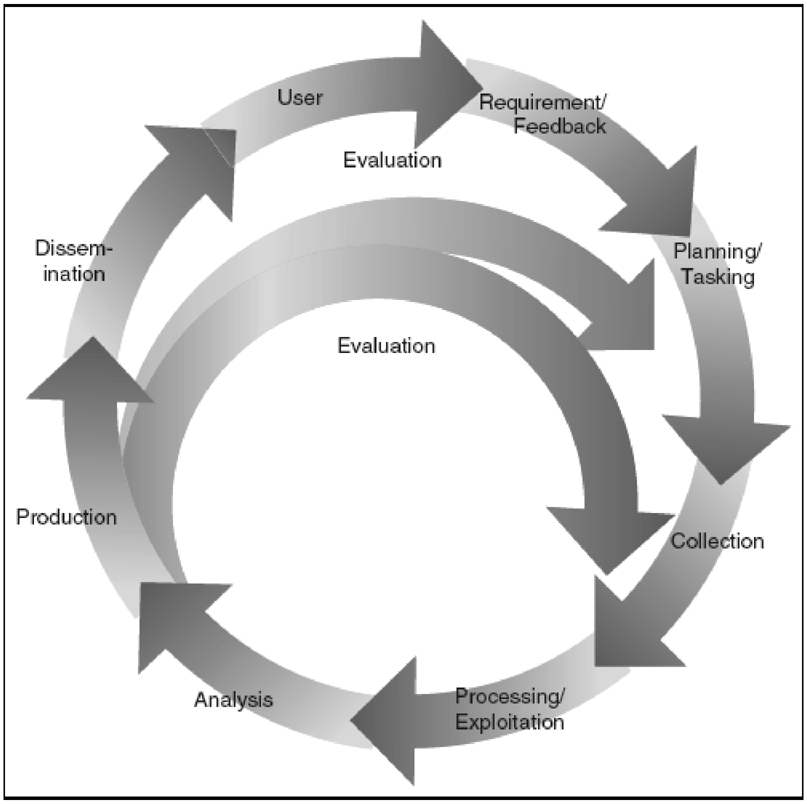
The Business Value of BI

How BI Can Help

- Assess the readiness for meeting the challenges posed by these new business realities
- Take a holistic approach to BI functionality
- Leverage best practices and anticipate hidden costs

- **Key Issues and Framework for BI Analysis**
- **How can enterprises maximize their BI investments?**
- **What BI functionality do enterprises need, and what are they using today?**
- **What are some of the hidden costs associated with BI initiatives?**

Intelligence Creation and Use and BI Governance



Process of Intelligence Creation and Use

The general process of intelligence creation starts by identifying and prioritizing specific projects

The project prioritization process within organizations is sometimes called BI Governance

Intelligence Creation and Use and BI Governance

A typical set of issues for the BI governance team is to address

- Creating categories of projects (investment, business opportunity, strategic, mandatory, etc.)
- Defining criteria for project selection
- Determining and setting a framework for managing project risk
- Managing and leveraging project interdependencies
- Continually monitoring and adjusting the composition of the portfolio

Intelligence Gathering

How modern companies ethically and legally organize themselves to glean as much information as they can from their:

- Customers
- Business environment
- Stakeholders
- Business processes
- Competitors

- Other sources of potentially valuable information

In order to be useful in decision making and improving the bottom line, the data must be:

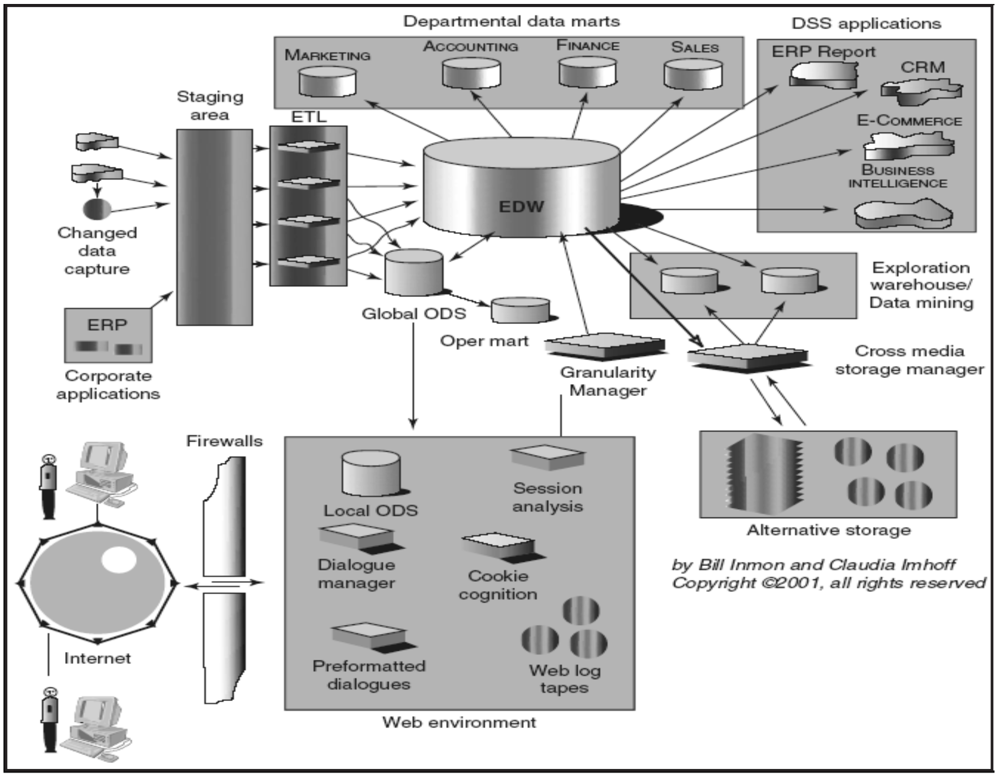
- Cataloged
- Tagged
- Analyzed
- Sorted
- Filtered

These activities are part of the BI creation cycle

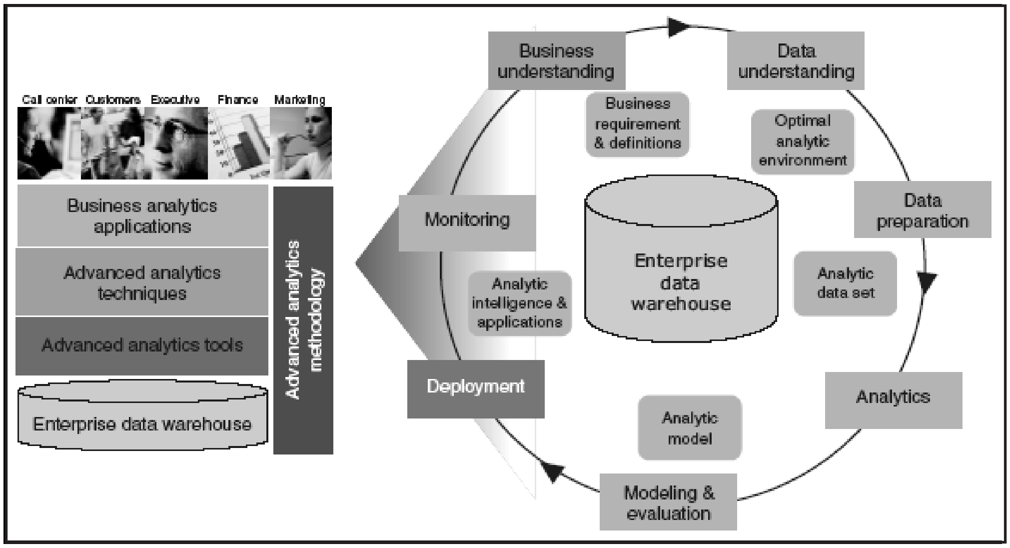
The Major Theories and Characteristics of Business Intelligence

- online transaction processing systems (OLTP)
- Systems that handle a company's routine ongoing business
- online analytic processing (OLAP)

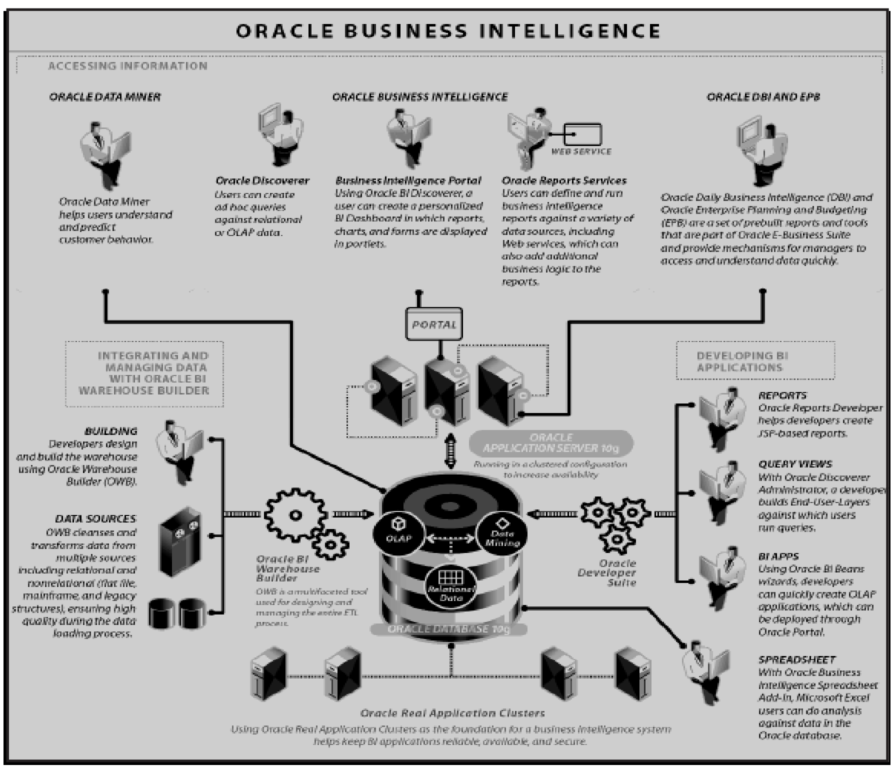
An information system that enables the user, while at a PC, to query the system, conduct an analysis, and so on. The result is generated in seconds



The Corporate Information Factory



Teradate Advanced Analytics Methodology



The Oracle BI System

Toward Competitive Intelligence and Advantage

The Strategic Imperative of BI

- Barriers to entry of a new competitor are being significantly diminished

- Because of the Web revolution and increasing globalization, companies throughout the world are challenging major players in industries
- The ability to deliver goods worldwide is making it easier for potential competitors to get products and services to more customers almost anywhere
- Companies are finding better or less expensive suppliers all over the globe

Competitive Intelligence (CI)

- CI implies tracking what competitors are doing by gathering material on their recent and in-process activities
- BI can obtain data from third-party vendors such as demographic data

BI can support a competitive strategy in an industry

- low-cost leader
- market niche

Sustaining competitive advantage through building brand and customer loyalty using BI applications

Successful Business Intelligence Implementation

- The Typical BI User Community
- IT staff
- Power users
- Executives
- Functional managers
- Occasional information customers
- Partners
- Consumers

Each group uses different BI tools and functions at varying levels of strategic importance

Appropriate Planning and Alignment with the Business Strategy

Planning and execution components

- Business
- Organization
- Functionality
- Infrastructure
- Define objectives while considering organization's skills, plan for change, prepare action plan

Establish a BI Competency Center (BICC) within the Company

- Support dissemination, training, and best practices

Successful Business Intelligence Implementation: Other Issues

- Real-time, On-Demand BI Is Attainable
- Developing or Acquiring BI Systems
- Justification and Cost/Benefit Analysis

- Security and Protection of Privacy
- Integration of Systems and Applications

Today's organizations are deriving more value from BI by extending actionable information to many types of employees, maximizing the use of existing data assets. Visualization tools including dashboards are used by producers, retailers, governments, and special agencies. More and more industry-specific analytical tools will flood the market to perform almost any kind of analysis and to facilitate informed decision making from the top level to the user level. A potential trend involving BI is its possible *merger with artificial intelligence* (AI)

Processing Management Account Information

1. Explain why sunk costs are not relevant costs.

- What are sunk costs?
- Sunk costs consist of those costs incurred in the past.
- They are the costs of resources already committed and cannot be changed by any current action.
- These costs are irrelevant in decision making.
- What are relevant revenues and costs?
- They are the revenues and costs that differ across the decision alternatives.
- Costs that remain the same regardless of the alternative chosen are not considered relevant for the decision.

2. Analyze make-or-buy decisions.

- What is a make-or-buy decision?
- It is to either make some parts and components in-house or subcontract with another company to supply them.
- What is outsourcing?
- It is purchasing a product, part, or component from an outside supplier instead of manufacturing it in-house.

3. Explain the influence of qualitative factors in making decisions.

- Are the quantitative estimates of revenues and costs the only relevant considerations for decision makers?
- No, because qualitative factors also need to be considered.
- What are examples of qualitative factors?
  — Reputation of supplier
  — Suppliers' ability to meet performance standards
  — Suppliers' ability to meet time commitments

4. Describe the different types of facilities layouts.

5. Discuss the theory of constraints.

- A central goal of the design process is to streamline operations and thus increase the operating income of the system.
- The *theory of constraints* (TOC) maintains that operating income can be increased by carefully managing the bottlenecks in a process.

- What is a bottleneck?
- It is any condition that impedes or constrains the efficient flow of a process.
- A bottleneck can be identified by determining points at which excessive amounts of work-in-process inventories are accumulated.
- The building of inventories also slows the cycle-time production.
- The theory of constraints relies on the use of three measures.
- The throughput contribution
- Investments
- Operating costs

(a) The throughput contribution is the difference between revenues and direct materials for the quantity of product sold.

(b) Investments equal the materials costs contained in raw materials, work in process, and finished goods inventories.

(c) Operating costs are all other costs, except for direct materials costs, that are needed to obtain throughput contribution.

(d) The TOC emphasizes the short-run optimization of throughput contribution.

6. Explain the purpose of just-in-time manufacturing systems.

- Just-in-time production requires making a good or service only when the customer, internal or external, requires it.
- It uses a product layout with a continuous flow.
- At the core of the JIT process is a highly trained work force.
- Just-in-time manufacturing has two major implications for management accounting.
- *First*, management accounting must support the move to just-in-time manufacturing by monitoring, identifying, and communicating to decision makers the sources of delay, error, and waste in the system.
- *Second*, the clerical process of management accounting is simplified by JIT because there are fewer inventories to monitor and report.
- What are some measures of a JIT system's reliability?

  (a) Defect rates

  (b) Cycle times

  (c) Percent of time that deliveries are on time

  (d) Order accuracy

  (e) Actual production as a percent of planned production

  (f) Actual machine time available compared to planned machine time available

7. Describe the concept of the cost of quality.

- The premise underlying cost reduction is to decrease costs while maintaining or improving product quality.
- If the quality of products and services does not conform to quality standards, the organization incurs the *cost of nonconformance to quality standards*.

Quality issues

- What is quality?
- Quality can be viewed as hinging on two major factors:
  - (a) Satisfying customer expectations regarding the attributes and performance of the product
  - (b) Ensuring that the technical aspects of the product's design conform to the manufacture's standards

How are quality costs classified?

- Prevention costs
- Appraisal costs
- Internal failure costs
- External failure costs
- *Appraisal costs* relate to inspecting products to make sure they meet both internal and external customers' expectations.
- *Internal failure costs* are incurred when the company detects defective products before they are delivered to customers.
- *External failure costs* occur when customers discover a defect.

Prevention costs are incurred to ensure that companies produce products according to quality standards.

- What is a cost-of-quality report?
- It is a report that details the cost of quality by the categories prevention, appraisal, internal failure, and external failure.

The Value of Information

- It is often said that we are in the information age, and that information is a valuable commodity.
- Why is information valuable? Because:
- It allows us to plan how to run our business more effectively – e.g. shops can stock what customers want, when they want it, and manufacturers can anticipate demand
- Marketing materials can be targeted at people and customers that you know could be interested in your products and services
- This can lead to increased customer satisfaction and therefore profit

Good Quality Information

- The characteristics of good quality information – it should be:
- Accurate
- Up-to-date
- Relevant
- Complete
- On-time
- Appropriately presented
- Intelligible

Collecting Information

How is information about people collected?

1. Obviously you can ask people questions about their spending habits, etc. (but they might not like it!)
2. Or you can use a more indirect approach:
   - Supermarket loyalty cards
     - e.g. easily identify wine-drinking vegetarians!
   - Credit card transactions
     - amounts and locations
     - can help prevent fraud, too!

ATMs, CCTV, till transactions, etc.

Coding Information

- Information stored in a computer is often coded
- Coding categorises information and can replace long, description strings with a few letters or numbers (or both!)
- You are probably familiar with examples such as F for female and M for male

Coding – Advantages

Information is often coded because:

- It is quicker to enter into the computer
- It require less disc space to store, and less memory to process
- It can make processing easier – or possible – as there will be fewer responses
- It improves the consistency of the data as spelling mistakes are less likely
- Validation is easier to apply

Coding – Disadvantages

Coding also has some negative effects:

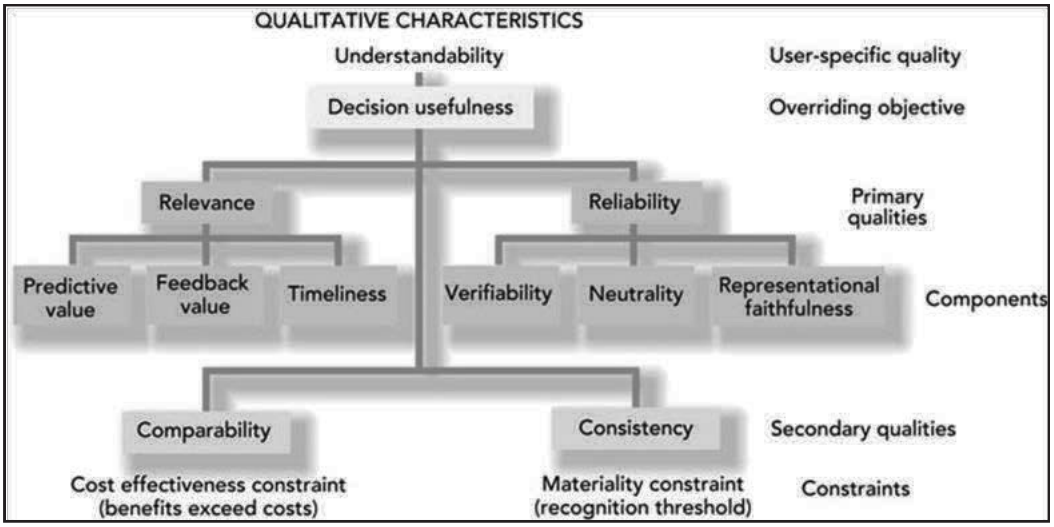
- Information is coarsened by forcing it all into categories – there might not be a category that matches what you want to record – e.g. hair colour
- The same can be true of rounding numbers – the intervals or numbers of categories is called the granularity – this needs to be chosen carefully to maintain the quality of the information

Knowledge

- Data and information deal with facts and figures
- Knowing what to do with them requires knowledge
- Knowledge = information + rules
- Rules tell us the likely effect of something
- For example: you are more likely to pass your A level IF you do your coursework and revise for your exam.

Desired Qualitative characteristics of Accounting Information

Graphic indicates these qualitative characteristics, presented in the form of a hierarchy of their perceived importance. Notice that the main focus, as stated in the first concept statement is on decision usefulness—the ability to be useful in decision making. Understandability means that users must understand the information within the context of the decision being made. This is a user-specific quality because users will differ in their ability to comprehend any set of information.



The primary decision-specific qualities that make accounting information useful are relevance and reliability. Both are critical. No matter how reliable, if information is not relevant to the decision at hand, it is useless. Conversely, relevant information is of little value if it cannot be relied on. Let's look closer at each of these two characteristics, including the components that make those qualities desirable. We also consider two secondary qualities—comparability and consistency.

Relevance. To make a difference in the decision process, information must possess predictive value and/or feedback value. Generally, useful information will possess both qualities. For example, if net income and its components confirm investor expectations about future cash-generating ability, then net income has feedback value for investors. This confirmation can also be useful in predicting future cash-generating ability as expectations are revised.

This predictive ability is central to the concept of "earnings quality," the ability of reported earnings (income) to predict a company's future earnings. This is a concept we revisit frequently throughout this textbook in order to explore the impact on earnings quality of various topics under discussion.

Timeliness also is an important component of relevance. Information is timely when it is available to users early enough to allow its use in the decision process. The need for timely information requires that companies provide information to external users on a periodic basis. The SEC requires its registrants to submit financial statement information not only on an annual basis, but also quarterly for the first three quarters of each fiscal year.

Reliability. Reliability is the extent to which information is *verifiable, representationally faithful,* and *neutral.*

Verifiability implies a consensus among different measurers. For example, the historical cost of a piece of land to be reported in the balance sheet of a company is usually highly verifiable. The cost can be traced to an exchange transaction, the purchase of the land. However, the market value o f that land is much more difficult to verify. Appraisers could differ in their assessment of market value. The term *objectivity* often is linked to verifiability. The historical cost of the land is objective but the land's market value is subjective, influenced by the measurer's past experience and prejudices. A measurement that is subjective is difficult to verify, which makes it more difficult for users to rely on.

Representational faithfulness exists when there is agreement between a measure or description and the phenomenon it purports to represent. For example, assume that the term *inventory* in a balance sheet of a retail company is understood by external users to represent items that are intended for sale in the ordinary course of business. If inventory includes, say, machines used to produce inventory, then it lacks representational faithfulness.

Reliability assumes the information being relied on is neutral with respect to parties potentially affected. In that regard, neutrality is highly related to the establishment of accounting standards. You learned earlier that changes in accounting standards can lead to adverse economic consequences to certain companies, their investors and creditors, and other interest groups. Accounting standards should be established with overall societal goals and specific objectives in mind and should try not to favor particular groups or companies.

The qualities of relevance and reliability often clash. For example, a net income forecast provided by the management of a company may possess a high degree of relevance to investors and creditors trying to predict future cash flows. However, a forecast necessarily contains subjectivity in the estimation of future events.

Secondary Qualitative Characteristics

Graphic identifies two secondary qualitative characteristics important to decision usefulness—comparability and consistency.

Comparability is the ability to help users see similarities and differences between events and conditions. We already have discussed the importance of the ability of investors and creditors to compare information across companies to make their resource allocation decisions. Closely related to comparability is the notion that consistency of accounting practices over time permits valid comparisons between different periods. The predictive and feedback value of information is enhanced if users can compare the performance of a company over time.

7.2 MIS IN FUNCTIONAL AREAS

INTRODUCTION

The purpose of this chapter is to introduce the students to accounting information systems applications. These applications are discussed in this chapter by means of flowcharts. These, however, cannot be grafted on a given organization i.e., they are just hypothetical in nature and are given here to explain the basic concepts involved in designing computerized applications.

We have chosen batch processing system to explain these applications, though on-line systems are more common. The transactions in these applications are entered on floppy diskettes, processed periodically against the master files to produce the desired reports, summaries, projections etc., in a computer step (also known as the computer run). These transactions may have to be sorted before the file updating run, by the key in which the master file has been arranged during sort utilities. The floppy diskette has been used for the transactions files and magnetic disk/tape has been used for the master files throughout this chapter merely for illustration.

Alternative media, however, can be employed. Which media actually to employ in a given situation is again a matter of systems analysis and design.

It is to be carefully noted that all the data fields appearing on various sample output reports, summaries, projections etc., are either directly picked up from the transactions/ master files or derived, after some arithmetic operations, from these. If, therefore the layouts of the outputs are well-defined during systems design stage and input layouts designed to suit the former, writing of the programs for a particular updating run becomes simple and can be entrusted to the programmer. Incidentally, we can also assert if the student is clear about a particular business application under manual system, he/ she can easily design the layouts of outputs and of transactions/master files for an application and the flowchart should flow out of his/her hands naturally. Besides, various checks and controls should be embedded in each program to serve as a check against accidental erasure or fraudulent processing of wrong transactions. Invariably, in an updating run, one of the outputs is an error list and summary information which contains such errors and also the batch totals computed by the computer. These totals are then compared with the ones derived manually prior to processing. If there is a mismatch between the two, error detected via the checks and controls are scrutinised by the user department and ultimately rectified and re-submitted for computer processing.

General form of Business Applications

The chart of fig. 1 shows the general form of business applications. It emphasises that all the outputs are prepared from the inputs (transaction and master files).

Accounting Information System Overview

Figure 2 provides an overview of the components of a typical accounting information system. The system can be divided into four separate areas:

1. The general ledger systems, which include the general ledger, budgeting, and responsibility/ profitability reporting.
2. The cash receipts/disbursements systems, which include the accounts payable, payroll and accounts receivable systems.
3. The production management systems, which include the materials inventory control, work-in-process control, cost estimation, and production scheduling systems.
4. The marketing systems, which include finished goods inventory control, order processing, and marketing analysis systems.

The flow lines between the various systems in the figure illustrate interfaces between these systems. The arrows on the flow lines indicate the direction of the information flow from one system to another.

We will now briefly discuss some of these subsystems.

ACCOUNTS PAYABLE

The purpose of an accounts payable computer system is to pay for merchandise or services received from vendors. Most services and supplies are purchased "on account", rather than by cash payment at the time of purchase. Therefore, a number of unpaid invoices accrue to a vendor. Prompt payment of outstanding invoices can be very important to the vendor, since money is needed to satisfy the vendor's creditors. To encourage payment, most commercial vendors allow their customers cash discount for paying the bill or invoice within a specified time. A cash discount is usually 2% of the total bill, although it can be more or less. Vendors frequently exclude freight charges from their discounting procedure. Some vendors also attempt to collect interest for late payment as another method of forcing prompt payment. However, this practice is usually not very successful; customers either will not pay the interest charges or will take their business elsewhere.

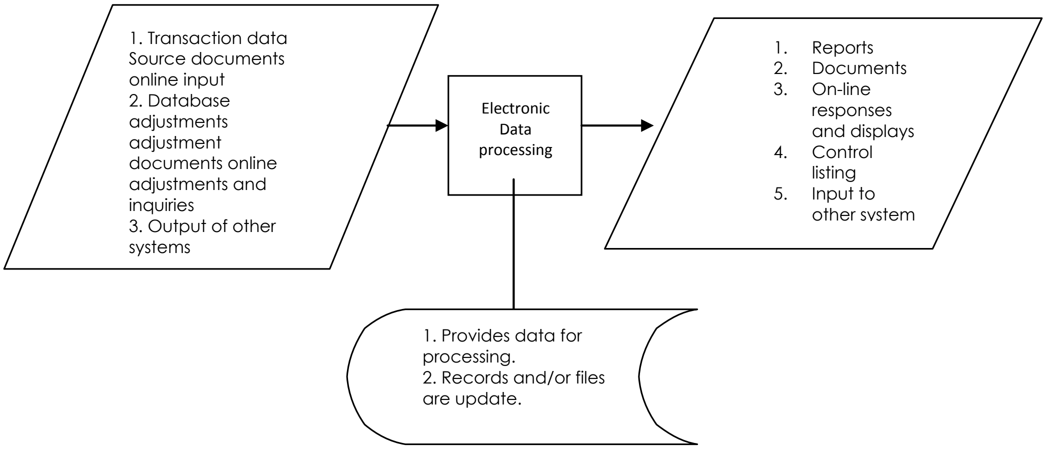


Fig. 1: General form of business computer application

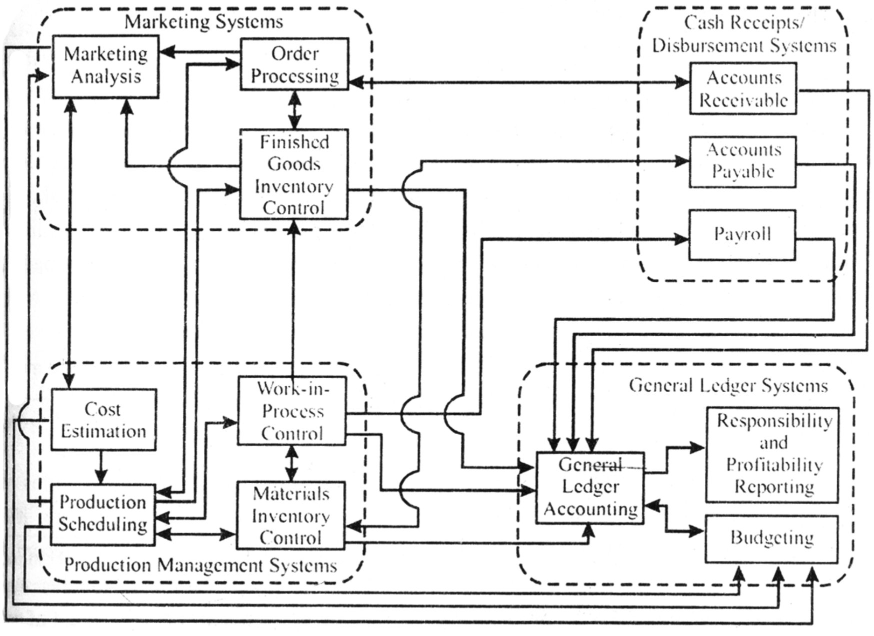


Fig. 2: Overview of the Accounting Information System

At first glance, it might appear wise to pay every invoice promptly in order to obtain vendor discount thereby reducing the cost of purchase.

However, not every bill is normally paid promptly, to avail the discount. Companies profit through full utilisation of capital. Every rupee available for immediate use improves return on investment. The longer a payment is delayed, the longer that amount of money is available for other purposes. Since the unpaid bill does not normally draw interest, the delay in paying a bill can be viewed as an interest free, short-term loan from the vendor.

The main objective in the management of accounts payable is to determine when to pay as well as what amount to pay. When to pay is based partly on the invoice due date, which is determined by the recorded date of the invoice and the stated discount policy. The computed discount is used to determine not only the net amount to be paid put also whether it is worth paying the invoice on time. Another objective is to provide management with the way of allocating available cash. A third objective of the system is to allow evaluation of company vendors, which aids in selecting the best sources for goods and services.

Payable System – Initial Input : The initial input to the accounts payable are batches of invoices supplied by the accounting department. When material is purchased, a number of documents accompany the purchase of material from a vendor. First, a written purchase order is usually sent from the customer to the vendor. When goods are shipped, a packing slip (which shows the quantity shipped) and a bill of lading (which shows the freight charges) are accompanied. The vendor then prepares an invoice giving the total amount due. This invoice is mailed to the customer after the goods are shipped. This document usually has the terms of purchase printed on its face. In some cases, the vendor requests payment on receipt of goods, based on the date printed on the packing slip. In other cases, the vendor asks for the payment on the basis of date recorded on the monthly billing statement which is prepared by the vendor for each customer, showing unpaid invoices at the end of the month.

Since every vendor may submit a different form of invoice, payable forms vary considerably in size, lay out, information contents and readability. Therefore, it is a common practice to extract by hand vital data from each invoice and record this information on a standardised disbursement voucher. This disbursement voucher-stapled along with the invoice it represents, is sent to the data entry department for input of data.

It is desirable to compare charges given on the vendor invoice to those on the company purchase order, on the receiving report, or on a return-for-credit slip. A purchase order shows what goods were ordered from a vendor and the actual or estimated charges for these goods. After the goods are received from the vendor, a receiving report is prepared which shows what goods are received by the firm. Finally, a return for credit slip is prepared which indicates what quantity of goods were sent back to the vendor. This comparison between vendor invoice charges and purchasing and receiving information can be done automatically or charges can be manually verified. Table 1 shows a lay out of an accounts payable disbursement voucher. When the batches of invoices are sent to data entry, the disbursement voucher for each invoice should be completed by the clerk. Also, when invoices are batched, the payable clerk should prepare a batch control slip by adding the net amount due from every invoice. These totals are later used for comparing computer totals with input totals. If there are errors in addition or in the input of payable details, this helps in locating them. The batch control slip is normally processed as a control record. It records the batch no., the branch office that sent the batch to the accounts department, and the batch control slip total. This record is the first in the set prepared for the batch of invoices. It will be followed by input records for each invoice in the batch. In addition special input records may be prepared for changes of vendor's name and address, or to set up records for new vendors. Usually, these are prepared at a different time to avoid confusion.

ACCOUNTS PAYABLE VOUCHER

Vendor Name: Kailash 'Hardware Stores

14, Laxman Road, SURAT

Vendor A/c No.	Invoice Date	Invoice Number
1321	16/07/12	2430
Voucher No.	Due Date	General Account
627	26.7.12	13-47-81
	Invoice Amount	968.38
Approved by		
	Discount	19.36
(Signature)	Net Amount	949.04
Account No.	Sub-code	Amount
326	185	339.84
326	114	101.06
326	227	527.48

Fig. 3

Accounts Payable System

Exhibit 1: illustrates the processing stages of the accounts payable system.

This processing may be carried out weekly or biweekly.

Input to daily processing of vendor invoices consists of accounts payable disbursement vouchers, batch control record and vendor change records. This system uses two input files namely vendor master file and the accumulated accounts payable file produced by the daily processing run. Both of these files are updated during daily processing of invoices.

The contents of the vendor master file and the accumulated accounts payable file are given below:

VENDOR MASTER FILE

Record code

Vendor number

Name and address

Discount percentage and code.

ACCUMULATED ACCOUNTS PAYABLE FILE

Control Input

Record code

Batch number

Branch number

Date

Control total

Keyed Input

Record Code

Batch number

Vendor number

General ledger number

Invoice number

Invoice date

Invoice due date

Invoice amount

Invoice discount

Added from A/c Payable Update run

Vendor number

Name and address

Discount code and amount.

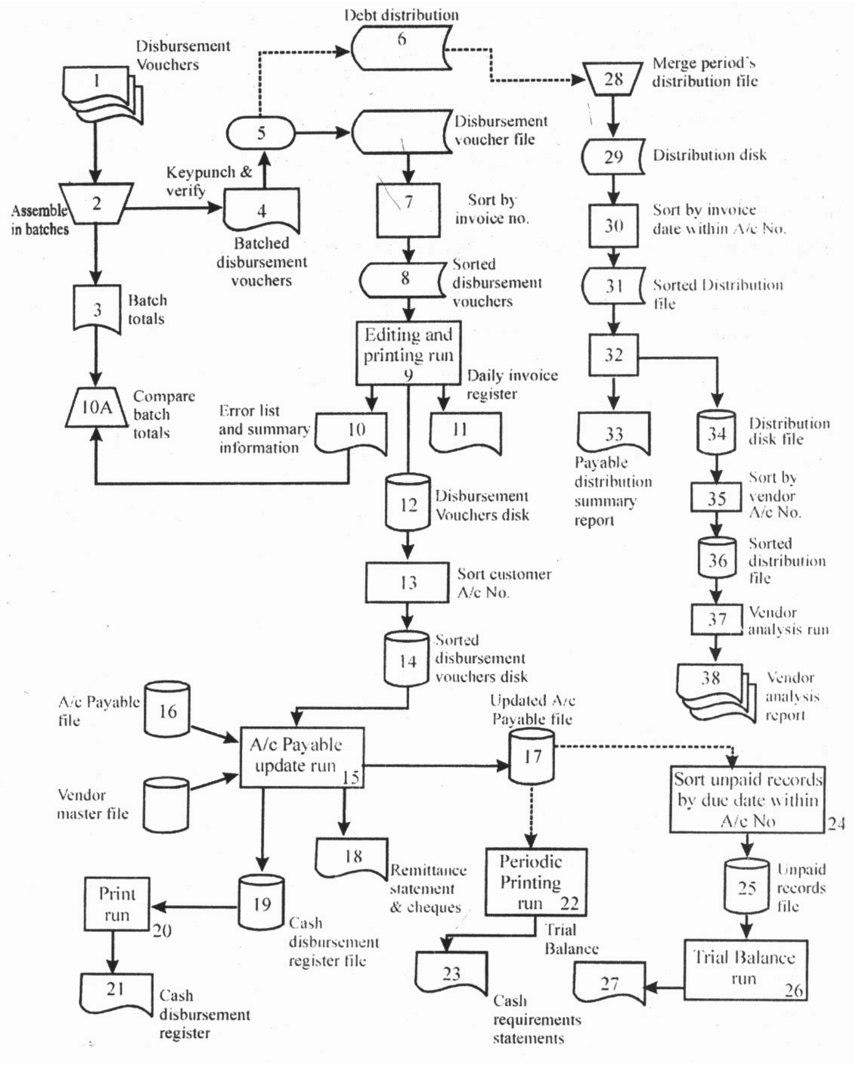


Fig. 4: Accounting payable application

Explanation to various runs shown in Fig. 4

1. The purchasing department receives the invoices from the vendors. After verifying and editing each of these, it prepares a disbursement voucher for it by assigning the voucher number serially and the vendor A/c number. A specimen disbursement voucher is shown in figure 3.
2. The disbursement vouchers for the day are assembled in a batch.
3. The following batch totals are derived on an adding machine.
   (a) Record count i.e. the number of disbursement vouchers in the batch.
   (b) Hash total of the vendor A/c numbers.
   (c) Financial total of the net amount data field.
4. The batch of the disbursement vouchers headed by the control totals slip is forwarded to the computer data processing department.
5. In the data-entry section, for each disbursement voucher, a disbursement voucher record is prepared on the data-entry machine as also as many debit distribution records as the number of items lines are prepared on the data-entry machine. The data fields of the two sets of records are given below:

Disbursement Voucher Record	Debit distribution Record
Record Code	Record Code
Entry data	Entry data
Invoice Number	Invoice Number
Invoice data	Invoice data
Vendor Number	Vendor Number
Gross amount of invoice	Department charged
Discount, if any	Invoice of Item Amount
Net Amount of Invoice	

   The records are verified also. The verified records are stored on a floppy disk.
6. The disbursement voucher records are sorted by the voucher number as the key.
7. It gives the sorted transaction file of disbursement voucher records on a floppy disk.
8. *Editing and Printing Run.* Various checks are applied to the disbursement vouchers transaction file. Those transactions that fail to clear these checks are printed in the error list (10) on which are also printed the batch totals as the summary information as derived by the program in this run. The daily invoice register in the following format is produced as another output. The disbursement voucher data is put into magnetic disk/tape (12) for subsequent speedier processing.

Arti Steel Appliances Company Daily Invoice Register

Entry Date	Invoice Date	Vendor Invoice No.	Vendor No.	Our Voucher	Record Code	A/c no./ Gen. Sub	Deptt. Charged	Item No.	Due Date	Quantity/ Discount	Item Amount/ Invoice Total	Net Pay able

10A. Error List and Summary Information is compared with the batch totals derived on an adding machine prior to computer processing. Also the erroneous transactions are investigated in the purchasing department. These would be resubmitted for processing after rectification.

13. The disbursement voucher disk/tape (12) is sorted by the vendor A/c no. in this run and gives the sorted disbursement voucher disk/tape (14) as its sole output.

15. A/c Payable Update Run. The A/c Payable file (16) along with Vendor master file is updated in this run by the disbursement vouchers disk/tape (15).

The program scans each vendor record for those pending disbursement vouchers for which payment is due today, prints cheques and remittance statements for them, and deletes them from A/c Payable File (16). The new disbursement vouchers are added to their respective vendor records. This run yields the following outputs:

A/c Payable File, OF (17)*

Remittance Statement & Cheques (18)

(Specimen format shown below)

Cash Disbursement register disk/tape file (19).

20. In this computer run, the cash disbursement register (21) is obtained as the output. Its specimen format is also shown below:

(* We have shown a separate disk file for case of understanding. In practice updated file will be created by overwriting the old file.)

Arti Steel Appliances Company

Statement of Remittance

Cheque No.	Invoice Date	Vendor's Invoice No.	Code	Invoice Amount	Discount	Net Amount

Arti Steel Appliances Company

Accounts Payable

Route Cash Disbursement Register Date

Vendor	Cheque No.				A/c Payable	Credit	
	Vendor No.	Day	Month		Date	Discount	Cash

22. In this periodic (weekly, perhaps) run, the A/c payable file is used to produce the Cash Requirements Statement of which the specimen format is shown below:

Arti Steel Appliances Company

Accounts Payable

Cash Requirements Statement*

Route to Mr. Subir Bose, Deprt. 101 Date

Vendor Name	**Vendor No.**	**Due Date**	**Invoice Amount**	**Discount**	**Cheque Amount**
Omega General Suppliers	1421	16/4	773.30	15.47	757.83
Peco Engg. Co	1416	16/4	162p.l8	36.40	1583.78

24. In this run which is carried out at the end of each accounting period, the unpaid records on the A/c Payable file are extracted, sorted and put on disk/tape as the unpaid file (25).

26. From the unpaid records file (25) the trial balance (27) is derived in this run and printed out in the specimen format as shown below:

Arti Steel Appliances Company

Trial Balance

Open Items — Payable

Closing Date

Vendor Name	Vendor A/c No.	Invoice Date	Due Date	A/c Payable	Discounts	Net Payable
				₹	₹	₹

28. At the end of the accounting period all the distribution records are merged in one file (29).

    (* N.B.: These are only sample reports. Data contained in this and all subsequent reports is fictitious and has been used merely for illustration purpose.)

30. The distribution record file is sorted by the invoice date within the A/c number to obtain the sorted file of distribution records (31).

32. In this computer run, the A/c payable Distribution Summary is printed under the following format:

Arti Steel Appliances Company

Accounts Payable Distribution Summary

Date

Record code	Invoice Date	Vendor Name	Vendor A/c No.	Our Voucher No.	A/c No.		Deptt. Charged	Due Date	Qty.	Invoice Amount
					Gen	Sub				

35. In this run, the distribution records (34) for the period are sorted by vendor A/c no.

37. The sorted distribution record disk/tape (36) is used in this run to produce the various vendor analysis reports (38) of which a specimen format is given below:

Arti Steel Appliances Company

Summary of Purchases

Account Name	Account		Sub. Account 1 total	Gen. Account total
	Gen.	Sub.		
Raw Materials Brass Forgings Castings Rolled Stock Baked Parts Lumber Varnishes				

Payroll Accounting

Payroll is one of the oldest and most common business computer applications. A decade or two ago, company payroll were frequently computed using calculators and then printed by tabulating machines. The basic purpose of the payroll system is to produce payslips and pay cheques for the employees every month. In spite of the modern high speed computers, the processing of payroll remains fundamentally the same as in the past. Preparing a payroll requires collecting employee work hours through their attendance cards, converting hours to gross earnings, and computing deductions and net pay. Of course, there are other activities to be performed as by products of payroll operations. These includes accumulating summary data for general ledger reports, printing quarterly and year-end reporting statements, and making labour distribution and job costing or job performance measurements and reporting them. In addition to accounting activities, a payroll system commonly performs activities that might be viewed as personnel operations: sick leave and earned leave accrual and usage, and home address maintenance. While these activities enlarge the size of computer records retained for payroll operation, they do not significantly increase the complexity of managing the overall operation.

Input Files

Master File: The payroll computer application is one of several business systems that can be processed using a combination of current and year-to-date master computer file. This file consists of records for the current reporting period as well as, for yearly reporting. The master file also contains permanent and current data.

The permanent portion of the file must be updated before current transactions are entered into the system, since information such as employee's rate of pay, accumulated earned leave, change in status code etc. are used to transform gross salary into net pay. Therefore, prior to actual processing of a payroll, a preliminary master file update must be completed. The payroll master file may consists of following field:

Payroll Master File

Personnel data

Record code

Employee number

Employee name

Address

Phone No.

Sex

Date of Birth

Date started employment

Payroll computation date

Job number

Department number

Type of cost code

Basic pay

Exempt status (exempt employees do not receive extra pay for overtime)

Overtime rate

Leave data

Earned leave accumulation rate

Sick leave accumulation rate

Accumulated earned leave

Accumulated sick leave

Earned leave used this year

Sick leave used this year

Payment data for this payroll

Current gross pay

Current dearness allowance

Current housing allowance

Special allowance

Current regular hours

Current overtime hours

Current provident fund

Current insurance Premium

Current voluntary deductions (several fields)

Current net pay

YTD gross pay

YTD income-tax

YTD provident fund

YTD insurance premium

YTD voluntary deductions (several fields)

YTD hours (regular and overtime)

Transaction file

Employee number

Regular hour

Overtime hours

Earned leave

Sick leave

Special deductions (several fields)

Payroll master file update

Before time cards are submitted at the end of a pay period, the accounting department obtains data on new employees and on recent changes to existing employees such as correct spelling of name, change in address, marital status, pay scale, overtime rate, rates of sick leave and earned leave, change in department employed by, and an employee number.

New employee information is submitted to the data entry department on a payroll change input form. These forms contain space for all vital data to be entered into the system. Fig. 5 shows the preliminary master files update procedure. Keyed employee additions and changes update the most recent version of the payroll master file. It can be seen in the system flowchart that the master file which is stored on a hard disk is randomly updated with the input change transactions. It may be noted here that copies of master file should be retained before and after updating. Thus, if an error is found, it can be corrected and updating can be repeated. An employee change report is also printed as a result of this update run. It is convenient if the change report is printed in the same sequence as the input documents, since the report can then be edited manually without searching for the corresponding change input form.

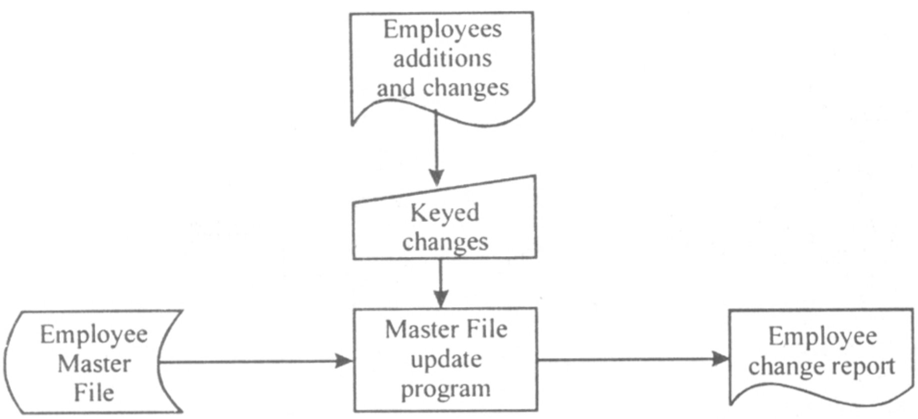


Fig. 5: Preliminary master payroll file update flowchart

Payroll Application – Input

After changes to the payroll master file, the actual payroll run begins. Time records are submitted for data entry. The information contained in these time cards is entered in the form of a transaction file. Batch control totals for various fields are computed. This batch control information is keyed to a lead record (the first record in a batched set of records for payroll input). Lead record information is used by the computer to check the accuracy and completeness of the batch of payroll records.

Payroll System – Processing

Fig. 6 shows the processing of payroll. Inputs to the system consist of keyed data for time cards, batch control information, and the employee master file, updated by the preliminary master payroll file update. Outputs from the system include a completed employee master file, updated by time cards information, and the reports and documents discussed below:

In run # 1, the payroll edit program is executed. The first function of this program is to detect errors in the input data (for example, an invalid employee number, excessive hours worked, or an hourly employee showing no regular hours worked). If an error is detected, it is immediately printed to permit correction. If accumulated totals computed by the computer program from individual records do not balance control totals contained on the lead record, the difference is also printed. Processing is discontinued at this point so that errors can be corrected. Once this is done, the edit program is rerun to produce an error free input file. The input file produced by the payroll edit program is recorded on magnetic disk or tape.

In run # 2, the payroll transaction file is sorted by the employee number within department number.

In run # 3, the sorted transaction file is used to update the master file on magnetic disk. The type of cost code stored in master file indicates the nature of the account to which employees' gross pay is charged such as direct labour, indirect labour etc.

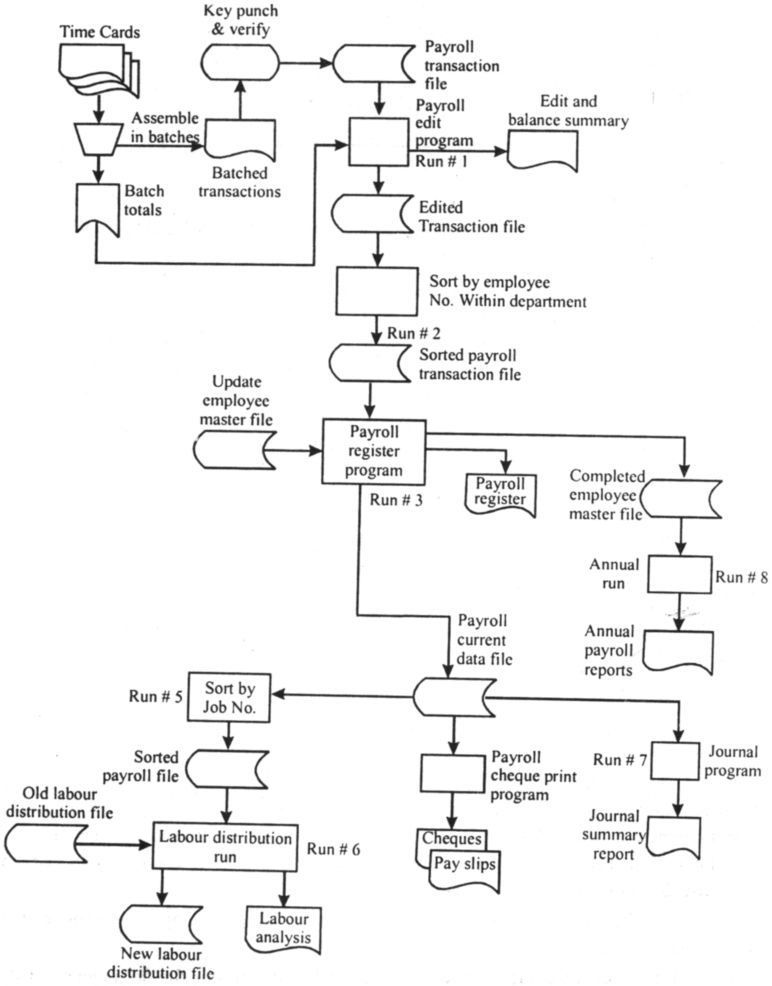


Fig. 6: Payroll Accounting

Gross and net pay are calculated in this run; year-to-date and current period data are accumulated and written on the payroll master file. The data necessary for printing payslips and pay cheques for the current period are put on a magnetic disk constituting another output of this run. Payroll register is also printed during this run. Payroll register is a printed record of details in the completed employee master file.

In run # 4, the current period payroll master disk is used to produce pay cheques and payslips.

In run # 5, the current period payroll disk is sorted by job number.

In run # 6, the output file of run # 5 is used to update the old labour distribution file. The specimen format of this file is given below.

Labour distribution file on magnetic disk

Job No.	Trade 01	Value	Trade 02	Value	Trade 40	Value
6ch.	2ch.	6ch.	2ch.	6ch.	2ch.	6ch.

The cumulative values of various trades as at the end of last month are updated to as at the end of this month by means of the payroll file.

This labour analysis is printed for each job as another output of this run.

In run # 7, a journal report is printed. This report is used to supply current and year-to-date entries to the general ledger, which is the final consolidated accounting document. Journal reports record total funds expended by source and by disposition. For example, total money amount for overtime and total amount for special advances etc., are summarised by separate account on the general ledger. Similarly, total insurance premium deductions, provident fund deductions, staff welfare fund, income tax deduction etc. make up other accounts. Illustrates a format followed in printing the payroll journal report.

Payroll Journal - Budget Report

ABC Co. January 12, 2012

General Ledger Code	Amount ₹	Description
110	1,30,201	Salary
610	45,000	Regular Pay
8511	34,500	Retirement deductions
8514	7,500	Staff Welfare Fund
8516	25,600	Income tax
8520	32,500	Car loan deductions

Fig. 7

In run # 8, the completed master payroll file is used to print quarterly/annual reports. Government regulations require quarterly/annual reports on payroll activities. Such reports include provident fund deduction statement, income-tax deductions, insurance premium deductions etc. Many other reports for internal accounting purposes may also be printed on quarterly/yearly basis.

Inventory Control – Finished Goods

Traditionally, the inventory carried by a firm serves as a buffer for stages of production. Thus, inventory management may seek to retain only enough inventory to meet the demand for stock, to never run out of stock, and to allow economic lots of stock to be purchased as well as carried in inventory. With the advent of the computer, the management of inventory has taken on a new dimension based on viewing inventory as an investment. As it often consumes a high proportion of working capital, it must be controlled in the most effective manner. Hence,; the objectives of the inventory control application are:

(i) To provide high quality service to customers by utilising fast, accurate and efficient method of filling customer orders and avoiding "stock outs",

(ii) To minimise the amount of money invested in inventory and money required to cover inventory "carrying cost",

(iii) To provide management with information needed to help achieve the two preceding objectives.

Inventory System Input Files – General Design

Inventory system generally requires the use of several data files. The basic file of this application consists of an "inventory master file" which keeps track of the quantity of each items available in stock. In addition, it also gives information regarding the location of each item in the warehouse, the cost of the item, the reorder point, the quantity currently on order, name and address of the vendor from whom the item is purchased, and the historical data.

It is advisable to keep track of each individual transaction that occurs within the business. Information on these individual transactions is recorded in a separate file called the transaction file. One transaction file is maintained to keep track of individual sale transactions: to which vendor items were sold, when, for what price, and the invoice or receipt number. A second type of transactions contains data describing stocks received by the receiving department of the business firm. Input may also include "miscellaneous inventory transactions" such as adjustments for lost or damaged stock. Using the transactions files, the master file is continuously updated to reflect changes in the inventory level caused by filling sales orders or receipt of new stocks. A "back order file" is also updated for sales orders that can not be filled because of stock outs. Some customers are willing to wait until new stock is received. The back order file provides data on outstanding back orders that must be filled when stock receipt notices are received for back-ordered items.

The sample file layouts for various files are given below:

Item master file

	Field No.	Width	Contents
1.	Item No.	5	Item number (key field)
2.	Title	20	Item description
3.	Qty.	4	Quantity in stock
4.	Cost	9	Purchase price per unit of the item
5.	UOM	3	Unit of measurement (kg/No.)
6.	Reorder	4	Reorder point
7.	Order Qty.	4	Quantity to be ordered in one lot
8.	Location	5	Location in warehouse
9.	Vendor	25	Vendor's name
10.	Vendor-add	25	Vendor's address
11.	Vendor-CSP	25	Vendor's city, States, pin code
12.	Date	8	Date of last update
13.	Qty. sold	4	Quantity sold since last update
14.	Qty. received	4	Quantity received since last update
15.	Safety	4	Safety stock
16.	Leadtime	3	Lead time
17.	On-order	4	Quantity on order from vendors
18.	Back-order	4	Quantity on back order
19.	YTDI	5	Year-to-date quantity issued
20.	YTDR	5	Year-to-date quantity received
21.	Max-L	5	Maximum-level of inventory
22.	Min-L	5	Minimum-level of inventory

The structure of the sales/issue file:

	Field No.	Width	Contents
1.	Item No.	5	Item number (key field)
2.	Inv- No.	6	Invoice Number
3.	Sales Prs.	12	Salesperson's name (code)
4.	Customer	12	Customer's name
5.	Qty.	4	Quantity sold
6.	Price	9	Selling price
7.	Date	8	Date on which item was sold

Structure for the new stock/Receipts Data file:

	Field No.	Width	Contents
1.	Item No.	5	Item number (key field)
2.	Qty.	4	Quantity received
3.	Cost	9	Purchase price of the item
4.	Date	8	Date on which item received
5.	Vendor	25	Vendor's name

System Outputs

The outputs of the inventory control system includes the following:

1. Inventory transactions listing for control purpose.
2. Inventory ledger
3. Customer's report
4. Back-orders file
5. Excess-stock
6. Under-stock
7. Slow-moving
8. ABC class items
9. Items-to-do ordered file

Exception reports.

Data describing filled orders, back-orders and miscellaneous sales order transactions is a major systems output and becomes the primary input into the billing and sales analysis system. Information concerning back orders, out-of-stock items, reorder points, economic order quantity is sent to the purchasing or production department for entry into their information system. Various exception reports analyse inventory status in order to help management to meet the objectives of inventory control.

Run Flowchart

This application on hand requires 5 runs. Each run has its own program and is performed in a computer set up after loading this program in the computer memory. The run flowchart for the application on hand is shown in fig. 8. The symbols in it are numbered from 1 to 21 to facilitate the following explanation:

1. The receipt and issue notes are prepared in the stores department as and when these transactions arise. It is desirable that the format of such source documents are so designed that they facilitate transcription of data from them into computer media. For example, the maximum length of each data field in them may be emphasised by putting as many boxes for it. If, for example, the quantity

received cannot exceed 4 numerics, 4 boxes could be placed and the actual quantity received may be entered in these right justified. An incorrect 5 digit quantity would then have little chance for entry. Also the receipt and issue notes may have different colours. The notes in a pad should be serially numbered to kee track of each of these.

2. The receipt/issue notes for the day are assembled in batch.
3. The following controls totals for the batch are derived on an adding machine,
   (i) Record count, that is, the number of notes in the batch.
   (ii) Hash totals of the item numbers.
   (iii) Financial total of quantities received and issued.
4. The batch of the receipt/issue notes alongwith the control slip bearing the batch totals is transmitted by the stores department to the data preparation section.
5. A record is prepared for each transaction. The records are also verified on the data entry machine by an operator who is different from the keypunch operation and who uses the same source documents (goods receipt notes and issue notes).
6. This transaction file is used as the input to run # 1.
7. In this run, editing is performed on the transaction records. A couple of the possible checks that can be performed are:
   (i) Check digit on the item code, and
   (ii) Date check.

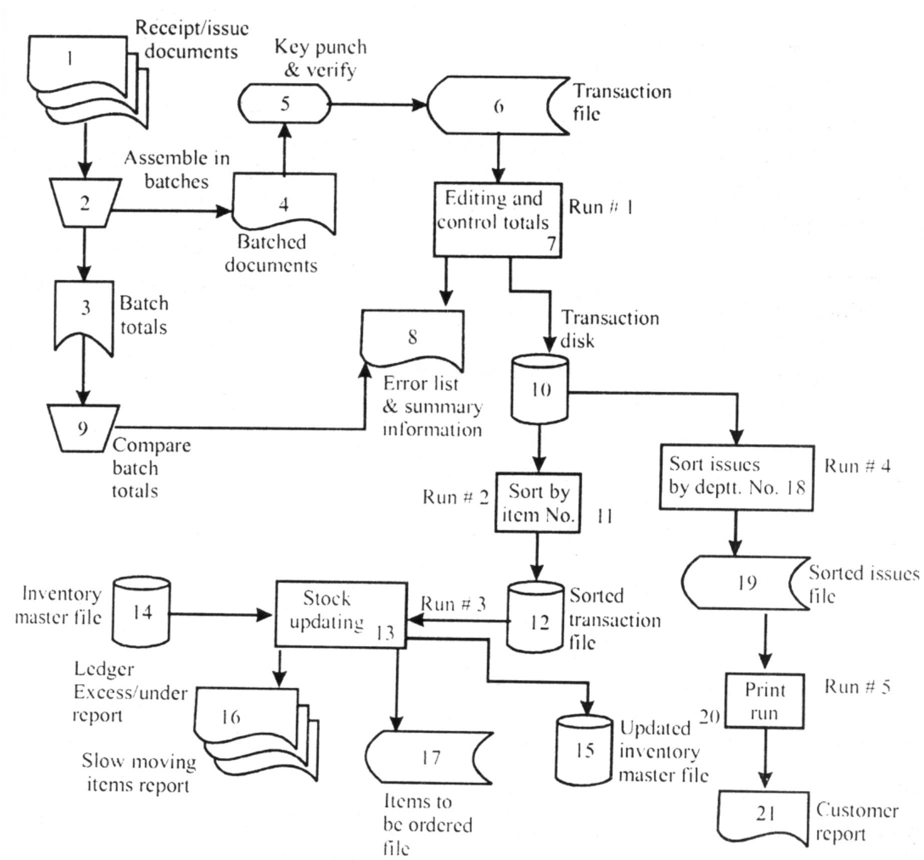


Fig. 8

Those control totals which were derived manually prior to processing are now derived by the program. The Error List and Summary Information (8) lists the erroneous transactions and also the control totals. These totals are then checked (9) with their opposite numbers derived manually (3) prior to processing. If they do not tally, investigations for the accidental/fraudulently motivated reasons would be under taken also. The Error List would be forwarded to the stores department so scrutinise the erroneous transactions, rectify and resubmit them for reprocessing. The corrected transactions file is output on a magnetic disk for subsequent speedier processing.

11. In this run, the transaction disk file (10) is sorted by the item number as the key to give the sorted transaction file (12).

13. In this run, the sorted transaction file is used to update the inventory master file on magnetic disk.

The following are the outputs of this run.

Updated Inventory Master file C/F (15).

Items to be ordered file (17) containing particulars of those items for which the stock level has fallen below the reorder. This file may be used in another routine to produce purchase requisitions or orders; but that we have not included in this application for the time being.

Printouts of the stock ledger, Excess/Under Report and Slow moving items report (16) under the following formats.

STORES LEDGER

Month Year

Description Part No.

Batch Qty. Order Point

Max. Level Min. Level

Date	Voucher No.	In	Out	Balance		Qty.	
				Qty.	Value	Excess	Under

(Excess Qty. is stock above the max. level and under Qty. is the stock below the min. level.)

Report on Slow Moving Items Month……………

Balance Qty ./Value

No Movements Since

1 year Part No.

6 months

Month

The transaction file for the period are merged, receipts ignored and sorted by the department number in run 4 to give the sorted issues file (19).

20 In this run the sorted issue file (19) issued to produce the printout of the customers report (21).

Processing System of Sales Order

The sales department prepares the sales, in duplicate upon receipt of the customer's purchase order or telephonic information from a salesman or the customer after satisfying themselves that the customer's account is not delinquent. One of the outputs of a computer run to be discussed subsequently is the list of delinquent accounts which the sales department consults to establish credit worthiness of the customer. One of the copies of the sales order is sent to the customer as an acknowledgement of the receipt of his purchase order. The other copy is sent to the shipping department as an authorisation to ship the goods to the customer. The format of the sales order should be so designed that it facilitates error-free and quick entry of data from the customer's purchase order as also transcription of data from it on to floppy disk subsequently. The sales department enters the quantity shipped and quantity back ordered against each line on the order, i.e., for each stock item on order, the price having already been entered by the sales department. The shipping department assembles the sales order in daily batches and compiles the following batch totals for it on an adding machine, perhaps: record count, financial total of the values of items shipped and hash totals of quantities shipped. quantities back ordered, customer's account numbers and stock item numbers. The batch of the sales orders together with the control slip bearing these batch totals is then forwarded to the data processing department for transcription on the floppy disk.

Likewise, the mailroom assembles the daily batch of remittance advises received from the customers and compiles the following batch totals for it: record count, financial total of the amounts remitted and the hash total of the customer account numbers. The batch together with the control slip bearing these totals is forwarded to the data preparation section.

We are dealing with only two types of transactions of this application for simplification of illustration though in practice there would also be the following inputs:

(i) Addition of new records to the file

(ii) Credits for sales returns and allowance

(iii) Account right-offs

(iv) Change of addresses and other routine adjustments and corrections.

The data preparation section of the data processing department records data on floppy disc for each item back-ordered, each item shipped and each remittance advice on the computer. This floppy disc is then given to the verifier operator who verifies the records by re-entering the transactions data. For economies in verification time, it may, however, be desired that just the critical data files on the records are verified.

These verified records are then sorted using SORT utility with the customer account number as the key.

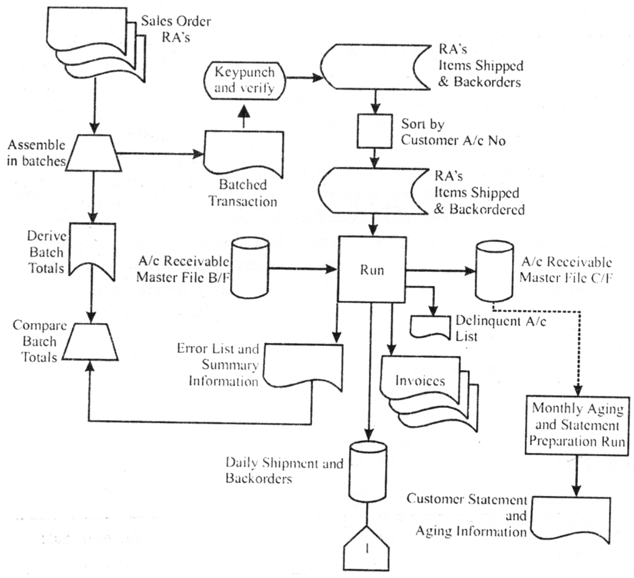


Fig. 9

The sorted file constitutes the transaction file which is used to update the accounts receivable **master file** by the account receivables update program in computer run. In this run, customer accounts are updated for the sales. Typically, the accounts receivable master file contains the following fields:

(i) Customer account number (control field).

(ii) Customer name and address.

(iii) Credit rating.

(iv) Credit limit.

(v) Balance due as of last monthly statement.

The **transaction file** consists of following fields:

(i) Transaction type code.

(ii) Documents number.

(iii) Date.

(iv) Amount.

(v) Current balance.

Incorporated in the program are also the various control checks discussed in detail in

The outputs of this run are as follows:

(i) The updated A/c receivable master file.

(ii) Delinquent accounts list which contains the particulars of those customers who have crossed V either the credit limit or the credit rating assigned to them,

(iii) Invoices in as many copies as desired. It has to be noted that invoice would be prepared for only the items shipped. A specimen of the invoice is given below:

ABC Manufacturing Company

15, High Street, Sometown Tx..........Tel..........Invoice No..........

INVOICE

Customer Order No.	Date	Salesman Code	Cost Acct No.
....	....	....	....
Sold to		Ship to name	
ABC Mfg. Co.		name	
13, Nehru Road			
Allahabad			
Shipper	Date Shipped	Invoice Date	Terms of Sale
....	....	....	....

Item Code	Description	Qty Ordered	Qty Back-Ordered	Qty Shipped	Unit Price	Total Price

(iv) **Daily shipment and back-orders file:** The data stored on floppy disc is put on to magnetic disk for a subsequent speedier resorting by stock item number as well as speedier processing against inventory file the discussion on which would follow.

(v) **Error list and summary information:** This contains the rejects i.e., those transactions which could not pass the control checks. These are ultimately investigated by the user department, rectified and re-submitted to the data processing department for reprocessing. The summary information consists of all the batch totals derived by the computer. These batch totals are compared with the ones derived manually prior to processing and entered into control slips travelling with the batches of the transactions.

The accounts receivable file is also processed every month to produce the customer statements and aging schedules, a specimen of which is shown below:

STATEMENT

ABC Manufacturing Company

15, High Street, Sometown.

To **ABC Limited** **13,Nehru Road** **Allahabad**	**Date**		**Account No.**	
Date	**Invoice Number**	**Charges**	**Credits**	**Previous Balance** ……………… **Current Account** ……………… **Total Amount**

Past Due Amount

Over 30 days ………………….

Over 60 days ………………….

Over 90 days ………………….

Linkage with Inventory processing application: The daily shipment and back-

orders file obtained as an output of a run in the previous flowchart can be used to update the finished goods master file according to the concept of integrating various business applications (as shown in Fig. 10. Since, however, the finished goods master file is scquenced by the product stock number as the key, the daily shipment and back-orders tile is also sorted in this order. In the daily finished goods update run sorted daily shipment and back-orders file constitutes the transaction file and by updating finished goods master file, the system produces the following output:

(i) Finished goods master file is updated for the various stock balances in it. Back order-sub-records may also be added.

(ii) Back-orders and replenishment orders list: The items for which the stock balance has fallen below the reorder level would find place in the replenishment orders list. "Backorder" means a consumer's order for an item against which goods cannot be supplied now but would be supplied as and when they are received from the works.

(iii) Summary information and error list: The summary information consists of the various batch totals derived by the computer. These will ultimately be compared with their counterparts derived manually prior to computer processing. The error list would contain erroneous transactions which could not pass the various cheeks built in the computer program.

The sorted daily shipment and back orders file, in consonance with the concept of integration, is used in the flowchart given in Fig. 10 for sales analysis runs.

Sales Analysis Runs

The sales analysis are made by updating the sales summary Master File by the daily shipment and back orders file (as shown in Fig. 11). The sales summary file consist of the following data fields.

Total Sales This months			Total Sales year to date		
Actual (This year)	Prior year	Quota (This year)	Actual (This year)	Prior year	Quota (This year)
Unit ₹	Unit ₹	Unit ₹	Unit ₹	Unit ₹	Unit ₹
1 2	3 4	5 6	7 8	9 10	11 12

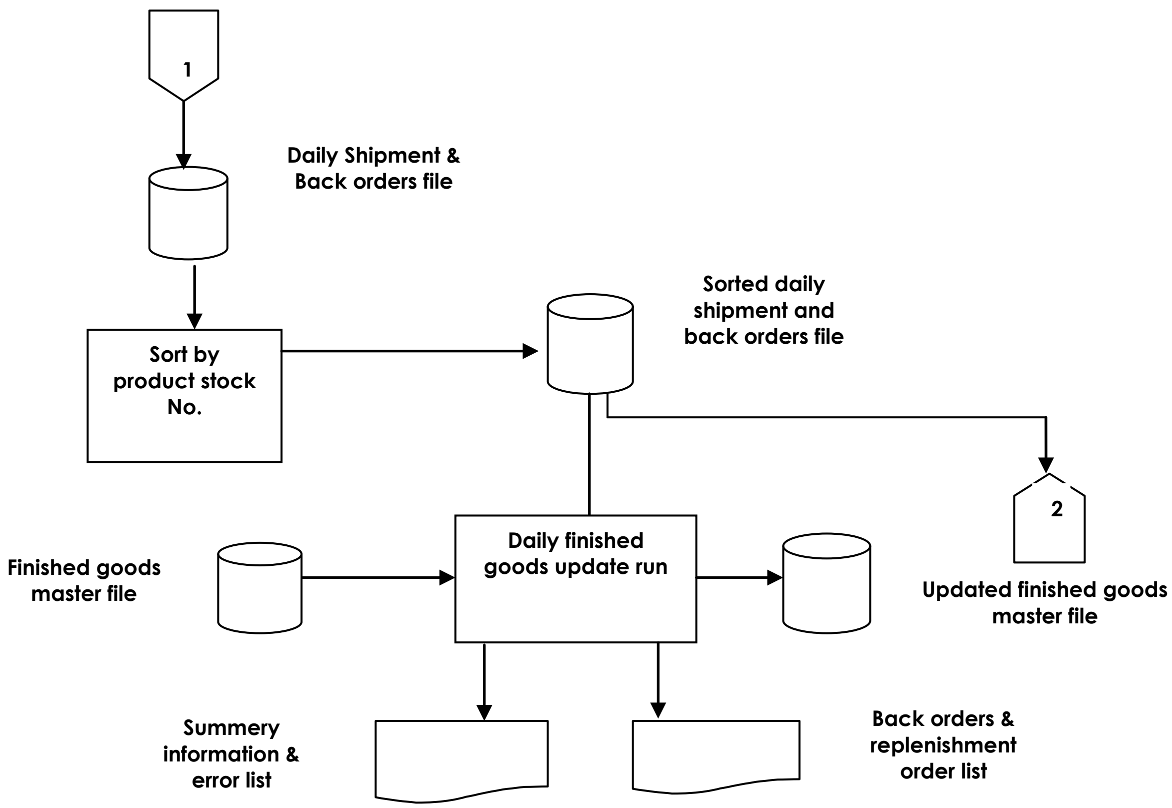


Fig. 10

This set of 12 data fields appears against each combination of a product, a customer and a salesman in the sales summary master file maintained on magnetic disk. For example, these 12 data fields would be there for Mr. X (a salesman) who is selling refrigerators to P (customer). Likewise, these 12 data fields would be there again for Mr. X who is selling refrigerators again to Q (another customer), and so on. In other words, for each combination of a salesman, a product and a customer, this set of 12 data fields would be there.

It is assumed, however, that to start with, the sales summary master file is sequenced by the product stock number and, therefore, it is straightway updated in run 1 by the daily shipment and back-orders file. As an output, the sales analysis report by product stock number is obtained.

Salesman	Period	Sales		%	Quota	%
		Actual	Prior year	Change		Variance from quota
		₹	₹			
Panikar	This month	7,500	8000	-6.25%	8,000	-6.25%
Natrajan	Year to date	60,000	75000	-20%	80,000	-25%
-						
-						
-						

The sales summary master file is then sorted by the salesman number as the key and in run # 2 a printout of the sales analysis by salesman is obtained.

The sale summary master file is finally sorted by the customer number as the key and in run # 3 a printout of the sales analysis by customer is obtained.

So far we have discussed various computerised business applications under batch processing mode merely for illustration. However, in practice, the trend is towards development of these applications in an interactive and on-line mode. Intact, with the wide-spread use of microcomputers, there are a number of software packages available for almost all business applications. Details of these can be obtained from software houses, computer dealers and computer magazines. Most of these micro-based software packages are interactive and menu-driven. They provide facilities for on-line entry of transactions and master files, validation of input data, creation of various analysis and summary reports and exception reporting for management requirements. We have given below an example of an on-line, real-time sales order processing system. Subsequently we have discussed a number of applications which are integrated, in the sense that output of one application may be used as input to another application.

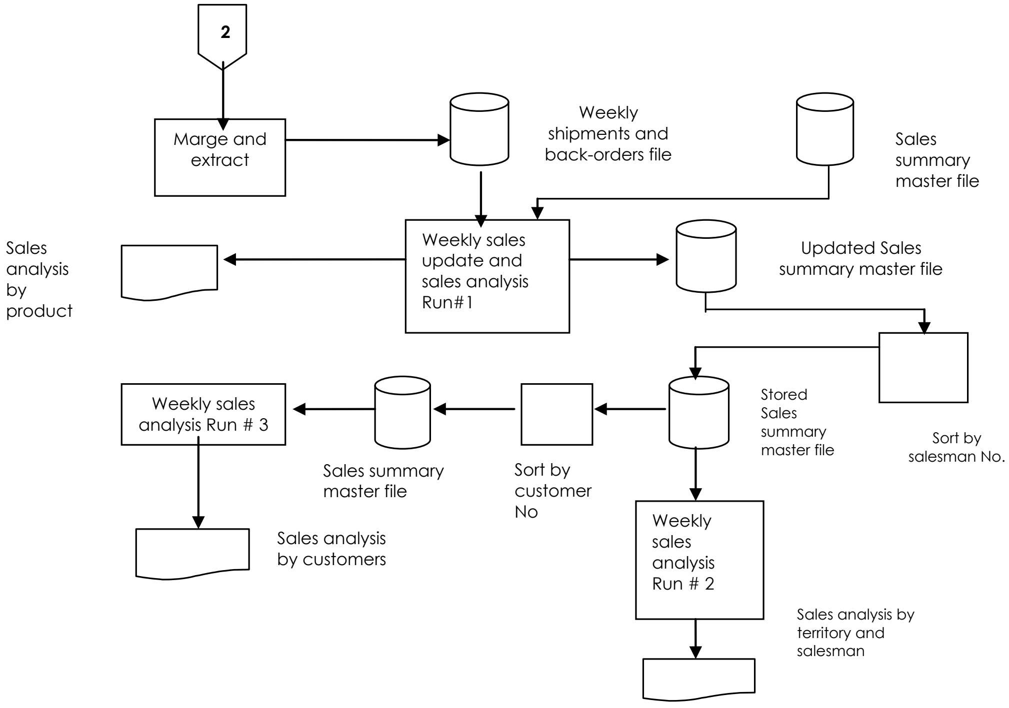


Fig. 11

The Sales Order Processing System: On-Line, Real-Time

An on-line, real-time (OLRT) sales order processing system can fully process a transaction as soon as it is entered: thus no delays occur during computer processing. When coupled with a point-of-sale (POS) transaction recording and entry system

whereby the transaction is initially recorded in machine-readable form "and entered directly into the computer, the system is fully automated, and even the delay in entering the transaction is eliminated. An OLRT system with POS transaction entry is illustrated in fig. 10.

In an OLRT system, all files of the subsystem related with a particular type of transactions processing must be electronically connected to the computer when a transaction of that type is entered into the computer. For technical reasons, the files of an OLRT system must consist of magnetic disks. Fig.10 shows six disk files, each containing accounts or other information that the computer programs can access immediately.

The OLRT system illustrated operates in a totally different manner from the way batch systems do. Assume that customers order by telephone and that the salesperson who receives customer's orders immediately keys the transactions at a terminal, as shown in the figure. Controlled by the sales order entry computer programs, the following events occur immediately in the sequence given below for each transaction:

1. The sales person tells the computer the nature of the transaction by entering a transaction code identifying it as a credit sales transaction; this activates the sales order processing computer programs. The customer number, the item number and quantity are then entered.
2. The computer program checks the customer's account in the customer file to "validate" the customer number (to establish that a credit customer exists with that number) and to see how much additional credit the customer can be granted; the up-to-date credit status of the customer is contained in the customer's account. If the customer cannot be extended further credit, the salesperson is notified by the computer and the credit transaction is cancelled.
3. The product number of the product ordered is checked for validity in the inventory file, and the stock level of that item shown by the inventory file is compared with the number of items ordered. If there is an insufficient quantity of a product, the program examines the purchasing file to establish when the next shipment is due. The system conveys this information to the terminal of the salesperson and awaits further instructions. The salesperson consults with the customer and then cancels the order for that item or changes the order to the quantity available and back-orders the additional items desired, according to the customer's wishes.
4. The computer program then seeks product pricing and quantity discount information from the price list file and special "preferred customer" discount information, if any, from the customer file. The total cost of the item to the customer, including tax, is calculated by the computer.
5. The details of the transaction, including the cost details, may appear on a display device at the salesperson's terminal so that they can be told to the customer. Changes may be made in the order by the customer and entered into the computer. The salesperson signals the computer when the customer approves the transaction.
6. An invoice is printed out for mailing, either at the salesperson's terminal or on a printer at a central location.
7. On a printer at the warehouse location of the merchandise, the computer system prepares a multipart shipping document, which is the authorisation for shipping personnel to select, pack, and ship the merchandise ordered. One copy of the document, known as the "bill of lading" is enclosed and shipped with the merchandise.
8. Product records in the inventory file are adjusted to reflect the decrease in inventory caused by the sale.

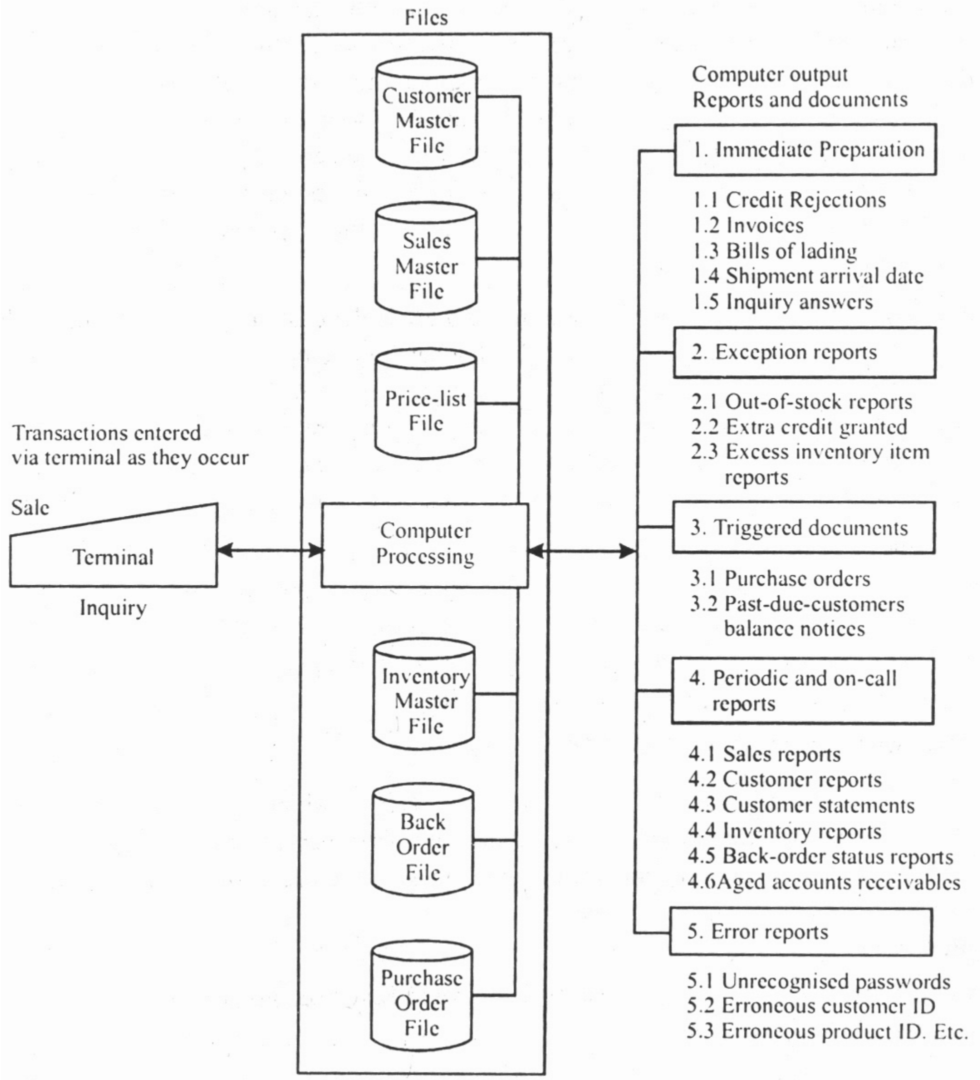


Fig. 12: Diagram showning an on line, real-time sales order entry system

9. The customer's account is updated to reflect the details of the transaction, and a new customer balance is calculated and placed in the account.

10. The record for each item in the sales file is updated with details of the transaction. This updating may include all details necessary for sales analysis based on customer type and territory, as well as other factors. A separate transaction listing that records all details of the entire transaction in one transaction file (not shown) may also be made for control and backup purpose.

The transaction processing described above may occur within a matter of a minute or two after the transaction is originally entered, while the customer is still on the telephone. In an OLRT system, the records can be kept current on a minute-by-minute basis. Inquiries from customers about the details of a recent transaction, about account balances, or about quantities of a product that arc available for sale can be entered through terminals and receive almost instant responses. If the price list file and the purchase order file are also maintained on a current basis, inquiries about prices and expected arrival dates of shipments can be answered promptly.

Additionally, transactions can be rejected immediately if the customer is not eligible for credit or if the item ordered is out of stock. With a batch system, neither credit eligibility nor product availability may be known for a day or more after the order is received. Common errors in batch systems, such as the entry of an incorrect customer number or an erroneous product number, may require days to detect and even more time to correct. With an OLRT system, such errors are usually detected and corrected immediately.

Each of the reports shown in Fig.10 can be produced at any location desired. Typically, the credit rejection report, the inquiry answers, and the error reports are displayed or printed at the terminal where the transaction is entered. Triggered reports occur when an internal condition automates a programmed algorithm, such as when the quantity of an item on hand drops below a reorder level.

Materials Inventory Control

The materials inventory control system is the point at which materials enter the manufacturing accounting system. This system controls inventory and minimises the costs of purchasing and holding of inventory shortages. Therefore, it needs the following information to function:

1. The timing of purchases.
2. Whether materials received meet specifications and have been properly costed.
3. The status of inventory on hand.
4. The status of unfilled orders.
5. Anticipated demand

Fig. 11 depicts the flow of information to and from the materials inventory system. One of its major functions is to maintain a subsidiary ledger with accounts for each item in the inventory. This ledger should balance in total to the materials inventory control account contained in the general ledger.

System Interfaces

The materials inventory control system interface directly with the accounts payable, general ledger, work-in-process control, and production scheduling systems. Materials inventory control provides accounts payable with information about vendors and the receipt of goods. Vendor information is required when sourcing decisions are made. When an order is received, the materials inventory control system reports to accounts payable, which in turn, reports to authorize payment.

Materials inventory control provides the general ledger with certain accounting information. Specifically, the general ledger system needs to know the value of the purchases received, material transferred into production, and the inventory on hand. The aggregate journal entries generated and sent to the general ledger for the accounting transactions in the materials inventory control systems are:

Materials inventory		XXXX
Accounts payable		XXXX
Work in process	XXXX	
Factory overhead control-indirect materials		XXXX

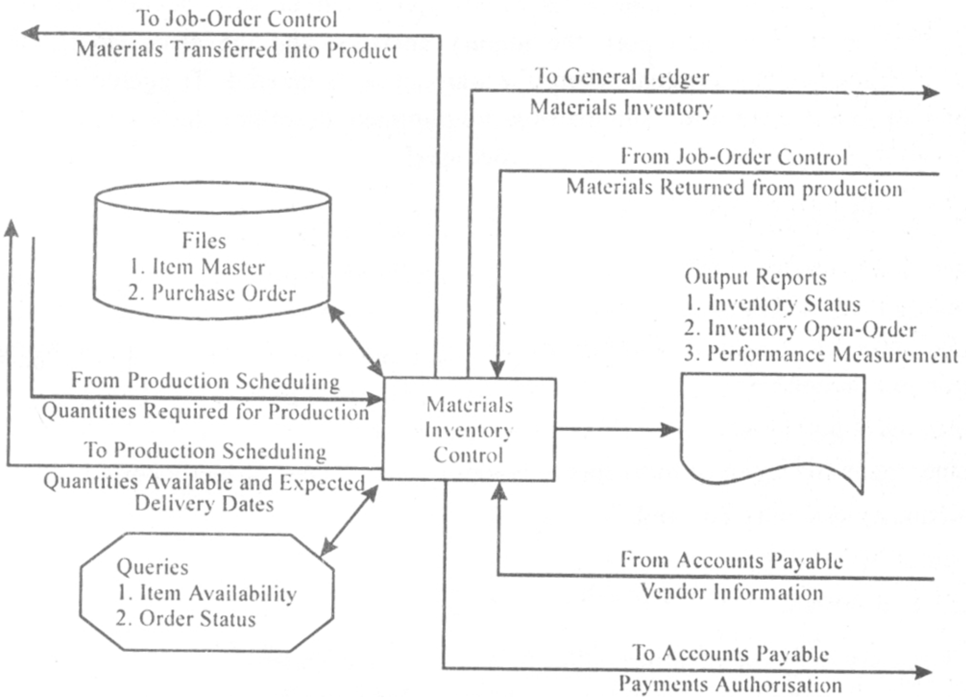


Fig. 13: Inventory Control System for Materials

The work-in-process control system contains the work-in-process accounts. Direct and indirect materials are requisitioned from the materials inventory control system and

transferred to these accounts. On occasion, materials are returned from the production departments to materials inventory control.

Information concerning the quantities of items required for scheduled production is provided to the materials inventory control system from the production scheduling system. This information is used in determining order quantities and timing. In a similar way, information concerning quantities available and expected delivery dates is provided to the production scheduling system by the materials inventory control system. This information is then used in scheduling production.

Files and Inputs

Typical materials inventory control systems require at least two files. The item master file contains one record for each item in the inventory. The following are a sample of the data items in each record:

— Inventory item number

— Item description and specification

— Current quantity on hand

— Current quantity on order

— Receipts-current period

— Receipts-year to date

— Issues-current period

— Issues-year to date

— Standard cost

— Vendor identification

The item file is updated when a purchase order is created or items are placed in the inventory. Most queries of the materials inventory control system are for information contained in this file.

A purchase order file contains information about new purchase orders. Purchase orders result from reduced quantities in the inventory or anticipated production requirements. The following are a sample of the data found in each record:

— Inventory item number

— Item description and specification

— Vendor identification

— Quantity ordered

— Date of order

— Delivery date

— Shipping instructions

— Order status

— Purchase cost

— Purchase order number

— Item quantity actually received

When materials are received into inventory, they are inspected and their quantity verified. Then the quantity and the cost based on the purchase order is sent to the accounts payable system to be used as a part of the data necessary to authorise payment.

Reports

On a periodic basis, the materials inventory control system produces at least some of the following reports. A inventory status report (Fig. 14) contains the quantities of each item available on a particular date. The unit cost is provided, and any costing technique (specific identification, FIFO, LIFO, average) can be used. Besides the ending balance, the beginning balance, transfers, receipts, and adjustments are also included.

A& B Corporation			**Inventory Status Report**			**Date: 12.11.2012**		
	Item Number	Item Identification	Quality on Hand	Quantity on Order	Expected Delivery Date	Quantity Allocated	Quantity Available	Standard Unit Cost
Bearings								₹
	1001	2 Dia BB	20	-		-	20	15.00
	1002	3 Dia BB	30	30	20.12.12.	20	10	17.50
	1003	1-1/2 Dia RB	60	-	20.12.12	10	50	23.00
	1004	2-1/2 Dia RB	15	20		25	-	25.00
Shafting								

A& B Corporation			Inventory Status Report			Date: 12.11.2012		
	Item Number	Item Identification	Quality on Hand	Quantity on Order	Expected Delivery Date	Quantity Allocated	Quantity Available	Standard Unit Cost
	2001	1-1/2 Dia	300"	100"	01.12.12	200"	100"	.75
	2002	2 Dia	200"	-		-	200"	.90
	2003	2-1/2 Dia	150"	-		-	150"	1.10
	2004	3 Dia	400"	-		100"	300"	1.30
Steel Shapes								
	3001	4 × 5.4	300'	100"	15.12.12	200'	100'	1.25
	3002	L 3 × 3×¼	200'	-	20.12.12	-	200'	.65
	3003	L3 × 2 ×¼	150'	50'		150'	-	.55
Bolts								
	4001	¼ Dia × 1	2,000	-		500	1,500	.20
	4002	½ Dia × 1-½	3,000	2,000	30.12.12	2,000	1,000	.30
	4003	¾ Dia × 2	3,000	2,000	30.12.12	3,000	0	.35

Fig. 14: Inventory Status Report

An open purchase order report (Fig. 13) contains information concerning the status of open purchase order. It includes the item number, vendor identification, date of order, unit cost, quantity ordered, promised shipping date, and other status information. This report can be used to identify potential problems. For example, if a vendor misses a shipping date, cost estimation and production scheduling can be notified so that production schedules can be adjusted.

A&B Corporation		Open Purchase Order Report				Date: 12.11.12	
Item Number	Purchase Order Number	Item Identification	Vendor Identification	Date of Order	Quantity Ordered	Promised Shipping Date	Expected Date of receipt
1002	K21894	3 Dia BB	Precision Bearing	20.11.10	30	15.12.12	20.12.12
1004	K22741	2-½ Dia RB	Precision Bearing	10.12.10	20	15.12.12	20.12.12
2001	K22841	1-½Dia SHAFT	J.P Steel	01.11.10	100"	15.12.12	22.12.12
3001	K22843	4×5.4	C & M Supply	01.11.10	100'	10.12.12	15.12.12
3003	K22844	L3 × 2 × ¼	J.P Steel	15.10.10	50'	15.12.12	20.12.12
4001	K22845	½ Dia × 3 BOLT	A.M. Bolt	30.11.10	2,000	15.12.12	30.12.12
4003	K22847	¾ Dia × 2 BOLT	A.M. Bolt	25.11.10	3,000	15.12.12	30.12.12

Fig. 15: Open Purchase Order Report

Performance measurement reports contain information concerning turnover, stockouts, shrinkage, investment, and other appropriate measurement related to management performance in inventory control .A sample is shown in Figure 16. Appropriate inventory performance measures vary with the industry and the type of items maintained in the inventory.

A&B Corporation	Inventory Performance		Measurement Report	Date:12.12.2012
Inventory	30.11.2012	₹ 228,429	Monthly Carrying Cost	₹ 2,284
Inventory	30.11.2012	₹ 197,485	Monthly Carrying Cost	₹ 1,975
Inventory Turnover YTD		2.9	Stockouts	YTD 8
Inventory Turnover Previous		3.4	Stockouts Previous	YTD 12
Number of Requisitions Processed YTD			681	
Number of Requisitions Processed Previous YTD			579	
Number of Adjustments YTD			97	
Number of Adjustments Previous YTD			49	
Number of Order Received YTD			74	
Number of Order Received Previous YTD			64	

Fig. 16: Report showing Inventory Performance Measurement Report

Work-in-Process Control

The work-in-process control system assigns materials, labour, and overhead costs to production jobs or products. In a job-order system, each cost is assigned to a specific job. In a process costing system, costs are assigned to departments and then to products. The objectives of a work-in-process system are to cost jobs through the manufacturing process and provide management with information to assist in controlling cost and measuring the performance of departments or other units within the factory. Therefore, to function properly, the system needs information concerning [1] materials requisitioned for each job, [2] labour employed on each job, [3] overhead costs allocated to each job, and [4] the production status of each job. **Fig. 17** depicts the flow of information to and from the job-order control system.

System Interfaces

The work-in-process control system interfaces directly with the payroll, general ledger, finished goods inventory control, production scheduling, and materials inventory control systems. Labour cost distribution and factory overhead allocation are inputs from the payroll and the general ledger systems, respectively. Aggregate work-in-process inventory transferred to finished goods is sent from work-in-process control to the general ledger. The aggregate journal entry is:

Finished goods inventory control	XXXX	
Work in process		XXXX

Once manufacturing is complete, jobs are transferred from work-in-process control to finished goods inventory control-that is, from the production management system to the marketing system.

Authorization to start production along with a bill of materials, specifications, production schedule, and budgeted standard costs are transferred from the production scheduling system. Job status reports are available to this system. Direct and indirect materials are requisitioned from the materials inventory control system.

Files and Inputs

A typical work-in-process system in a manufacturing firm contains a job file that has one record for each job in the manufacturing process. The following is a sample of some of the data contain in each record:

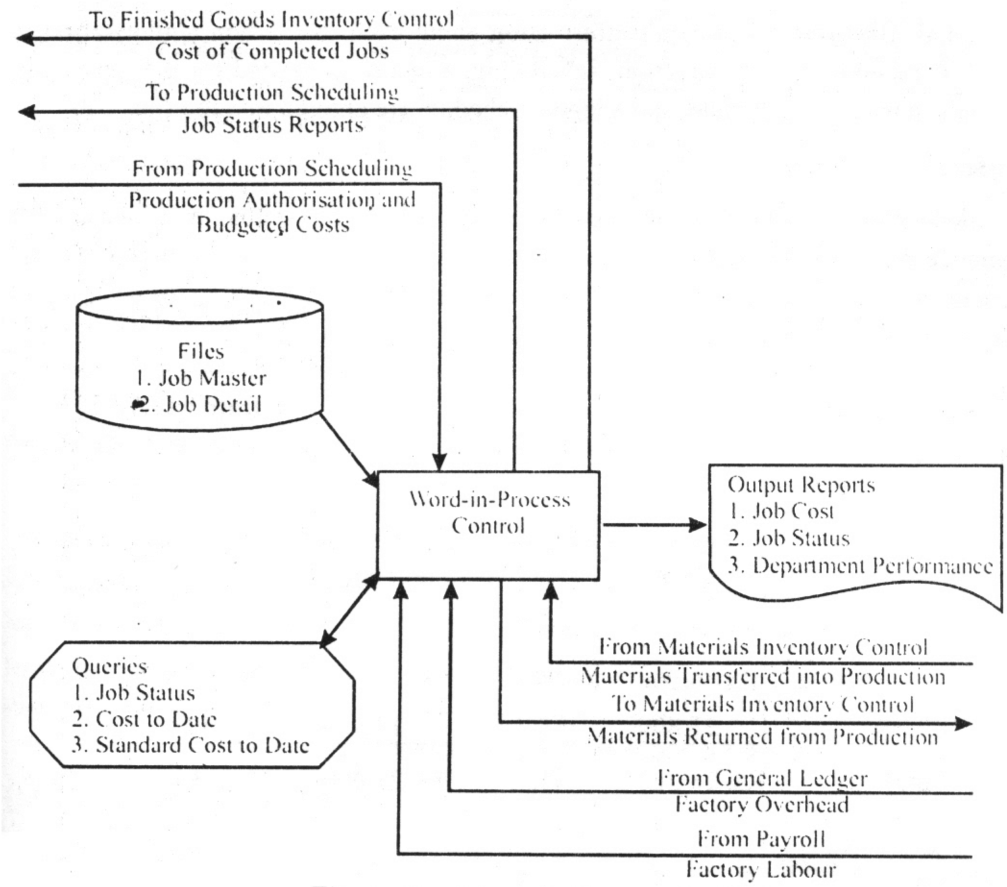


Fig. 17: Work-in-Process Control

- Job identification number.
- Customer identification.
- Promised completion date.
- Estimated shipping date.
- Promised shipping date.
- Estimated completion date.
- Total estimated material cost.
- Materials cost to date.
- Total standard labour cost
- Labour cost to date
- Total standard overhead cost
- Overhead cost applied to date

The job detail file contains in-depth information about each job. When authorization to start a job is received from production scheduling, a record is created for the job. A bill of materials, a machine schedule, and a labour schedule are entered into the file.

Reports

The work-in-process control system produces job cost, job status, and department performance reports periodically. A job cost report contains a detailed summary of the costs incurred to date, the budgeted cost, and estimated completion dates for each job in the system. Fig. 1 8 contains a sample job cost report.

A & B Corporation Job Number 3893	**Job Cost Report** Customer Pradeep Tandon & Co.		**Date : 12.12.2001** Estimated Completion Date : 2.4.2002		
	Standard Cost	Percent	Actual Cost to Date	Percent	Percent
Material					
Steel	Rs. 6,500	10.6	Rs. 6,700	15.3	103.0
Machinery	21,800	35.7	14,900	34.0	68.3
Total	Rs. 28,300	46.3	Rs. 21,600	49.3	76.3
Labour					
Welding	Rs. 3,840	6.3	Rs. 4,120	9.4	107.0
Machining	7,860	12.9	4,780	10.9	60.8
Electrical	600	1.0			0
Painting and preparation	800	1.3			0
Total	Rs. 13,100	21.5	Rs. 8,900	20.3	67.9
Overhead	Rs. 19.650	32.2	Rs. 13,350	30.4	67.9
Total	Rs. 61,050	100.0	Rs. 43,850	100.0	71.8

Fig. 18: Job Cost Report

In departmental performance reports, costs are associated with departments rather than jobs. These reports enable management to evaluate the performance of various departments. A sample performance report for a machine shop department is shown in Fig. 19.

A& B Corporation	**Department Performance Sheet**	**Date: 31.12.2012**	
Machine Shop	For Month of November, 2012		
Type of Machine	Standard Hours	Actual Hours	Difference
Drill Press	100	80	20
Screw Machines	370	433	(63)
Lathe	485	468	17
Planner	47	45	2
Automatic Cutter	197	209	(12)
	1,199	1,235	(36)
	Budgeted Cost	Actual Cost	Difference

Labour Cost	₹ 12,889.25	₹ 12,647.50	₹ 241.75
Number of jobs processed	17	Number of jobs completed on schedule	14
Number of jobs in Process	6	Number of Jobs not complete on schedule	3

Fig. 19: Department Performance Report

Estimation of Cost

A customer order is received by the firm after a customer has accepted an estimate of the cost of a job. The cost estimation system provides with manufacturing cost estimates based on inquiries received from potential customers. Cost estimates are a primary input when determining a price that will be quoted to a customer. When an order is received, the cost estimation system forwards the budgeted costs to the production scheduling system. Interfaces between the cost estimation system and other systems are shown in Fig. 20. No function within the cost estimation system result in general ledger entries.

System interfaces

The cycle in the cost estimation system begins when the job specifications and a request for a cost estimate are received. Materials, machine time, and labour requirements for the job are then estimated and costed using standard costs. Overhead costs are also estimated, and the job cost estimate is then returned to the system. This estimate serves as the basis for the selling price that is quoted to the customer. When customer's order is received, the standard costs for the job are transferred to the production scheduling system.

The budgeting system reports any changes in the standard material, machine, labour or overhead costs. Summary reports of all cost estimates are transferred to the budgeting system and used to prepare annual budgets for the firm.

The cost estimation system requires a standard cost file. Here, standard costs are maintained for each labour, material, and machine classification as well as for standard manufacturing operations. These costs are the basis for preparing manufacturing cost estimates. The standard costs are updated on the basis of information provided by the budgeting system.

The cost estimation system also maintains the bill of materials file, which contains a list of all materials required to produce each product. The file also includes approved vendors for each material.

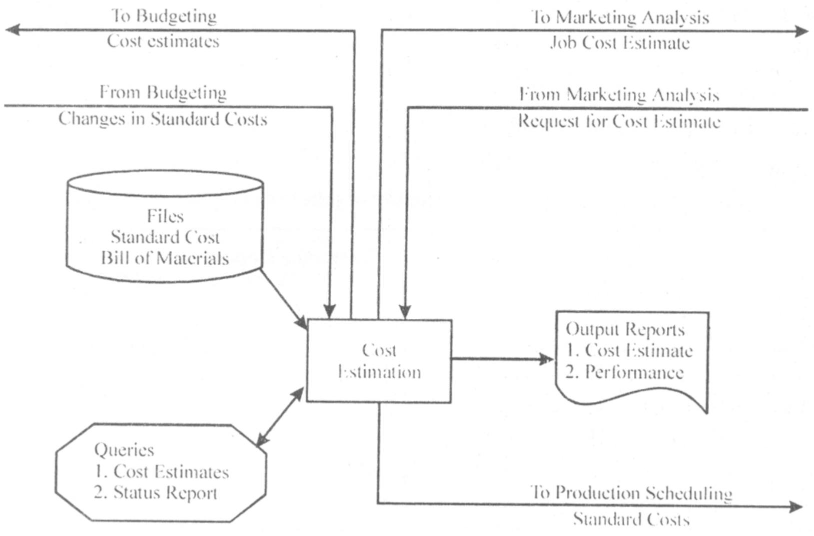


Fig. 20: Cost Estimation System

Reports

The cost estimation system can prepare manufacturing cost estimation reports for each job and performance measurement reports. The former are the primary output from the system. A sample is shown in fig. 21. The performance measurement report shows how many cost estimation reports were processed and how many orders were received. The estimated and actual costs on orders received are compared for each cost classification. This enables over or under estimation to be identified. A sample performance measurement report is shown in Figure 22.

A& B Corporation	**Cost Estimation Report**	**Date: 03.12.2012**
Customer: C.D. corporation		Estimate Number 9-1051
Type Fabrication: Steel Bridge Supports		
Date Specifications Revised: 08.11.2001		
Materials		₹
130' – 0" 20 WF 40		3,600
100' – 0" 12 WF 16		2,000
PL 36" x $\frac{3}{4}$" x 12' – 0"		900
PL 24" x $\frac{1}{2}$" x 16' – 0"		600
Labour: Wielding 300 hours @ ₹ 23		6,900
Painting and Preparation 100 hours @ ₹ 15		1,500
Overhead		16,800
Total Estimated Manufacturing Cost		32,300

Fig. 21: Cost Estimate Report

A & B Corporation **Cost Estimation Performance Report** **Date 3.12.2012**

Job Number	Materials Cost Estimated	Material Cost	Labour Cost Estimated	Labour Cost	Overhead Estimated	Overhead Cost	Total Cost Estimated	Total Cost
₹	₹	₹	₹	₹	₹	₹	₹	₹
JK 3890	9,800	10,300	11,900	12,400	24,000	25,000	45,700	47,700
JK 3893	17,400	17,250	9,870	10,450	9,800	9,550	37,070	37,250
JK 3895	135,485	140,600	130,680	148,900	1,31,000	145,800	397,165	435,300
JK3901	45,987	40,850	65,480	68,790	130,000	138,490	24 ,467	2,48,130
JK 3904	94,085	121,680	105,790	109,580	210,000	204,600	409,875	435,860
JK 3905	270,400	271,800	220,400	279,600	190,000	194,000	680,800	745,400
JK 3907	13,590	10,970	6,800	6,480	3,400	3,150	23,790	20,600
Total YTD	632,737	667,230	584,820	682,020	732,200	759,590	949,757	2,108,840

Fig. 22: Cost Estimation Performance Report

Production Scheduling

Production scheduling is the nerve 'centre of the production management system. It produces no general ledger journal entries, but it schedules production and monitors all physical flows. Figure 23 shows the information flow involving the production scheduling system.

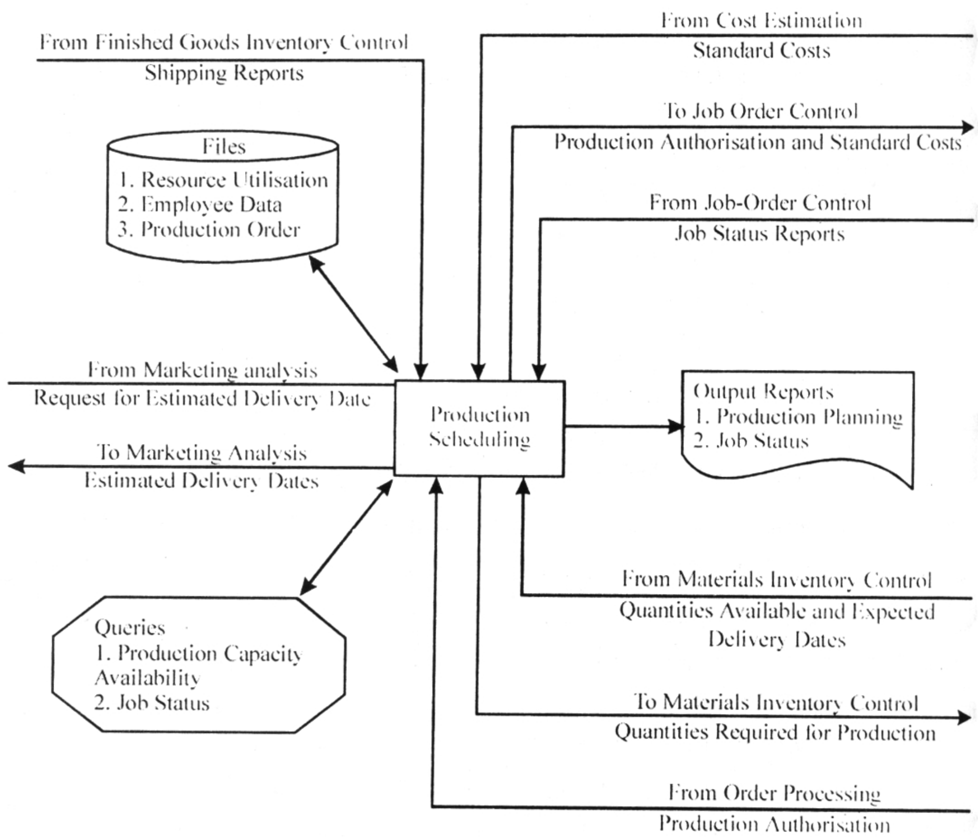


Fig. 23: Production Scheduling System

System Interfaces

The production scheduling system and various systems discussed earlier interact frequently. The sales order processing system authorizes production scheduling to start work on a job. Production scheduling then provides with estimated delivery dates and receives shipping reports from the finished goods inventory control system. Thus, all job scheduling information is kept in one system.

Within the production management system, the production scheduling and materials inventory control systems interface frequently. Production scheduling informs materials inventory control of the items and quantities required to schedule production, and inventory control indicates the quantities available. Work-in-process control receives production authorization from the scheduling system. This authorization creates a new record for a job, and production costs can be charged to the job. At the same time, the work-in-process control system receives the standard cost for the job and provides status reports to the scheduling system. Cost estimation provides production scheduling with budgeted standard costs for all jobs production.

Files and Inputs

Three files are required in the production scheduling system. The-resource utilization file contains a record for each machine and production process in the factory and maintains work schedules for them. The employee data contains data concerning employee skills and scheduled work assignments. The production-order file maintains completion dates and schedule information for each job.

Reports

The scheduling system produces periodic production planning reports. They indicate the available capacity and scheduled future utilization of labour and machinery. A sample report is shown in Figure 24. Such reports are useful to management because they indicate where excess capacity exists for the planning period. Sales and pricing strategies can be considered to alleviate the situation. On the other hand, if frequent scheduling problems are encountered, then an adjustment in capacity may be necessary.

A & B Corporation **Cost Estimation Performance Report** **Date 3.12.2012**

	Capacity YTD	**Utilization YTD**	**Capacity December**	**Planned Use December**
Labour (Hours)				
Welders	16,500	15,790	1,500	1,450
Machinists	24,750	25,050	2,250	2,300
Electricians	4,950	4,870	450	375
Painters	8,250	7,680	750	680
Total (Hours)	54,450	53,390	4,950	4,805
Machine (Hours)				
Drill Press	15,360	6,870	1,280	265
Automatic Screw Machine	11,520	11,460	960	1,040
Lathe	9,600	30	800	490
Planner	1,920	680	160	45
Automatic Cutter	5,760	6010	480	460
Total (Hours)	44,160	25,050	3,680	2,300

Fig. 24: Production Planning Report

Job status reports concern the status of jobs in the production process. They compare scheduled and actual completion times in the production process. A sample job status report is shown in Figure 25. This report emphasizes scheduled times whereas the job-order control report emphasizes costs.

Financial Accounting

All organizations keep accounts. Accounting involves recording, classifying and summarizing transactions and events which are of financial nature. The result is analyzed. Financial accounting is mainly concerned with the preparation of Profit and Loss Statements and Balance Sheets. Modules for managing Accounts Receivables and Accounts Payable are often included in financial accounting packages.

A& B Corporation Job Number - 3893	**Job Cost Report Customer Pradeep Tandon & Co.**			**Date: 12.12.2012 Estimated Completion Date: 02.04.2012**		
			Source			
Materials	**Inventory**	**Purchase**	**Shipped**	**Received**	**Delay**	**(Days)**
$\frac{11}{22}$ Plate	Y	-	-	-	-	
6" WF 20	-	Y	Y	Y	-	
2" Bearings	-	Y	N	N	Y	20
2" Shaft	Y	-	-	-	-	
Labour	**Budgeted Hours**		**Actual Hours**	**Difference**	**Estimated Hours to complete**	
Welding	384		412	(28)	0	
Machinery	524		319	205	240	
Electrical	40		0	40	40	
Painting and Preparation	80		0	80	80	
Total hours	1,028		731	297	360	

Fig. 25: Job Status Report

Every transaction in a financial accounting system has a credit side and a debit side. The total debit amount in a transaction matches the total credit. One account head may be credited and another will be debited with the same amount. A transaction could involve multiple accounts being credited and debited while maintaining the total credit amount equal to the total debit amount.

Financial accounting is concerned with entering all transactions and keeping track of the balances of the various account heads. The summary of the balances and of the transactions is presented in the form of profit and loss statement and balance sheet. The reports are used to understand the financial operations of the organization.

Organizations are also concerned with the money owed by them to others (accounts payable) and amount of money which are owed to them (accounts receivable). Collection of money owed is usually a focus area for an organization and therefore an analysis of the accounts receivable is very important.

Financial accounting as an area is extremely amenable to computerization. All processing is well defined and numerical. Since accounts are subject to audit, existing manual systems are usually smooth and consequently the transition from manual systems to computerized systems is relatively smooth. The method of accounting is similar across companies, with a few minor differences. A large number of readymade software packages are available in the market.

To set up a financial accounting system, master data containing account heads (main as well as subsidiary accounts heads) along with a classification of accounts needs to be maintained.

The regular processing involves:

- entry of transactions
- printing of cash and bank books
- printing the general ledger
- producing the profit and loss statement and balance sheet
- producing other reports on accounts receivable and payable

Annual processing involves closing the year, producing year-end reports and initializing the account heads for a new year.

For processing, transaction forms the regular input. The following transactions are typical in most financial accounting systems:

- Sales invoices
- purchase bills
- Payment vouchers (bank and cash)
- Receipt vouchers (bank and cash)
- Transfer of money between various bank accounts
- Journal vouchers
- debit notes
- Credit notes

While all transactions are essentially processed using the conventional double entry (debit and credit) system, different forms are used for different transactions in order to capture additional information (e.g. cheque number and date in a bank payment) and reference data.

Processing includes:

- Validation of the transactions-valid account heads, credit equal to debit, transaction date in valid range, etc.

- Posting the transaction (credit and debit) under the correct account/sub account heads.
- summarizing the accounts and transactions to produce the periodic profit and loss account and balance sheet
- Printing details of accounts receivable (including age-wise analysis)
- Printing details of accounts payable
- Printing the day books and ledgers (records of transactions by date and type of transactions)
- Facilitating reconciliation of accounting entries.

Annually, year-end activities require additional processing for incorporating the annual accounting entries and generating the Annual profit and Loss statement and Annual Balance Sheet. After the annual reports are generated and found satisfactory, the accounts are initialized with the year opening balances for the next year's processing.

Outputs of financial accounting systems include:

- Cash book
- Bank book
- Sales day book
- Purchase day book
- General ledger
- Subsidiary ledgers
- Trial balance
- Profit and loss statement (usually monthly/quarterly)
- Balance sheet (usually monthly/quarterly)
- Accounts receivable details
- Customer statement of account
- Age-wise accounts receivable
- Accounts payable detail statement
- Transaction details for given type of transaction, date range, account head, etc.
- Annual profit and loss statement
- Annual balance sheet.

Accounting of Shares

Share is an investment option used by many persons. A person may purchase shares either from the company (at the time of a public or a rights issue) or from the share market.

A share accounting system needs to maintain an updated list of shareholders. For each shareholder, the main information held is the name and address, names of joint holders (in any) the number of shares held, and the identification of the certificates through which these shares are held.

When a person purchases shares from a share holder, a share transfer form along with the certificates is sent by the buyer to the company for incorporating the transfer. The system records a change in ownership for the shares from the seller to the buyer.

Periodically, the company declares a dividend. Dividend warrants (cheques) need to be mailed on a particular day to the various shareholders who hold shares. Calculation of income tax to be deducted at source is also done before the printing and mailing dividend warrants.

Other facilities usually provided in share accounting system are:

- Bank mandate facility, where the shareholder's dividend warrant is sent to a bank account at the shareholder's request
- Splitting of share certificates, where a single certificate containing a large number of shares is replaced with a number of certificates containing a smaller number of shares
- Consolidation of shares, where many certificates belonging to a single shareholder are combined into one share certificate.
- Mailing annual reports and invitations to various meetings.

Main inputs in a share accounting system are:

- Shareholding data from a fresh issue-this is usually supplied by the issue agency on electronic media.
- Share transfer request
- Split request
- Consolidation request
- Request for bank mandate
- Tax exemption forms
- Request for duplicate certificates
- Request for duplicate dividend warrants
- Change in shareholder's address.

Processing involves:

- *Updating* shareholders master file
- *Recording* the transfer of shares
- *Handling* splitting, consolidation and duplicate requests and printing new certificates
- *Calculation* of dividend and income tax to be deducted.

Outputs are (main):

- Transferred share certificates
- New share certificates in case of consolidation, splitting and duplicates
- Dividend warrants and counterfoils
- Statement of Tax deductions.

Marketing information consists of people, equipment and procedures to gather, sort, analyze, evaluate and distribute needed, timely and accurate information to marketing decision makers.

Marketing decision makers use the data to identify and solve marketing related problems.

Marketing Information system supplies three types of information.

- Recurrent Information
- Monitoring Information
- Requested Information

Recurrent Information

This is the data that an MIS supplies periodically about the market share of a specific product and customer's awareness of company's brands. The data may be supplied on weekly, monthly or yearly basis.

Monitoring Information

This is the data obtained from the regular scanning of certain sources. Marketing managers may need data related to competition or the industry. It is essential so that marketing managers can be alert and identify potential problems

Requested Information

This information is developed in response to some specific request by the marketing manager. Secondary data or primary data through survey research are collected in response to the specific request. The MIS supplies the requested information for decision making.

Sources of Marketing Information

The MIS information inputs come from different sources, viz., both within and outside firms . Some of the commonly used internal sources of information are:

- **Sales Analysis-** The marketing information system retrieves sales information and put them in usable and disaggregated form. It detects various marketing strengths and weaknesses. Computer assisted sales analysis uncovers significant details for management needs.
- **Cost Analysis-**The cost analysis is possible with the effective accounting system. The classification and analysis of the cost of production, cost of distribution and selling may provide adequate information for the management purposes .
- **Financial Records-**The financial records & publications may provide adequate opportunities for management of sales & marketing activities .Many companies prepare periodical final statement to observe the balance of each item of financial records.

Importance of Marketing Information System

- **Anticipation Of Customer Demand**-Every marketer needs up-to-date knowledge about consumer needs and wants.
- **Systematic Approach**-Expanding markets and competitive marketing environment require adequate market intelligence system.
- **Economic indicator**-Marketers must have latest information on the changing trends of supply, demand and prices
- **Significance of Analysing Competition**-Marketer cannot survive without having information regarding nature , character and size of competition to be met.
- **Development of Technology**-Marketers must have latest information regarding technological development.
- **Understanding the Consumer**-Information system can establish proper two way flow of information and understanding between marketers and consumer.
- **Marketing Planning**-Marketing plans and programmes are based upon information supplied by economic forecasts and market research.

Financial modeling

What is Financial Modeling?

- A financial model illustrates relationships using real (realistic) numbers so that it can answer "what if?" questions or make projections.
- Financial Theory
  Accounting & Financial Relationships $\longrightarrow$ Financial Model
- Models are stylized representations
  - Abstractions from reality
  - Designed to capture essentials

- Goal of modeling is to achieve insight
  - Not to replicate reality
  - Desire to understand how elements fit together and interact.

Assumptions and Outcomes

- Assumptions
  - Identified variables
    - Independent variables
    - Dependent variables
- Structural relationships among variables
- Values and distributions of possible values
- Outcomes
- Dependent variables the model is designed to explain

Model Types

- Mathematical models
  - Highly abstract
  - Emphasis on structural relationships
- Empirical models
  - More value-specific assumptions
  - Specific quantitative outcomes sought
- Spreadsheet models
  - Codified empirical models

Model

A Model specifies the relationship between inputs and outputs.

Outputs $$FV = P\left(1+\frac{r}{m}\right)^{n*t}$$ **Inputs**

Deterministic Model

A Deterministic Model generates the same output every time you calculate

$$₹\ 219{,}112.31 = ₹\ 100{,}000\left(1+\frac{8\%}{2}\right)^{2*10}$$

What happens to the Future Value if the interest rate increases?

Stochastic Model

A Stochastic Model uses random inputs and gets a different output every time you calculate

$$r \sim N(3\%,\ 2\%)$$

$$FV = P\left(1+\frac{r}{m}\right)^{n*t}$$

Study Note - 8

ENTERPRISE RESOURCE PLANNING

This Study Note includes

8.1 ENTERPRISE RESOURCE PLANNING

Enterprise Resource Planning: An enterprise planning system is an integrated computer based application used to manage internal and external resources, including tangible assets, financial resources, material and human resources.

Basically, an ERP combines several traditional management functions into a logical integrated system and facilitate flow of information across these functions. It is designed to model and automate basic processes across the organization over a centralized database and eliminates the need of disparate systems maintained by various units of the organization.

Need for Enterprise Resource Planning

Separate systems were being maintained during 1960/70 for traditional business functions like Sales & Marketing, Finance, Human Resources, Manufacturing, and Supply Chain Management. These systems were often incongruent, hosted in different databases and required batch updates. It was difficult to manage business processes across business functions e.g. procurement to pay and sales to cash functions. ERP system grew to replace the islands of information by integrating these traditional business functions.

Advantages of The successful implementation of an ERP system

- **Business integration and Improved Data Accuracy:** ERP system is composed of various modules/ sub modules where a module represents a particular business component. If data is entered in one module such as receiving, it automatically updates other related modules such as accounts payable and inventory. This updating occurs at real time i.e. at the time a transaction occurs. Since, data needs to be entered only once at the origin of transaction, the need of multiple entries of the same data is eliminated. Likelihood of duplicate/ erroneous data is, therefore, minimized. The centralized structure of the data base also enable better administration and security provisions, which minimizes loss of sensitive data.
- **Planning and MIS:** The various decision support tools like planning engines and simulations functions, form integral part of an ERP system which helps in proper utilization of resources like materials, human resources and tools. Constrained based planning help in drawing appropriate production schedules, thereby improving operation of plant and equipment. As a part of MIS, an ERP system, contains many inbuilt standard reports and also a report writer which produce ad hoc reports, as and when needed.
- **Improved Efficiency and Productivity:** In addition to provision of improved planning, ERP system provides a tremendous boost to the efficiency of day to day and routine transactions such as order fulfillment, on time shipment, vendor performance, quality management, invoice reconciliation, sales realization, and cash management. Cycle time is reduced for sales to cash and procurement to pay sequences.

- **Establishment of Standardized Procedures:** ERP system is based on processes of international best practices, which are adopted by the organizations during implementation. Department silos are purged and maverick practices are done away with. Because of top down view available to management, chances of theft, fraud and obsolescence are minimized.
- **Flexibility and technology:** Due to globalized environment, where production units, distribution centers and corporate offices reside in different countries, organizations need multi currency, multi language and multi accounting modes, in an integrated manner. These provisions are available in most of the ERP systems, particularly in products offered by tier 1 and tier 2 vendors. ERP vendors are also quick to adopt latest technologies, from mainframe to client server to internet. Unlike a bespoke system, Upgrading to latest technology for a running ERP system is uncomplicated, involving mostly adoption of service packs and patches.

Evolution of ERP System

Pre ERP systems

In the sixties, computers were bulky, noisy and without the facility of standard operating systems. The organizations used to develop computerized systems that were stand alone, tailor made and without an integrated approach. The software development, in a sense was re-inventing wheel, as basic business process is similar for all organization in the same business sector. Due to this restrictive environment, Development, maintenance and modification cost became prohibitive. Developer ended up developing isolated and piece meal systems, even within an organization. Thus, a pay roll system, accounting system and inventory system were developed in isolation as per specific need of business units and were incompatible to each other.

MRP-Advent of ERP

Stand alone systems, in vogue during sixties, were incapable of processing planning requirement of an enterprise encompassing production planning, procurement and inventory, which became an impediment in adopting Materials Requirement Planning (MRP). MRP was first adopted by IBM and J I Case (a tractor maker from USA) during late seventies, when integrated systems started taking shape. The basic idea of MRP was to assimilate planning and scheduling elements to the manufacturing process. The process of MRP was to plan and procure purchase requirements based on finished products, inventory on hand, allocated inventory and expected arrivals. Subsequently, it was supplemented by Capacity Requirement planning (CRP) to create capacity plans of shop floors and sub-contractors.

There was continued development of MRP system during 1980s. The need moves beyond shop floor and MRP II was introduced incorporating planning element of distribution as well as forecasting requirement.

ERP was introduced in late 1980 to integrate other business functionalities not covered by MRP or MRP II. It is not confined to manufacturing only but covers all facets of organization such as:

i. Finance

ii. Human Resources

iii. Supply Chain

iv. Warehouse management, and

v. Project Management

ERP development from software solution provider mainly emerged as a sequel of their MRP products. Some of the early solution providers are

i. SAP from Germany

ii. BaaN from Netherland

iii. JD Edwards from USA, and

iv. Lawson from USA

Few vendors did not follow this course. Starting point of Oracle ERP was their accounting package whereas People-soft ERP evolved from their HR suite.

During 1990s, ERP products continued to evolve. Vendors added new functionalities, incorporated Graphic User/ Internet browser interface and brought out new versions of their products. Some solutions were found to be more suitable for a particular vertical such as discrete manufacturing, utility, process industries, public sector and retail. Several vendors brought out reference models of their product, meaning that through pre-configuring basic and common data, a particular flavor of their product will be more compatible to the business need of a particular sector/ sub-sector.

Traditionally, the biggest purchaser of an ERP solution is fortune 500 companies. But, this market has since been saturated. Vendors are now looking to increase their presence in small and medium business sector. Due to fierce competition and financial crisis, there are also a number of takeover and mergers across ERP solution providers during early 2000 such as Oracle taking over People Soft, Infor taking over BaaN and Microsoft taking over Axapta.

Current trend

ERP solutions, which were mostly, operating as a back end system, is now broadening its horizon. ERP vendors are extending their products to become Internet enabled. ERP extension products (mostly as an add on to their existing products) now provide solutions for Advanced Planning and Scheduling, Manufacturing Execution System, Advanced Business Intelligence and Dashboards, Sales force automation, Product Lifecycle Management and Warehouse Management. Business to Businesses and Business to Commerce functionalities, as add on solution, is now getting seamlessly integrated with back end, thus making it possible to bring e-commerce under the gambit of ERP.

ERP and e-Commerce

During 1990s', the popular method of exchanging information between trading partners were Electronic Data Interchange (EDI) and all major ERP vendors added EDI facilities to their products. However, EDI did not achieve its desired outcome as each organization needs its own customized EDI (to account for its unique data format), high set up cost (requiring privately run Value Added Network) and little cohesion or standardization. A majority of organizations did not use EDI functionality, while implementing their ERP systems.

The advent of internet and intranet technologies since mid 1990s' saw the exponential growth of electronic commerce (e-commerce). E-commerce involved buying of goods through internet (comprising of advertising need, issue invitation to tender, reverse auction etc.), selling of goods through internet (comprising electronic auction, publishing electronic catalogues) and handle related processes electronically such as receive invoice, making payment, monitoring performance.

Response of ERP vendors: ERP vendors were not agile to quickly respond to the changing need where customers and suppliers, wanted information, contained in the back end ERP system, for effective collaboration, better information flow and minimizing cost across the supply chain. Customers demanded supply status, billing information, warranty compliance over web whereas suppliers wanted on line information on inventory, supply schedule and payment status. ERP products are having rigid architecture and any modification/ development requires complex coding and developing a link between back end ERP with front end web based e-commerce, was a challenging task.

ERP vendors responded to this challenge by their effort to web enable their product. They have developed some functionality in house but also used/ acquired third party products such as storefront. They have developed new workflows encompassing vendors, customers, shippers, distributors and bankers. They have made these workflows web enabled by adopting open standards such as Java and XML.

Another challenge faced by the ERP vendors for web enabling their product was security issues relating to e-commerce transactions, which are carried out through Virtual Private Network (VPN) over internet backbone. They have to adopt authentication tools such as electronic signatures and digital certificates, Secured Electronic Transactions (SET) and confidentiality through symmetric key encryption/ public key cryptography.

E-commerce transactions can be broadly classified under e-procurement and e-selling particularly under the context of business to business transactions. Some details under these classifications are given below:

E-Procurement - A typical e-procurement requirement of an organization is depicted below:

- Electronic tendering comprising of tender publication, submission, short listing, evaluation and award. Facility for evaluation of IT/ Service contracts containing Complex evaluation matrix.
- Compliance of agreed quantity Vis-a-Vis called quantity, consolidation of called quantity for obtaining agreed quantity discounts.
- Facility for publication and updating of electronic catalogues by vendors.
- Analytics for spend analysis which is used for strategic decisions, supplier relation management and minimization of maverick buying.
- Facilities for reverse auctions through business to business marketplace.

For meeting the above requirement, ERP vendors carried out integration of web based front end with generation of demand (planning module), preparation of purchase order (procurement module), receiving of goods (warehouse module), payment (account payable module), dealt by back end ERP system.

E-Sales - The biggest change that has been brought by e- commerce in respect of selling and marketing of goods is creating a new sales channel based on web. This has impacted retail sectors in a big way through increased sales, expended market reach including oversees market, improved customer loyalty and reduction of transaction cost.

E-sales enhance value in respect of following business process:

- Reaching the customer quickly and a transparent way through the process of electronic auction.
- Processing customer orders promptly through web storefront applications.
- Checking credentials of the customer.
- Arrange drop shipment where the nearest distributor ships goods.
- Providing facility to customer to check status of order through web.

For meeting the above requirements, integration of web system with back end ERP system was done. Before order acceptance, ATP (Available to Promise) status of the item is verified from planning module. For quoting price, dispatching of good and receiving of payment, sales, warehousing and accounts receivable modules of ERP system are interrelated.

ERP Vendors

During 1990, ERP market was dominated by few vendors namely SAP, BaaN, Oracle, People Soft and JD Edwards, who were also known as big five of ERP market. The market was, then, was growing at compound rate of approximately 35%. Fortune 500 companies were the major customers. Key focus of ERP vendors, during that period, was to expand functional scope of their product and provide sharper vertical focus. Manufacturing made up for the largest segment of ERP spending.

Trend during 2000

IT spending as a whole slumped after the collapse of internet bubble and 9/11 terrorist attack,. Market for ERP also saturated for fortune 500 companies. ERP vendors started to face financial difficulties. ERP market went into an upheaval and following trend emerges:

- Increased acquisition and merger activities: Financially stronger ERP vendors started to swallow their weaker brethren. Private Equity firms also started to play a big role. BaaN was taken over by Invensys and subsequently by SSA Global. SSA Global was later merged with Infor, which was supported by a large private equity company. J. D. Edwards was merged People Soft which in tern was taken over by Oracle through a hostile takeover.
- Segmenting / diversifying of ERP Market: Due to saturation at top end, ERP vendors were trying to penetrate medium and small market segments. The market thus got segmented into tier 1(large organization), tier 2(medium organizations) and tier 3 (small organization). Major ERP vendors started offering products for lower end of the market either through extension/rationalization of their products or through acquisition. ERP vendors were also diversifying their product to different verticals. Whereas, manufacturing provided the major chunk of their revenue, the focus area turned to retail, public sector, utility, financial sector, and telecom.
- Web enablement: Rising opportunity of ERP vendors was to leverage their existing products with niece acquisition, to extend beyond their earlier solutions, limited to four walls of an organization. The explosive development of internet made possible seamless web based collaboration by organizations with their vendors and customers, such as “mySap.com” solution from SAP and e-business suite from Oracle.

Some Key Vendors

- SAP: They are the largest ERP solution provider with more than 75,000 customers and 12 million users and holding around 30% of market share. The Flagship Solution, R/3 is unmatched for its sophistication and robustness. R/3 software gives an option of around 1000 pre-configured business processes. This solution is available in all major currencies and languages and can be hosted on several Operating Systems and Databases. As mid market option, SAP has brought out, Business All in One, a solution with industry tailored configurations. SAP offering for smaller organization is SAP Business One. SAP offers a hosted solution, namely SAP Business by Design, for organizations lacking IT resources.
- Oracle: Oracle is next to SAP in ERP market breadth, depth and share. It offers a comprehensive, multilingual and multi currency solution, mostly through its channel partners.. It is the first to implement internet computing model for developing and deploying its product. Oracle also took over various ERP solution providers during 2000 such as People Soft, J.D. Edwards, Retek (retail industry solution), and Siebel (customer relationship management software). It has taken up project Fusion (based on Service Oriented Architecture) to integrate various products, outcome of which is keenly awaited.
- Infor: Infor is of recent origin and expanded through a number of acquisitions. Its acquisition of SSA global during 2006 made it a forerunner as ERP solution provider. SSA global had two strong product lines, BPCS and BaaN. SSA also made a number of other acquisitions, such as MAPICS, Lily Software Associate and GEAC. SSA is focused on building, buying and integrating best of breed solutions.
- Microsoft Dynamics: Microsoft, which did not have an ERP portfolio, started by acquiring a host of ERP products like Navision, Solomon, Great Plain and Axapta. Excepting Axapta, which is strong in manufacturing and suitable for mid market, other products are meant for smaller organizations. Microsoft is much dependent on channel partners, not only for sales and consulting but also for add on development. Their solutions are closely integrated with their office suit.

ERP Architecture

Information technology is changing at a fast pace. Underlying ERP technology is needed to keep pace with first changing IT scenario and should also be flexible to adopt ever changing business scenario. ERP technical architecture basically defines layout of layers of application deployment between servers and desktops, interfaces and software objects. ERP architecture is no more meant to just provide technical functionality, user interface and platform support but should be able to absorb emerging technologies. It should be expandable and maintainable to meet future business needs such as business process changes, merger and acquisitions, compatibility with future regulations etc.

Mainframe Era: During, 1980s, ERP systems were running on mainframe, capable of supporting hundreds of users concurrently. Users were connecting to this monolith system through dumb terminals (terminals without any memory or processing power), only to access and input data. Concept of Graphic Users Interface was still to come and only a few knowledgeable users were comfortable with this set up.

Client Server: During 1990s, client server (C/S) ERP application became popular. PC became powerful and provided a better user interface (UI), through Graphic Users Interface (GUI). Mainframe computers were getting replaced by midrange system such as AS/400 or powerful PC servers. PCs (clients), networked with server / cluster of servers, are known as Client Server platform and have the following characteristic:

- Server hosts central database and application programme.
- PC Clients, provide input, request service from server, performs display and does some processing.
- System functions are done in three logical layers (i) Presentation layer-at client PC (ii) Application layer, executing instructions from users and transferring and receiving data from database (iii) Database layer for centrally managing data. Under C/S concept, server denotes either a physical or a virtual server.
- Application programme and database may be hosted in a single server or in two separate servers. For multi location or large systems, application program is divided in a number of networked servers which enhance speed and reliability of the system.
- Monolith system of mainframe era gave away to multilayered and decentralized architecture of C/S. Consequently, ERP vendors started adopting more and more Object Oriented Program (OOP) and third/forth generation programming language (3GL/4GL). This componentized development environment enables them to develop more modular solutions which can be customized, tested, deployed and retrofitted easily and separately.

Web enabled ERP

Adoption of Internet technology allows access to an ERP system from anywhere anytime, enabling new ERP functionalities like Sales Force Automation.

User Interface (UI) under a Client/Server system was normally a small software programme which needed to be installed, maintained and updated, at each desktop. Carrying out this task over a number of desktops located at various nodes of Wide Area Network, became a cumbersome assignment. Consequently, the concept of Uniform Resource Locator (URL) was adapted and internet browser was used to access server from client side. This development eliminated the need of installing client program but made use of Java applets, which gets downloaded whenever a connection is made by the client, through URL. This was the beginning of adoption of internet technology by ERP systems.

Additionally, on server side, a new layer of web server (HTTP server) was added for generating HTML pages, to respond to client instructions. A Caching server was, also, added to improve speed and performance. Browser enabled client and additional layer of web servers, provided the first step of web enablement of ERP solutions.

The next step of web enablement is to extend backend ERP system to the web so that mobile workers, suppliers and vendors can access and collaborate through secured internet link. To achieve this, ERP systems are needed to be redesigned and made compliant of standard like Java 2 Enterprise Edition

(J2EE). This is a time consuming work as traditional ERP systems are complex, inflexible and developed on proprietary platforms and is progressing slowly.

Business Preocess Re-engineering

Enterprise Resource Planning (ERP) and Business Process Re-engineering (BPR) evolved almost at the same time i.e. 1st half of 1990. Both relates to radical redesign of an organization at a relatively short period. Both are having the primary intend to optimize workflow and improve productivity. But, the chicken and egg question remained, whether an organization reengineer business process before implementing ERP or directly implement ERP and reengineer by adopting standard business process, included in the ERP package.

What is Business Process Re-engineering (BPR)?

BPR means not only change but radical change within a short period. This change is achieved by complete revamp of organizational structure, business process workflow, job description, performance measurement and adoption of information technology.

Some of Basic characteristics of BPR are:

- View business as a set of customer (both internal and external) oriented processes rather than a set of departmental functions.
- Processes must have clear cut ownership.
- Non value adding activities within a process should be eliminated.
- Gather information only once at the point of origin.

A successful BPR implementation brings significant improvement to productivity, customer service and bottom-line. There are pain and difficulties during implementation and instances where BPR efforts did not achieve desired result. Notwithstanding, the risk is worth taking. Otherwise, there will be grater risk of being overtaken by competitors who develop and progress rapidly through BPR.

Implementation phases

i. **Project kick off**: Project goal, project team and communication standards are agreed upon. A number of workshops are held where project scope, sponsors commitment, project risk, milestones and deliverables are discussed. A SWOT (strength, weakness, opportunities and threat) analysis is carried out with active participation of all.

ii. **Process identification and data gathering:** "As is" processes are assembled through flow charts. Current practice of interfacing with business partners is gathered. Bottlenecks, delays, complexity, internal blame games, idle assets etc. are brought forward. Use of existing technologies is comprehended. Major and strategic business processes to be reengineered, are identified. Stakeholders categorize the processes to be reengineered and agreed upon on the timeline of implementation.

iii. **Process Reengineering:** In this phase, actual reengineering begins. A number of brain storming sessions are held with project team and other stakeholders, where current business processes are critically analyzed to determine non value adding activities and identify excess control and check, always with customer value as a focal point. Impact of new technologies on process improvement is also evaluated. New process ideas with reduced check and control and enabling technologies such as Workflow Automation and ERP, are envisaged. Benchmarking is also done with best of breed industrial peers.

iv. **Blueprint of new system:** Blueprinting involves modeling workflow and information requirement, of new business processes. "To be" processes are modeled using various modeling tools. New organization structures, human resource need, performance monitoring and compensation, technological needs, are also outlined. Normally, a first cut redesign scheme is produced which is modified after gathering actionable feedback from the stakeholders.

v. **Transformation:** A migration strategy and a migration plan is the first step of transformation. Migration strategy may decided as a pilot, phased or big bang implementation. The migration plan would include establishment of new organizational structure, detailed training and reallocation of workforce, and cut off dates for implementation. Change management and introduction of new technologies will form an important part and may need engagement of outside consultants for this specific purpose. There should be provision on the plan to tweak the implemented system so as to get maximum value out of it.

BPR or ERP: For successful of BPR implementation, Information Technology plays the role of a key enabler. Therefore, a question is raised whether it is logical to directly implement ERP and re-engineer business processes by adopting world class practices, contained in ERP packages. This approach would avoid embarking on BPR which is expensive, time consuming and often risky. Also reengineered process arising out of BPR exercise may not be best of class. On the other hand, there is a grave risk in this approach if a proper ERP package is not chosen. Process orientation and ownership will be lacking from employees which may lead to major implementation difficulties.

Initial investment in acquiring and implementing an ERP system is substantial in terms of both human efforts and financial resources. After, successful implementation, the system goes to maintenance mode and organizations start getting value out of their investment. After a prolonged period, due to changes in business and technological paradigm, it becomes more and more difficult and expensive to maintain and extend the system. The process of reimplementation and beginning of a new cycle starts.

ERP life cycle Phases

ERP life cycles, which encompass entire 10 to 20 years of effective operating life, are often confused with ERP Implementation Life Cycle. Some of the **phases of ERP life cycle** is shown in following diagram.

1. **ERP Roll out:** The initial roll out of an ERP system itself consists of various phases commencing with Request for Proposal (RFP) and vendor selection and ending with go live and hand holding phase. Some important matter concerning this phase, as given below, will have direct bearing on subsequent phases of ERP lifecycle:
   - Degree of matching of vanilla ERP product to current business need and extent of customization done, particularly source code customization.
   - Commitment of the vendor for future development and their financial health
   - Support issues including License fees and escalation thereof.
2. **Optimization:** After the system is live and rolled out, there will be a period of turmoil. Due to lack of understanding, a lot pf confusion will prevail amongst users. There will be teething problems and some software bugs will invariably appear. With retraining, some tweaking of the system and assistance from a responsive help desk, this phase should be over within six months to one year and the system should start stabilzing.
3. **Maintenance:** This is the longest period of life cycle, when the organization starts realizing value of their investment. Users will get familiar and start owning the system. Some changes will be continuing such as new reports, different workflows, some localization on taxes etc. Maintenance will be covered by service level agreement, entailing payment of license fee to the vendor. For a complicated system, there may be a third party vendor, helping maintenance at site. The license fee, due to provision of escalation, gets escalated at regular intervals and after some years, adversely effects Total Cost of Ownership (TCO).
4. **Extending Values:** This phase overlap with the phase of maintenance. New or changed business processes necessitate minor or moderate changes in the system. There may be extensive changes under scenario such as (i) implementing a new accounting system e.g. International Finance Reporting standard (IFRS) (ii) A new regulatory requirement like Goods and Service Tax Act (GTA)

(iii) Mergers and acquisitions/restructuring. (iv) Extending the system with add on products such as Customer Relationship Management and Business Intelligence (BI). Sometime the cost changes may be prohibitive, particularly for systems where a lot of customization has been done during implementation phase.

Parallel to business changes, technological changes also occur. New release and versions appear for underlying technological platforms like Operating System and Data Base. ERP vendors release patches and versions of their products at regular intervals which needed to be incorporated in the existing system. This usually involves minor or moderate efforts. But, problem arises where many software objects were customized during implementation. Retrofitting these objects for making them compatible with later versions, may turn out to be a major migration exercise involving exorbitant cost and effort.

5. **Decaying Performance:** For an enterprise, business need and technological requirement, continue to evolve. Cost, Complexity and difficulty to modify and update the existing system mount. Fixing existing system is no more viable and provides diminishing return. Alternatives are investigated and decision of reimplementation is taken.

6. **Reimplementation:** Similar to Roll Out phase as mentioned above. However, the organizations are better organized now. Initial process will be carried out more professionally. It is likely that they will adopt more of a vanilla version with minimum need of customization, so that the next cycle gives a better Return on Investment (ROI).

Implementation of ERP System

Implementation of ERP System, is a complex exercise, involving many process alterations and several legacy issues. Organizations need a implementation strategy encompassing both pre implementation and implementation stages. The fallout of a poor strategy is unpreparedness of employees, implementation not in conformity with wider business strategy, poor business process redesign and time and cost overrun.

Following issues must be carefully thought out and formulated, as a part of implementation strategy, before embarking on actual implementation:

Business Process: Hypothetically, company insiders should know best about the processes of their organization. But employees often constrained to work in departmental soils and overlook wood for the tree. Under most circumstances, prevailing business practices are not properly defined and no as is" flow charts, documenting existing processes, are available.

An ERP implementation could be a great occasion to assess and optimize existing business processes, control points, breaking points between departments, and interfaces with trading partners. But, often, due to resistance to changes and departmental clouts, ERP implementation is comprehended as an exercise to automate legacy processes. This may lead to little improvement in underlying business processes, resulting in no appreciable return on investment.

Automating existing manual processes peculiar to a company necessitates, significant source code customization, as even a best fit ERP product match to a maximum of 85% to 90% of legacy processes. Source code customization will not only require changing of software objects but also need changing data models. The efforts needed to make such changes are significant in terms of development, testing and documentation. The future cost of maintenance and upgradation will be substantial, affecting entire life cycle of the system.

Unless a considered view favoring process changes is taken as a part of implementation strategy, pressure will mount subsequently for more and more customization, when the exercise of Business Process Mapping and Gap Analysis is taken up during implementation.

ERP systems are highly configurable and contain series of design trade off to meet various nuances of the same business cycles/processes. This should, normally, be sufficed to cover needed processes, probably with a little bit of swapping whenever needed. At occasions, it may be imperative to change source code to account for some unique core processes of the organizations. Procedure for authorization of such changes, normally requiring attention from sponsor, should also form part of the strategy document.

Implementation Methodology: Selection of implementation methodology constitutes an important component of implementation strategy. Most popular implementation methodology is "big bang" approach where on a scheduled cut-off date; entire system is installed throughout the organization. All users move to the new system and manual/legacy systems are discontinued. The implementation is swift and price tag is lesser than a phased implementation. On the flip side, risk element is much higher and resources for training, testing and hand holding are needed at a much higher level, albeit for a shorter period of time.

Another major implementation strategy is "phased implementation", where roll out is done over a period. This method is less focused, prolonged and necessitates maintenance of legacy system over a period of time. But, phased implementation is less risky, provides time for user's acquaintance and fall back scenarios are less complicated. There are various choice of phasing such as (i) phased roll out by locations for a multi location company (ii) phased roll out by business unit e.g. human resources (iii) Phased roll out by module e.g. general ledger.

Methodology of implementation should form an important constituent of implementation strategy, which should be formulated after considering availability of resources, state of preparedness, risk perception, timeframe of implementation and budgetary provisions.

Other important strategy issues:

- Legacy data: Gathering, cleaning and removing of duplicate data.
- Hardware and software: Addition and updating of existing resources. Compatibility with existing Operating system and Database.
- Project structure: Project champions and competency centre.

Evaluation and selection of ERP Packages:

Evaluation and selection of ERP package is an essential criterion for successful ERP implementation. Quality of selection will have a long term impact on the processes of the organization. It is also not easy to switch to another product with concomitant scale of investment and complexities. This evaluation and selection process should be properly directed and normally comprises of following activities:

Formation of an evaluation committee: An ERP implementation is not an IT project but a business oriented development. Therefore, in addition to Chief Information Officer, this committee should comprise of all functional heads and driven by a top management representative. Since all business functions are represented in selection process, the chosen package would have wide acceptance subsequently.

Requirement Analysis: This analysis should outline functional expectations of various business divisions, such as warehouse, finance, procurement, from potential ERP package. Vital requirements specific to the company should be highlighted e.g.

- Must have Distribution Requirement Planning (DRP) functionality.
- In transit inventory and pallet tracking, as a part of shipping requirement.
- Multiple purchase orders linked to one bill of lading.
- Multi currency and multi locations functionality.

Requirement analysis forms a base for preparing a Request for Proposal (RFP), where important technical and commercial perquisites are incorporated. Common examples of technical perquisites: flexibility, Upgradability, User friendliness, field level security, Operating system and database compatibility. Common examples of commercial perquisites: cost, reference sites, high level project plan, resumes of consultants, post implementation support, financial health of the company, local presence, number of installation and upgrade.

Selection Criteria: A pre-determined selection criteria should be ready before actual selection process commences. Selection criteria are normally in the form of questionnaire and point system, where each question represents a business or technical need. Weightage for each point or a group of points are predetermined which varies according to criticality of the issue. These processes help in making the selection process objective and transparent.

Selection Process: Selection process constitutes various stages as mentioned below:

1. **Short listing of vendors:** Hundreds of ERP packages are available in the market, which have different concept, architecture and sets of functionalities. Analyzing all the packages is not feasible. Organization need to identify a few best suited packages by looking at product literatures of vendor, finding out which product is being used by their peer organizations and getting help from external consultants. Once a few packages are short listed, respective vendors should be asked to respond to the RFP, as per its format.

2. **Demo and Presentation:** Responses from shortlisted vendors are evaluated by the selection committee after collating scores obtained by them and a consensus is reached about their final ranking. Anyone not fulfilling a predetermined vital requirement is eliminated at this stage. Top two or three vendors, are then invited for demo and presentation. Mode of presentation should be carefully scripted and send to the vendors in advance. They should be asked to walkthrough a particular business cycle through their vanilla software. They should be specifically asked to clarify any area of concern about their proposal, which may expose weak/ problem area of their offer.

3. **Site visit and contract negotiations:** After the committee has reached a decision on best suited package, visits to reference sites are imperative. The vendor should provide reference sites of similar size and industry, identical version and belonging to same geographical location. Team members should have look and feel of the systems operating at reference sites and ask pertinent questions covering overall satisfaction, functionality, cost/ time over run, support concerns etc. After site visit, if the committee members feel that their selection is right, they proceed with final negotiation and procurement. Negotiations are normally held on license and annual maintenance cost, payment plan including a leasing option, support issues and other commercial and legal terms.

ERP Implementation - Do's and Dont's

ERP systems are complex, time consuming and expensive. Instances of failure of ERP projects abound including some high ticket failures such as Hershey, (largest chocolate maker of USA), where a SAP implementation was abandoned after three years. There are various "Do's" and "Dont's" effecting success or failures of an ERP implementation. Some of critical success factors, needing focused initiative, are appended below:

- **Commitment from project sponsor:** Project sponsors normally belong to top echelon of the organization. A deep commitment and active involvement is needed from them and bare monitoring and oversight may not suffice. Their vigorous engagement should get other executives in board. One of their important roles will be to resolve any inter departmental conflict which is bound to occur during the course of implementation. They should also ensure that most knowledgeable executives are engaged in the project and released from routine functions whenever needed.

- **Commitment of resources:** An ERP project needs a significant financial commitment and budgetary support. Expenditure involves not only direct expenditure relating to ERP package but a host of indirect cost such as integration with other software, gathering and cleaning of input data, archiving data from legacy system, engaging expert/consultant, additional support need, provision for contingency etc.

- **Selection of package and consultant:** The selection of ERP package should be absolutely need based, as detailed on business requirement analysis, done beforehand. Selection should not be influenced by extraneous factors such as glamour involved in the name of big ERP packages. Selection of a consultant, who will provide advice independent of the interest of vendor and guide the entire process of implementation, should be done carefully and with due diligence. The consultant should be truthfully independent and should not be linked to a particular ERP vendor. This is also applicable to consultants from big named consulting firms as they may have tendency to recommend a complex product, requiring added consulting effort during implementation process.

- **Project Management:** An empowered project manager, supported by IT and functional experts and appropriate project management methodology, is key to success of ERP implementation. Setting up of project team, resource allocation, milestones and deliverables etc. form important part of project management. Tailor made training programme for different type of users and a predefined change management process, are also crucial.
- **Legacy Data:** Legacy data are stored manually, in excel files or in legacy system. Collection of legacy data is needed to be planned carefully to avoid the syndrome known as "garbage in and garbage out" which will undermine the confidence on the system after implementation. Cleaning of data should be done by removing duplicate and unnecessary information, before importing to ERP system.

Critical failure factors: Critical factors for failure may be defined as contrary to critical success factors. Some specific concerns of failures are mentioned below:

- **Creeping in of additional functionality:** Pressure often mounts for additional functionalities not envisaged earlier during implementation. This may lead to conflict with ERP vendor. Dealing through change management process also involves additional cost and time and should be avoided as far as possible.
- **Unrealistic expectations:** ERP system is not an all cure silver bullet. Users often like to see an immediate improvement after installation. There are bound to be initial period of frustration which may snowball, undermining confidence on the system.
- **Information overload:** An ERP system contains hundreds of reports and queries. Too much information creates a lot of confusion amongst users. Notwithstanding information overload, many a time, users feel cheated as the system fail to generate identical reports to which they are accustomed.
- **Resistance to Change:** Users are overwhelmed by all the new features of the system. Some of the aged employees may be unwilling to adopt a new way of working. Some may be uncomfortable with the awareness that their supervisor will now keep a better trail on what they are doing.

Environment of ERP Implementation

Any ERP implementation attracts expenditure on account of Operating System (OS) and Relational Database Management (RDBMS) for hosting the system. Networking issues also assumes importance particularly when the system is rolled out at different locations. Additionally, licensing options associated with ERP packages need to be carefully evaluated during final contract negotiation.

Operating System and Database

Unless a system is implemented from scratch, it may be a better option to integrate the chosen ERP system with existing OS and RDBMS of the organization, which will reduce upfront expenditure of implementation. Therefore, the important consideration is that whether the preferred ERP system is compatible with current hosting platform.

Another important consideration is how robust and scalable is existing platform. Most popular players of RDBMS market are Oracle, IBM, Microsoft and Sybase, constituting about 90% of market share. In the OS sector (for mainframe and server segment), there are offering of various flavors of UNIX (IBM, HP, Solaris etc), propriety OS from IBM and Microsoft windows (Linux OS is also used to run some open source ERP package like Compiere but yet to be popular for commercial applications).

The chosen ERP package should conform to one of the popular OS and RDBMS. If the existing platform of OS and RDBMS does not belong to mainstream offering, it may be prudent to explore an alternative.

Off course, there may be exceptions, such as an organization selecting QAD solution, may consider use of “Progress” RDBMS with which this package is most compatible.

Another important factor relating to ERP platform is whether the ERP system to be hosted in house or hosted remotely. If hosted remotely, all upfront cost relating to hardware, OS and RDBMS are eliminated. The vendor may then charge an additional hosting cost periodically.

Networking Issues

Important networking issues relating to ERP implementation are network topology, detailed networking design, networking printers etc. Setting up new or leveraging existing Local Area Networking (LAN) and Wide Area Networking (WAN), constitute an important part of pre implementation/ implementation process. This includes cabling to planned workstations, laying fiber optic backbone, provision for sufficient bandwidth to remote sites (particularly hosting distributed application/database). Mode of sharing networked printers in various functional divisions such as warehouses, accounting offices and sales units need to be planned beforehand.

Licensing Issues for ERP products

Implementation of an ERP package necessitates entering into a software license and support agreement with vendor. This agreement constitutes a complex legal document containing details of license and maintenance fee and formula for escalation thereof. Before finalization of this contract, following issues should be given due consideration:

- If the licensing agreement covers only the core ERP products or contain additional business software like report writer, interfaces and middleware.
- What are the user type definitions? User type may be a (i) power user with full access to development tools, (ii) Informational user meant for management with access to dashboards, MIS and approving role of a workflow. (iii) Normal user with transactional roles and limited access.
- There are other user categorizations like named users, where a license is needed for each user of the system and concurrent users indicating maximum number of users with right to access the system simultaneously.
- It is, imperative that a proper assessment is made for types of licenses to be procured as license fee varies for type of users. Price should be negotiated before entering into the agreement when the vendors may be willing to offer significant discount over their list prices.
- It is also important to decide when to buy the licenses. Agreement may be made to procure only a few licenses at the commencement of project, for training, development and testing and rest during go live. It is also important to secure fees for additional licenses that may be procured during next couple of years.

Change and Risk Managment

An ERP system is a process and not an end in itself. Perfunctory Implementing of ERP system will not boost efficiency. Reasons for failure of an ERP project such as lack of commitment from management and employees, lack of communication, knowledgeable employees not available for the project, are mostly organizational issues and have nothing to do with technical matter. Hence, to alleviate the risk of failure due to organizational issues, adoption of proper change and risk management process, plays a crucial role.

Change/Risk management

Implementation of ERP necessitates a broad based organizational change which is more disruptive than incremental. Change management effectively deals with the process of managing such changes, and broadly encompasses all major segment of the organization such as:

- People-Employees education and competence.

- Organization- Organizational structure, Business functions and processes
- System-Information planning, Hardware and Software.

Tangible and Intangibles benefits of ERP

Some of the quantifiable and tangible benefits of ERP system are mentioned below: Implementation of ERP, however, does not lead to headcount reduction (redundancies of few lower ended positions of payroll and accounts payable gets counterbalanced by additional higher paid IT staff).

1. Reduced level of inventory, including raw material, work in progress and finished goods, through improved planning and control.
2. Reduced materials cost through improved procurement and accounts payable practices, less obsolescence and wastage.
3. Reduced labor cost through better allocation and reduction of overtime of workmen directly involved with production such as technicians and skilled workers.
4. Improved production throughput through better scheduling of critical equipment and sub contracting operations, there by minimizing shortages, interruption and rework.
5. Reduction in the cost of after sales services.

In addition to tangible benefits, following intangible benefits also occur:

1. Integration of information resulting efficiency, transparency and effective MIS.
2. Error reduction, accuracy of inventory record.
3. Improved customer service, on time shipment, shorter order to shipment cycle.
4. Establishment of standardized procedures.
5. Improved accounting control and shorter sales to cash cycle.
6. Legal and regulatory compliance.

Configuration Control and Setting Up of Base in ERP System

What is configuration?

Configuration of an ERP system deals with handling of numerous usage controls, which can be switched off or switched on, so as to balance its functionalities to extant needs. First thing to happen is to install specific modules needed and configuring these modules, as per the scope of the project. Thousands of configuration tables are present, which define how the system should operate, how the data entry screen will look like, how the signals and massages will appear etc.

The above process is extremely complex, particularly for tier 1 vendors like SAP and Oracle. To alleviate this complexity, ERP vendors are creating pre configured modules suitable for a particular business vertical. ERP vendors are also developing automated pre configuration tools such as Orgware from BaaN. SAP has also brought out “Accelerated SAP Solution” containing industry specific templates which can be tweaked for an individual company.

General Mode of Configuration:

1. A function can be turned on or turned off or made optional.
2. XOR i.e.to chooses only one flow that fulfills the specified condition.
3. OR where a configuration supports optional activities or flow requiring all, none or some of the activities.
4. AND - indicate mandatory parallel flows.

Some configuration choices are irreversible e.g. if "negative inventory allowed" option is chosen, it can not be reversed at a latter stage. Some configurations are reversible e.g. purchase order quantity may exceed blanket order quantity or not. In some case if a specific choice is not made, configurable function can be switched on or off by default.

Setting up of basic system: Some important activities related to setting up of base system, having impact on all modules, are given below:

1. **Creation of a company:** This is basically to create a data base. A number of data bases can be created of which one may be for actual transactions where as the others may be for used for testing and training. A Company may different hierarchies such as single logistics / single finance, multi logistics /single finance, multi logistics / multi finance etc.
2. **Setting up of currency:** Currencies need to be configured as (i) base currency which is the legal currency of the country where the organization is operating (ii) Alternate reporting currencies, (iii) transaction currencies used for transaction with vendors and customers who may be spread over a number of countries.
3. **Setting up of calendar and periods:** Calendars are used to record information on the availability of resources. Periods are time intervals that can be utilized for statistical, financial, planning and cost control purpose.
4. **Units of Measure:** Base units of length, surface area, weight, time and their conversation factors for transactional purpose.
5. **Integration between finance and logistic:** Setting up of inter company relations, mode of updating finance tables either in real time or in batch mode, mode of inventory valuation such as LIFO, FIFO, Standard Costing or Weighted Average, treatment of finalized and non finalized transactions on financial ledger etc.
6. **Defining number group, series type and series length:** To be used as ID of a unique transaction like purchase orders, sales order, production order etc.
7. **Defining Countries:** Customers and vendors are located in various countries for which country code need to be defined. This is very important due to necessity of tax calculation and reporting.
8. **Assigning Tax codes:** Needed to be defined for sales, purchase, service, project transactions.

Master Data Management of an ERP System:

ERP packages contain several modules, such as finance, sales and distribution, materials management, manufacturing and production control, human resources, plant maintenance and quality management. Main characteristics of ERP system is that all its modules function in an integrated manner. Due to integrated nature of functioning, a few master tables are referenced frequently all across the system and databases, and shared by different applications, functional areas and sites. Data incorporated thereon need to be accurate, complete, timely and consistent. The quality of data as inputted in master tables, is a major reason for success or otherwise of an ERP system.

Collection and maintainance of master data

1. Clear cut process and procedure for maintenance of master data.
2. Ownership of data is properly defined.
3. In built workflow and authorization for adding and modifying data.
4. Documentation of the process.
5. Audit trails of master tables are activated and modifications are logged in the system.
6. Proper excel templates or data mapping with legacy system, for initial collection of data.

Classification of Master data

Collection of master data may be broadly classified under the following categories.

1. **Business Partner Master Data:**
   a. Customer role-Delivery, shipment, invoicing, payment method, parent company of customer, country location (for tax and statistical purpose), status (active, inactive, potential), credit rating, financial groups, contact name and address, default currency, prices and discount, sales channel, sales office.
   b. Supplier Role-Receiving, transport, payment term, prices and discount, invoicing method, country location (for tax and statistical purpose), status (active, inactive, potential etc.), financial groups, contact name and address, default currency, purchase office.
2. **Item Base Data:**
   a. Product category- whether purchase, manufacture, service or cost item with specialized management separately for each category.
   b. Measurement unit and alternate unit for the item with conversation factor.
   c. Item ordering system (manual, SIC or MRP), reordering factors (service level, safety stock, ordering interval, minimum ordering quantity, forecasting mode, seasonal pattern etc)
   d. Item costing data (cost component, surcharges, standard cost, transfer cost etc.), automatic process for generation of cost.
   e. Status of the item (running or obsolete), alternate and reversible item, list item (with user defined components).
   f. Rates-applicable price, price limit, rules for applying prices to purchasing and sales.
   g. Adding up segments to item code, such as project segment that assigns the item to a project, cluster segment used for planning and distribution.
   h. Vendors by item, freight categories and transportation services.
3. **Employee base data:** Name, ID, personal details, service centre, service point, skill, hourly rate, overtime rate etc.
4. **Finance Master Data:** In addition to master data requirement for specific financial modules such as general ledger, accounts payable, accounts receivable, cash management, budgeting etc. following finance master data are having impact across non financial modules:
   a. Basic finance parameters for the parent organization and individual company.
   b. Chart of accounts, periods, dimensions and transaction type.
   c. Integration parameter and mapping accounts for logistical transactions (originating from sales, procurement, manufacturing, service, subcontracting).
   d. Integration parameter and mapping accounts for warehouse orders such as inventory adjustment, inventory revaluation and warehouse transfers.

It may be reiterated that the above list is not exhaustive. The process and terminology used for maintaining master data in different packages, also differ.

ERP - General Ledger and Accounting Management

Financial accounting module of an ERP package provides company wide control and integration of financial information. This module provides the ability to centrally track financial accounting data within a framework of multiple companies, languages and currencies.

The General Ledger (GL) module is the heart of finance package of an ERP system. Through integration with logistics, business processes as well as with accounting sub ledgers of other finance modules such as accounts payable, accounts receivable, cash management, GL provides a central pool of accounting data required for finance reporting (including statutory reports) and other purpose. One of the important functions of GL is to real time update of sub ledger, thus eliminating the time consuming reconciliation. GL also provides summarized data for use in planning, control and reporting.

The important components of GL are:

1. GL master data set up.
2. GL integration set up with logistics modules.
3. Period and year closing.

Integration with other modules: Some of the modules, integrated with GL are:

1. Accounts payable for purchase invoices, credit notes.
2. Accounts receivable for sales invoice, credit notes and adjustment.
3. Cash management wherefrom payment details are transferred to GL.
4. Asset management for transferring depreciation details.
5. Cost accounting for allocation of cost.

GL master data set up: One of the important processes of GL is setting up Chart of Accounts, which is a complete structure of ledger accounts used by the organization. Chart of Accounts can be flexibly structured both at a parent and individual company level. Chart of Account may also be defined separately for statutory purpose as well as well as for the purpose of reporting to management. In some packages, the concept of dimension is used which gives a vertical view on ledger account. Another important parameter of GL is transaction type which identifies different categories of transactions such as journal voucher, sales invoice, cash, and corrections. Other important parameters of GL are (i) parent company and company parameters (this will contain accounts for profit and loss, currency fluctuations etc. (ii) Periods (Fiscal and Tax), (iii) Tax code by countries.

GL integration set up with logistics modules: Integration mapping scheme needs to be defined for posting of logistics transactions into finance. Examples of logistics transactions (for different transaction origins) that result in a corresponding financial transaction and for which corresponding Chart of Accounts are needed to be defined, are given below:

1. **Purchases -** (i) Making and releasing of a purchase order (ii) receiving materials against the purchase order (iii) inspection and approvals of the received materials (iv) registration of the supplier invoice in logistics.
2. **Sales -** (i) Making of a sale order (ii) releasing of the same to warehousing (iii) issuing material against the resultant warehouse order (iv) release the issue order to invoicing.
3. **Inter Depot Transfers -** (i) Making of an inter-depot transfer manually or transfer the same from planning (ii) issue materials from the issuing warehouse (iii) receiving materials in the receiving warehouse.
4. **Issues for subcontract orders -** (i) Making of a production order (ii) making subcontract purchase order based on the production order (iii) initiate inventory issue to the subcontractor, (iv) issue of inventory (v) receive subcontracted item, (vi) completion the production order (vii) closing the production order.
5. **Cycle Counting -** (i) Generate cycle count orders (ii) approve cycle count orders (iii) process cycle count orders.

Period and Year Closing: If a period or year is past its end date, it needed to be closed and the result is to be posted in next period/ year. Before closing any period it is necessary to check the status of the period. Next, auditing, reconciliation, passing of final correction entries and rebuilding of ledger history is carried out.

In the last part of this process, closing of the periods, final closing of the periods and closing the year end and archiving of data is done.

ERP - Accounts Payable and Receivable

Accounts payable and Accounts receivable modules are two important execution modules under finance segment of an ERP system. Financial relationship with vendors who are providing input to the organization in the form of goods and services are maintained in Accounts Payable (AP) module. On the flip side, the financial connection with customers who use output of the organization, are dealt through Accounts Receivable (AR) module. Both these modules maintain personal accounts either of debtors or creditors and maintain various sub ledgers such as control account, currency fluctuation accounts etc. as an integral part of General Ledger (GL).

Accounts Payable Module (AP) - This module provides the functionality to enter, monitor, maintain and process for payment of invoices and credit notes, that the organization received from its vendors. The key functionality of this module is as follows:

1. Immediate registration of incoming invoices
2. Tracking & authorization of incoming invoices
3. Entry of order-based and sundry invoices
4. Automatic matching of invoices with receipts
5. Separate procedure for approval of invoices that exceeded the user tolerances
6. Self-Billing Invoices this is suitable for JIT environment where receipt of goods automatically generates approved invoices in the system which is paid through remittances and supplier need not send any invoice.
7. Accounts Classification for reconciliation

Master data set up of AP: The initial set up of AP module is critical for its proper functioning, where following parameters are needed to be defined:

1. Blocking codes for blocking an invoice, Aging Analysis periods for outstanding invoices of vendors, tolerated price difference limit for approving invoices (by users and vendors), whether matching with receipt is manual or automatic.
2. Linking ACP with GL through a schedule of Chart of Accounts to which various transactions originating from AP are posted. Some of these accounts are (i) control accounts (ii) anticipated payment (iii) invoice accrual (iv) price difference and (v) payment difference.

Automatic Matching of Invoices: This is an important functionality of AP module, through which invoices from vendors are automatically matched with purchase orders and receipt.

Accounts Receivable Module (AR) - This module helps in tracking all the invoices that is awaiting payment from customers. The key functionalities of AR are:

1. Accounts classification for reconciliation & control.
2. On-line credit management.
3. Reminder letters with varying degrees of severity.
4. Aging Analysis reports for review.
5. Interest for late payments.
6. Customer statements.

AR Master Data set up

1. Defining chart of accounts for linking to GL such as (i) control account (ii) discount account (iii) advance receipts (iv) unallocated receipts.
2. Terms of Payment parameters such as (i) credit period (ii) cash discount (iii) payment days (iv) tolerance for discount.
3. Free definable problem types to exclude invoices from reminding and direct debits
4. Flexible periods for Aging Analysis.
5. Currency / Payment Differences.
6. Default Data - for Tax Calculation Level.

Credit Control: An important feature of this module is to monitor invoices overdue for payment and generate reminder letters for sending to customers. In case the invoice is still not paid, increasingly urgent reminders are generated in the system subsequently at a predefined interval. The system also maintains a credit diary, which contains details of all unpaid invoices whether due for payment or not.

Asset Management and Budgetary Control

One of the major financial functions is the management of fixed assets. Asset management module primarily maintains asset register, which provides information about asset related transactions. Asset Management thus helps in keeping track of fixed assets, handling fixed asset depreciation for fiscal reporting and revaluation of asset. Budgetary Control (BC) module is another important finance module which helps in planning and comparison of actual results with budgeted amount and quantity. This module helps business units to calculate business target, budget release as well as provide extensive analytic tools for budget monitoring.

Asset Management - Some of the important functionalities are:

1. Investment and disposal method.
2. Users' defined depreciation method.
3. Periodic revaluation of fixed assets.
4. Business and insurance information.

This module is linked to general ledger to post depreciation result as well as to accounts payable and accounts receivable for buying and disposing assets. A few important master data parameters for Asset Management are:

1. Defining of a schedule of Chart of Account which is needed for linking to general ledger.
2. Depreciation method.
3. Remainder value or percentage.

- **Investment and Disposal Method:** This procedure is applicable when a new asset is acquired by the organization. While payment is made through accounts payable for asset acquisition, an investment transaction is generated, and the result is posted to general ledger. The asset is registered in asset management and is linked to a depreciation method. The asset is then ready for periodic depreciation and revaluation. Similarly, when an asset is sold/discarded, a disposal transaction is created in this module which generates a sales invoice in accounts receivable and post relevant transactions in general ledger.
- **Users' Defined Depreciation Method:** This functionality provides a flexible way of maintaining depreciation cost. The system allows a depreciation method which determines how the system calculate depreciation such as by a fixed amount, by a percentage of purchase price/ book value or an amount on the basis of number of years in operation. The system also allows accounting for

remainder value. The depreciation method may be applicable globally for the entire organization or specific for one or more groups of assets.

- **Periodic Revaluation of Fixed Asset:** This functionality enables periodic revaluation, which is a positive correction of book value of the asset, to account for market price changes. Revaluation of asset is linked to some user defined indices which are integrated in the system. Revaluation amount is, normally, calculated by the system during fiscal year closing and result is posted as year end transaction in general ledger.
- **Business and Insurance Information:** Under this functionality, additional information regarding fixed assets which are non-financial in nature, are stored in a users' defined manner. Information is stored after classifying assets under various groups and sub groups. Details of insurance policies are also maintained and are linked to fixed assets.
- **Budgetary Control Module:** This functionality enables registering, handling and monitoring of budget amount by ledger accounts. This functionality also helps in preparing performance budget for reference units (such as fuel consumption for vehicles), in addition to price based financial budget. Budget amounts and quantities are planned over the year and broken down into period values. It is also possible to set up a flexible budget by distinguishing between fixed and variable budget.

Steps for Preparation of Budget

1. Setting up of master data such as defining budget codes, periods of budget.
2. Defining reference units (by amount or quantity) and budget method such as bottom up or top down approach.
3. Generation of budget distribution data and maintaining budget amounts over the year/ period.
4. Printing budget amount and trial balance.

Encumbrance Budgetary Control: This functionality, which enables recording of pre expenditure in the form of commitment, is important particularly for government/ public sector, where budgetary control is a statutory requirement. The system creates encumbrances from a requisition, purchase order or a work order, where related amount is needed to be paid in near future. The committed amount is automatically blocked and is not available for other transactions. When the payment is finally made, the encumbrance is relieved, after the account is debited with paid amount.

Cost Estimate and Accounting in ERP

The costing module is one of the important controlling modules which enables effective internal cost control and accounting. All functionalities regarding cost analysis and cost allocations are provided by this module. The cost accounting module is highly integrated with budget and general ledger modules as well as draws input and provides output to various logistics modules such as sales, procurement, warehousing, shop floor and bill of materials.

Cost Accounting module: Cost accounting module consists of following functionalities:

1. Overhead Cost controlling.
2. Cost price calculation.
3. Hours accounting.
4. Activity based costing.

Overhead Cost controlling: Overhead cost, which is an indirect cost, can not be directly assigned to the products manufactured or services rendered. Sometime, overhead cost is a significant percentage of overall cost. This functionality helps in defining allocation relations in the form of surcharge/rate applicable to various cost centers which in turn is comparable to budgeted surcharge/rates. The overhead cost control thus helps to monitor and allocate of indirect cost.

Cost Price Calculation: Under cost price calculation functionality, simulation (such as to make or subcontract), and calculation of price for standard and customized items are performed. This functionality is crucial in determining the lowest price limit for which a product is profitable. The cost price for standard item is calculated based on the following:

1. Material cost: Which may be latest procurement price or simulated purchase price.
2. Operation cost which may consist of labor and machining cost.
3. Subcontracting rate.
4. Surcharges for coverage of overhead such as management cost / inspection cost.

For calculation of cost price for customized items, project specific rates and surcharges are applicable. Cost price calculation also forms basis of calculation of valuation price (where a surcharge is added such as warehouse transfer surcharge) which in turn is used for internal financial transactions such as inventory transfer, Work in progress inventory. Sales price or suggested retail price where a sales price surcharge is added to cost price is also derived from this functionality.

Hours Accounting: This functionality is used to account for employees and machine cost and charge these costs to appropriate production orders. Hours spent can either be entered directly or the system can automatically back flush an estimated hour, on completion of an operation. When hours are posted, financial transactions are created in general ledger. Hours accounting is normally done through a working timetable and normal and overtime rates can be defined in the system. It is also possible to enter estimated / budgeted number of working hour for an employee or a work centre for a particular period (such as month / year) and compare the estimated / budgeted hours with actual hours.

Activity Based Costing: This is an extension of traditional system of distribution of overhead allocation, where only a few allocation bases are used. This functionality helps in controlling cost objects (which may be anything like products, services, projects, distribution channel) with their cost drivers, through a bill of activities and activity results. Thus, this functionality determines the consumption of business process by products, customers and other cost objects based on the cost drivers and helps in monitoring and controlling cross departmental business process.

Cash Management Module in ERP

Cash management module provides information relating to cash flow of the organization, by processing and analysing all cash and bank transactions, arising out of payment of supplier's invoices, receipt from sales invoices, stand alone payment and unallocated payment/receipts.

Cash management module also allows analysing financial transactions for a given period of time and provides information regarding sources of fund and use of fund to ensure liquidity in order to meet payment obligations of the organization.

Integration with other modules

1. Accounts payable where from processed purchase invoices are received.
2. Accounts receivable wherefrom processed sales invoices are received.
3. General Ledger where transactions processed within this module are posted.

Maintaining Master Data: Some of the master data parameters for cash management modules are

1. **Maintain payment / receipt method:** This will determine how payments/receipts are processed, for which following parameters are needed to be defined:
    a. Whether automatic (where invoices or receipts are selected automatically depending upon payment term) or manual Payment/Receipt.
    b. Maximum Amount per Business Partner in a single payment batch.
    c. Bank Account/Bank Address for making/receiving payments.

d. Output option-whether paper (cheque) or file (Direct debit).

e. Composing Options - Where receipt/payment are processed individually (remittance) or combined for a number of invoices.

2. **The bank relations:** Where details of currency (home currency/foreign payment), type of bank, whether blocked for payment or receipt, default priority etc. are maintained.

3. **Linking to General Ledger** - Defining of several chart of accounts related to posting of various stages of transactions processing within cash management to General Ledger, such as anticipated payment, anticipated receipts, cheque issued not realized.

4. **Payment authorization** - Maximum amount a user can pay to a supplier or if the user is authorized to make advance payment.

Functionality of Cash Management module

1. **Supplier Payment** - The standard procedure for supplier's payment is given below. However a variation of this process is followed for payment relating to standing order (where payments are made without an invoice), payment against proforma invoices, stand alone payment etc.

   a. Select and compose invoices for payment

   b. Print payment advice list

   c. Modify payment advice

   d. Reconcile amount as per payment advice and invoice

   e. Assign bank

   f. Print cheque or post bank orders in an electronic file.

   g. Post cash transactions to general ledger

2. Receipt of sales invoice amount:

   a. By Cheque:

      i. Cheque received from customer (anticipated receipt).

      ii. Cheque sent to bank (cheque anticipated status).

      iii. Cheque paid by bank (bank relation-reconciliation).

   b. Direct debit: Applicable for customers who have authorized the organization to directly debit their bank accounts.

      i. Select Invoices for Direct Debits

      ii. Direct Debit Advice

      iii. Compose Direct Debits

      iv. Assign Banks to Direct Debits

      v. Audit Direct Debits

      vi. Create Direct Debit Orders

      vii. Print Remittance Letters

      viii. Post Direct Debits into General Ledger.

3. **Cash flow Forecast**: This functionality provides an insight of the projected liquidity position of the organization at a certain point in the future. While forecasting cash flow the system uses available data regarding (i)purchase orders and purchase invoices, (ii) sales quotation, sales order and sales invoices (iii) standing orders and (iv) financial budgets.

8.2 INVENTORY MANAGEMENT IN SAP-ERP

Introduction

Inventory Management is a component of Materials Management and is fully integrated with the entire logistics system. The basic purpose of Inventory Management in any business enterprise is:

- Management of material stock on quantity and value basis (stock may be inputs like Raw Materials, Stores& Spares , In-Process material , Finished goods , Scraps etc.)
- Planning, Entry & Documentation of all Goods Movements
- Physical Inventory (Stock Verification)

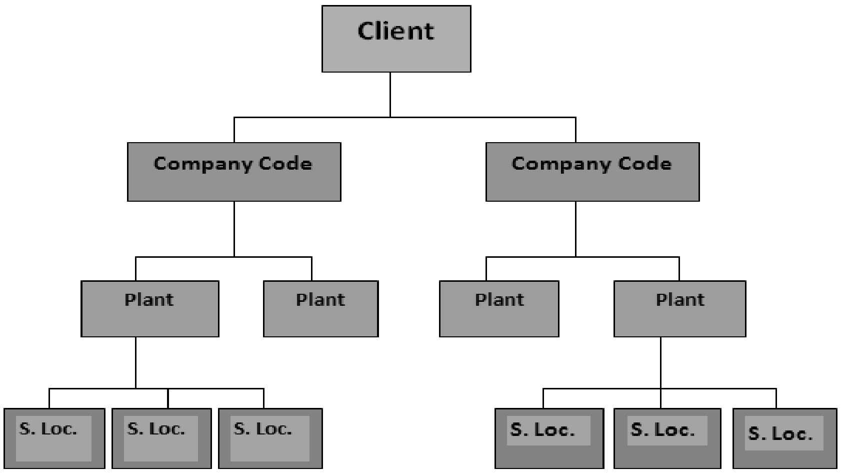
It is directly linked with Material Requirement Planning (MRP) which may be automatic or manual, Purchasing and Invoice Verification. It is also closely linked with Production Planning, Sales & Distribution, Quality Management and Plant Maintenance.

Features of Inventory Management in SAP:

- Entry of goods movements (receipt, issue, transfer posting etc.) are on real time basis. Goods movements include both "external" movements (e.g. goods receipts from external procurement, goods issues for sales orders) and "internal" movements (e.g. goods receipts from production, withdrawals of material for internal purposes, stock transfers, and transfer postings)
- Creation of a document for every goods movement
- Automatic updating of quantity & value for inventory management and creation of accounting documents (Cost Accounting and Financial Accounting).
- Division of the stocks into different categories (such as Unrestricted-use stock, stock in quality inspection or blocked stock)
- Batch management
- Management of special stocks (e.g. Vendor consignments, material provided to vendor etc.)
- Physical Inventory (Stock verification)
- Various analyses (such as the stock overview, Age Analysis etc.)

Organisation Structure in SAP:

The Organisation structure (a new concept) for a Business Organisation in Inventory Management consists of four levels viz Client, Company Code, Plant & Storage Location as explained below:



- **Client**: It is the highest hierarchical level in SAP. From business perspective, the client refers to a Corporate Group. All areas of an organisation that are to be integrated into SAP should be included under one Client. There is a common set of tables, database, master data (Material no. and description, Vendor number and name, Customer, General ledger number and description etc.) across the Client.
- **Company Code**: It is the smallest organisational unit having independent financial accounting records. Balance Sheet and Profit & Loss Statement as required by law are created at Company Code level.
- **Plant**: It is a logistic organisational unit that divides the enterprise from the perspective of production, material planning, procurement and maintenance. It can be an operating unit concerned with production and planning or even a combination of locations with material stocks.
- **Storage Location (S.Loc.)**: It is the organisational unit which allows the differentiation of material stocks within a plant. It is an amalgamation of all storage bins in a Plant that are managed together. Inventory management at quantity basis is carried out at Storage location level in a plant. A storage location can't exist without a plant.

Goods Movement:

Any transaction resulting in a change in stock is defined as Goods Movement.

When we post a goods movement in SAP, the following chain of events starts in the system:

- A material document is generated, which is used as proof of the movement and as a source of information for any other applications involved.
- If the movement is relevant for Financial Accounting, one or more accounting documents are generated. The stock quantities of the material are updated.
- The stock values in the material master record are updated, as are the Stock and Consumption accounts.
- All updates are based on the information contained in the material document and the financial accounting document. For example, in the case of a goods issue for a cost centre, the consumption values of the items are also updated.

The categories of Goods Movement are listed below:

Goods receipt

A goods receipt (GR) is a goods movement with which the receipt of goods from a vendor or from production is posted. A goods receipt leads to an increase in warehouse stock.

Goods issue

A goods issue (GI) is a goods movement with which a material withdrawal or material issue, a material consumption, or a shipment of goods to a customer is posted. A goods issue leads to a reduction in warehouse stock.

Stock transfer

A stock transfer is the removal of material from one storage location and its transfer to another storage location. Stock transfers can occur either within the same plant or between two plants.

Transfer posting

A transfer posting is a general term for stock transfers and changes in stock type or stock category of a material. It is irrelevant whether the posting occurs in conjunction with a physical movement or not. Examples of transfer postings are:

- Transfer postings from material to material

- Transfer from quality inspection stock to Unrestricted stock
- Transfer of consignment material into company's own stock

Movement Types:

A movement type is a three-digit identification key for a goods movement to differentiate between the various goods movements. The movement type has important control functions in Inventory Management.

Some of the commonly used movement types have been elaborated below:

- 101: Goods Receipt (GR). With this movement stock gets updated and accounting documents generated.
- 103: Goods Receipt into GR Blocked Stock . It may be noted that in this case GR itself is blocked. With this movement stock update or creation of accounting document do not take place. Wherever inspection is to be carried out after receipt of material, inspection lots get generated simultaneously with posting of 103 document. Posting of 103 document is at Plant level and not at any Storage Location level.
- 105: Goods Receipt from GR Blocked stock. This goods movement takes place always with reference to a 103 document. After posting of 105 GR (which is release of blocked GR) , Stock gets updated and Accounting documents gets generated.
- 124: Return of material to vendor from GR Blocked stock. Subsequent to creation of 103GR, if a material gets rejected, this document gets generated.
- 201: Consumption to Cost Centre. With this transaction, material gets consumed immediately on posting and the cost is charged to Cost Centre.
- 261: Consumption of materials against Maintenance/Production Order.
- 301: Plant to Plant Stock Transfer.
- 309: Transfer Posting from Material to Material.
- 311: Stock Transfer Storage Location to Storage Location in a Plant.
- 321: Transfer Posting from Quality Stock to Unrestricted stock.
- 343: Transfer posting from Blocked Stock to Unrestricted stock.
- 561: Initial entry of stock balance.
- 601: Goods issue against Sale Order.
- 701: Physical Stock Reconciliation of Excess Stock.
- 702: Physical Stock Reconciliation of Shortage of Stock.

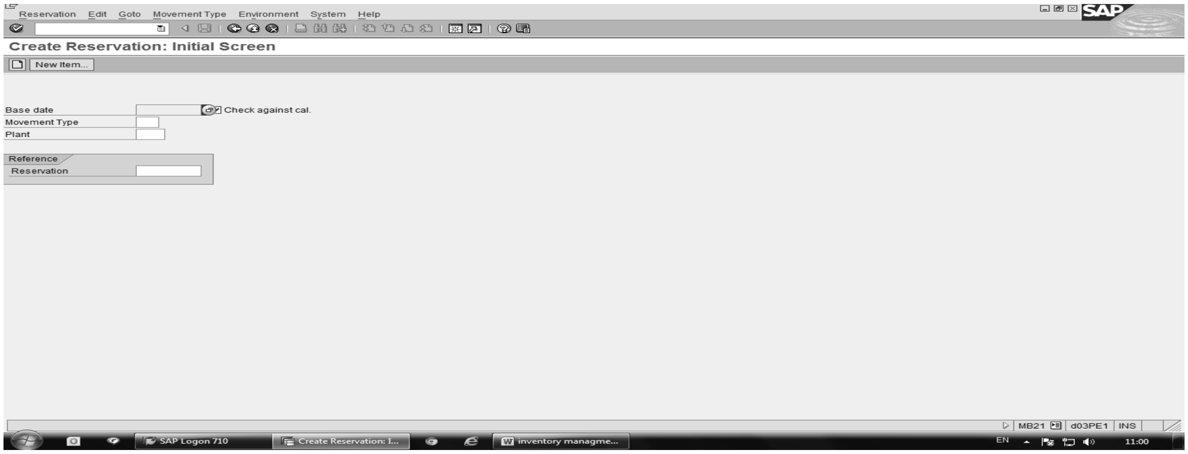
Creation of Reservation to draw materials from Central Stores:

In most of the legacy system, material drawn from stores is charged to consumption. During the Annual Closing of accounts, based on declaration of the departments regarding availability of some stock at Shop Floor, consumption is reversed.

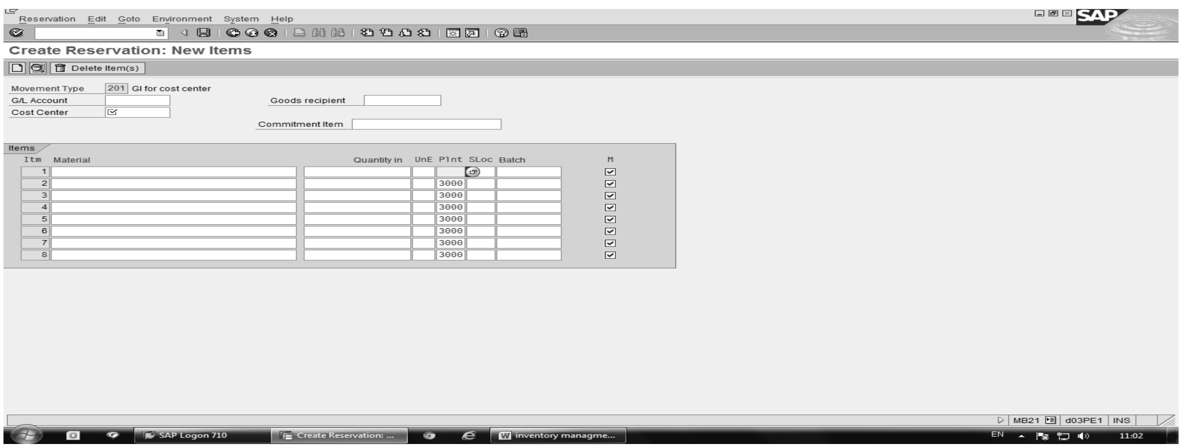
In SAP system, however, we have two distinct methods as explained below: -

Reservation is created with Transaction Code MB21. In the initial screen movement type can be either 201 (Consumption against a Cost Centre) or 301 (Stock Transfer from plant to plant).

Reservation with movement type 201



In the next screen, Cost Centre is a mandatory field. In the field SLoc 4 digit Store House no. of Central Stores should be entered from where material is to be drawn. Unit should not be entered as system automatically takes it from master data.

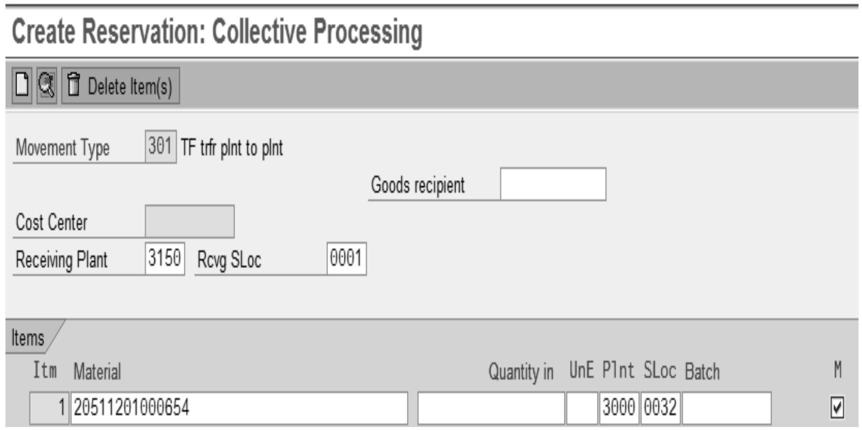


If a material is issued against reservation with movement type 201, stock gets consumed on posting of the document and the cost is charged to the Cost Centre appearing in the reservation. In such cases no stock gets transferred to Shop Floor.

Creation of reservation with movement type 301:

For the remaining material groups, reservation should be created with movement type 301.

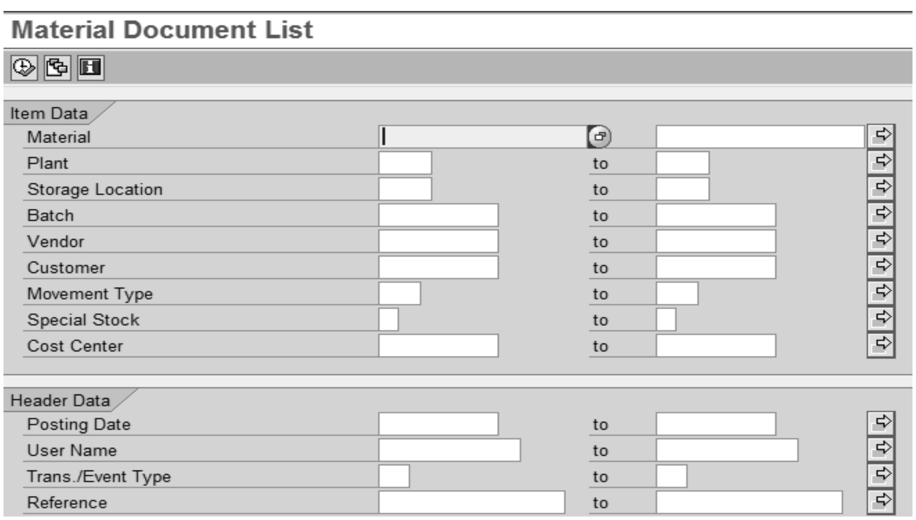
In the next screen enter the Receiving Plant and Receiving Location . Cost Centre is not mandatory.



On posting of the reservations created with movement type 301, Stock transfer takes place from one Plant to the Receiving Plant and the material appears in the Shop Floor inventory till it is consumed against Maintenance /Production order.

Some useful reports for daily monitoring:

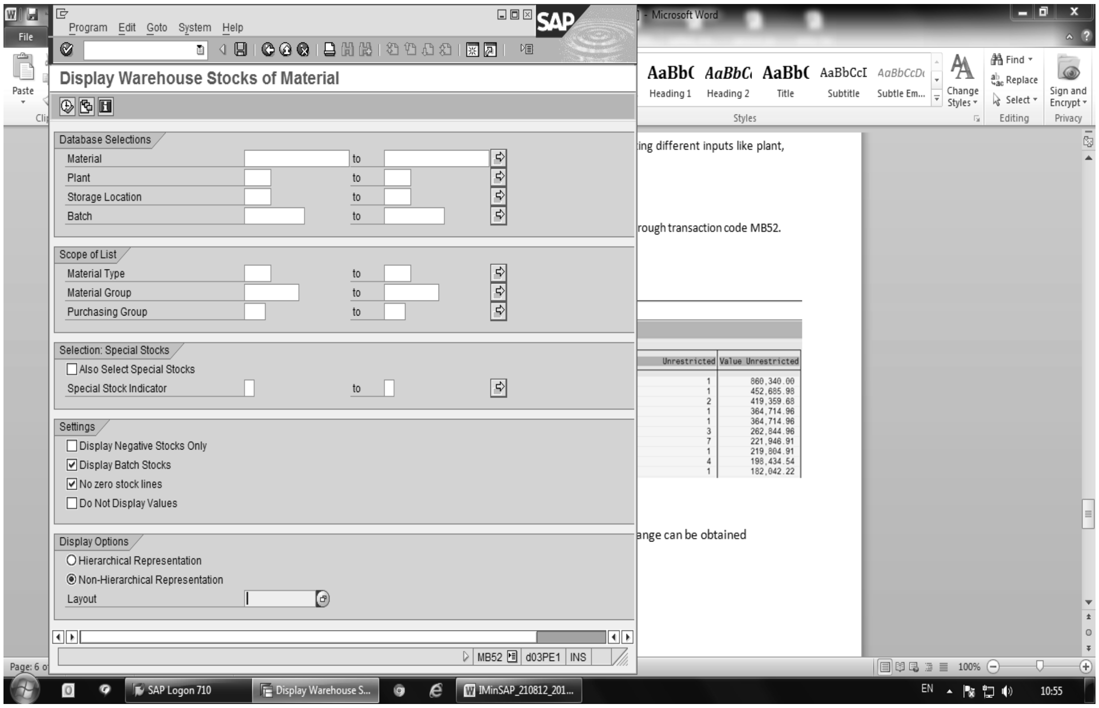
(i) Transaction Code: MB51: Material Document List



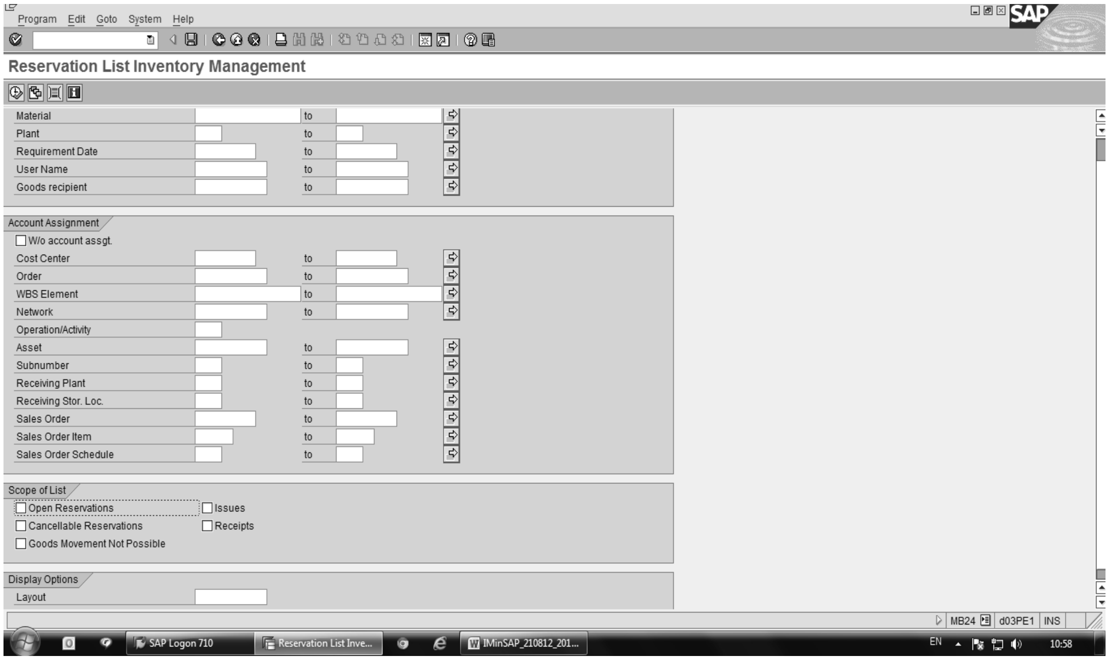
Through this report, total movement of a material at a plant e.g. receipt, transfer posting, consumption quantity and value etc. and correspongding material documents can be obtained. A large number of analysis can be made through this report by selecting different inputs like plant, movement types, Cost Centre, posting dates etc.

(ii) Transaction Code: MB52

Stock of materials and their values on current date can be obtained through transaction code MB52. This is very useful in monitoring the Shop Floor Inventory.



(iii) MB24 : This report gives details on Reservation created and materials drawn against them.



Study Note - 9

CYBER LAW, E-COMMERCE

This Study Note includes

9.1 CYBER LAWS

Introduction:

If you are in a school or in any educational institution you are a student. You have to wear uniform and to follow norms and ethics of that school or educational institution to create order. Similarly, if you are in cyber space you are netizen and you have to follow norms and ethics of cyber space. In the knowledge society of 21st century it is difficult to escape from becoming netizens. To match with the society we must know ethics, norms, rules and regulations of cyber space. These norms, ethics, rules and regulations are called Cyber Law and is essential to create order in cyber space.

In today's society computer, Internet and Information & Communication Technologies (ICTs) or e-revolution has changed the life style of the people. Today paper based communication has been substituted by e-communication, paper based commerce by E-commerce and paper based governance by E-governance. Accordingly we have new terminologies like cyber world, netizens, e-transaction, e-banking, e-return and online contracts. Apart from positive side of e-revolution there is a seamy side also and computer, Internet, and ICTs in the hands of criminals have become weapon of offence. Accordingly, a new branch of jurisprudence emerged to tackle the problems of E-commerce and of Cyber Crimes in Cyber Space commonly known as Cyber Law or Cyber Space Law or Information Technology Law.

For the first time, a Model Law on E-commerce was adopted in 1996 by United Nations Commission on International Trade and Law (UNITRAL). It was further adopted by General Assembly of United Nations by passing a resolution on 31st January, 1997. Further, India was also a signatory to this Model law, and had to revise its national laws as per the said model law. Therefore, India also enacted the Information Technology Act, 2000.

9.1.1 Components of Cyber Law

It is difficult to answer this question that what are various components of cyber law because it is a debatable concept. Many jurists believe that as cyber law is to create order in cyber space therefore every branch of law dealing with cyber space would be covered under the components of cyber law.

After the advent of Information and Communication Technologies (ICTs) we have various new concepts such as E-commerce, E-governance, E-contract, E-transaction, Cyber crimes, IPRs in digital medium and so on. Therefore laws dealing with computer, internet and with these various new concepts would be covered under the components of cyber law. Further, telecommunication is very important aspect of Information and Communication Technologies affecting cyber space therefore telecommunication regulations would also be covered under this net. Apart from this, cyber space also has impact on various conventional areas of laws such as Criminal Law, Evidence Law, Business Law, Taxation Law, Banking Law, Financial Law, Consumer Protection Law, Contract Law, Tort Law, International Law, Health Care Law, and Security Law and so on. At international level we have two main laws dealing with these new concepts i.e. the Model Law on E-commerce (1996) and the Model Law on Electronic signature (2001).

Rightly observed by John W. Bagboy that "The exact content of Cyber law is somewhat controversial. Most observers agree that it includes many aspects of Intellectual Property (IP) and technology transfer. It also includes the impact of information technology on legal process (e.g. eGovernment), electronic aspects of commercial transaction processing, and most aspects of traditional computer law. Beyond this substantive core, cyberspace is also having significant impact on many, if not most, traditional areas of law. The list here is legion, including Internet aspects of employment contracting, antitrust and trade regulation, privacy law, telecommunications regulation, international trade, consumer protection, healthcare, criminal law, taxation, financial/banking regulation and securities law. Other areas of law are likely to be impacted by the Internet as information systems become more broadly networked.

Given the impact that cyberspace is having on law; will the idea of a separate legal field called Cyber Law endure? The answer to this query may depend on whether e-commerce and traditional commerce converge, and if so, how. Two methods of convergence seem plausible. The first is incremental and evolutionary. Under this method, the details of Cyber Law will be slowly absorbed into traditional fields of law. Eventually the cyberspace aspects of IP, legal process, commercial transactions and other fields will become so commonplace that the study of Cyber Law will disappear as a separate pursuit. Under this scenario, Cyber Law serves only as a temporary signal that cyberspace is important. Its sole role is to prompt traditional fields of law to consider the unique aspects of cyberspace and to make adjustments".

"Legal framework for Cyber Law encompasses all legal aspects of interacting in cyber world. Often this relates to economic aspects of such interactions, since it is important to ensure that transactions that moved from real world into cyber world are just as valid and that the rights of interacting parties are safeguarded. Accordingly, contractual aspects of Cyber Law seek to establish the rules for validity of contracts concluded by electronic means and procedures of enforcing such contracts or resolving disputes arising from such contracts".

Another component of Cyber Law which was discussed was cyber jurisdiction especially in E-contracts. In was opined that in traditional commerce of physical world, the main principle on the basis of which the courts of a country have jurisdiction to resolve a dispute or intervene in a matter is that all material elements of the contract lie within the relevant country's territory. This is often not the case in E-contracts, as cyberspace undermines the connections between transaction and physical location. Thus, jurisdictional aspects of Cyber Law lay down the basic principles that help establishing whether the courts of a particular country have the competence to decide the matter.

Another element of Cyber Law highlighted was law relating to privacy in cyberspace. In cyberspace, collection and use of personal data is made much easier and sometimes can be done without even the knowledge of the person involved. This increases the risk of improper use of such data and may go against the individual's right to privacy. Thus, personal data protection is another important aspect of Cyber Law.

Security extends beyond privacy-related issues to measures protecting against criminal acts such as hacking, international damage to or misuse of computer system, storing and disseminating in illegal content (e.g., child pornography) and other abusive acts. Criminalization of the above acts is an essential measure that will help to prevent computer crime. The importance of international arrangements and cross-border coordination of efforts in this field was also highlighted.

Crime is both a social and economic phenomenon. It is as old as human society. **Crime** in any form adversely affects all the members of the society. In developing economies, cyber crime has increased at rapid strides, due to the rapid diffusion of the Internet and the digitization of economic activities. Thanks to the huge penetration of technology in almost all walks of society right from corporate governance and state administration, up to the lowest level of petty shop keepers computerizing their billing system, we find computers and other electronic devices pervading the human life. The penetration is so deep that man cannot spend a day without computers or a mobile. Snatching some one's mobile will tantamount to dumping one in solitary confinement.

Cyber Crime is not defined in Information Technology Act 2000 or in the I.T. Amendment Act 2008 or in any other legislation in India. In fact, it cannot be too. Offence or crime has been dealt with elaborately listing various acts and the punishments for each, under the Indian Penal Code, 1860 and quite a few other legislations too. In a cyber crime, computer or the data itself the target or the object of offence or a tool in committing some other offence, providing the necessary inputs for that offence. All such acts of crime will come under the broader definition of cyber crime.

The United Nations Commission on International Trade Law (UNCITRAL) adopted a Model Law on e-commerce, providing for equal treatment of users of electronic communication and paper-based communication. All members of United Nations are required to consider the Model Law in their respective countries.

In India, the legislation seeking to grant recognition and legal infrastructure to e-commerce is The Information technology Act, 2000.

The Information technology Act, 2000

The IT Act 2000, passed by both the houses of Indian Parliament in May 2000 and subsequently received the assent of the President in August 2000, contains the Cyber Laws. It provides the legal infrastructure for e-commerce and it is important to understand the various perspectives of the Act.

(A) The objectives of the Act are:

- To grant legal recognition to transactions carried out through electronic data interchange and other means of electronic communication commonly referred to as "electronic commerce" replacing the paper-based communication;
- To give legal recognition to Digital Signature for authentication of any information or matter which requires authentication under any law;
- To facilitate electronic filing of documents with Government Departments;
- To facilitate electronic data storage;
- To facilitate and give legal sanction to electronic funds transfers between banks and financial institutions;
- To give legal recognition for keeping of books of account by bankers in electronic form;
- To amend the Indian Penal Code, the Indian Evidence Act, 1872; the Banker's Book Evidence Act, 1891 and the Reserve Bank of India Act, 1934.

(B) Scope of the Act: This Act is applicable to whole of India, unless otherwise provided in the Act. It also applies to any offence or contravention there under committed outside India by any person.

Different provisions of this Act came into force on the different dates as notified by the Central Government.

The Act shall not be applicable to the following:

- a negotiable instrument as defined in Section 13 of the Negotiable Instruments Act, 1881;
- a Power of Attorney as defined in Section 1A of the Powers-of-Attorney Act, 1882;
- a trust as defined in Section 3 of the Indian Trusts Act, 1882;
- a will as defined in Section (h) of Section 2 of the Indian Succession Act, 1925 including any other testamentary disposition by whatever name called;

- any contract for the sale or conveyance of immovable property or any interest in such property;
- Any such class of documents or transactions as may be notified by the Central Government in the Official Gazette.

The Act consists of 94 Sections spread over thirteen Chapters and four Schedules to the Act. The Schedules to the Act contain related amendments made in other Acts as outlined in the Objectives of the Act, namely, the Indian Penal code, the Indian Evidence Act, 1972, the Banker's Book Evidence Act, 1891 and the Reserve Bank of India, 1934.

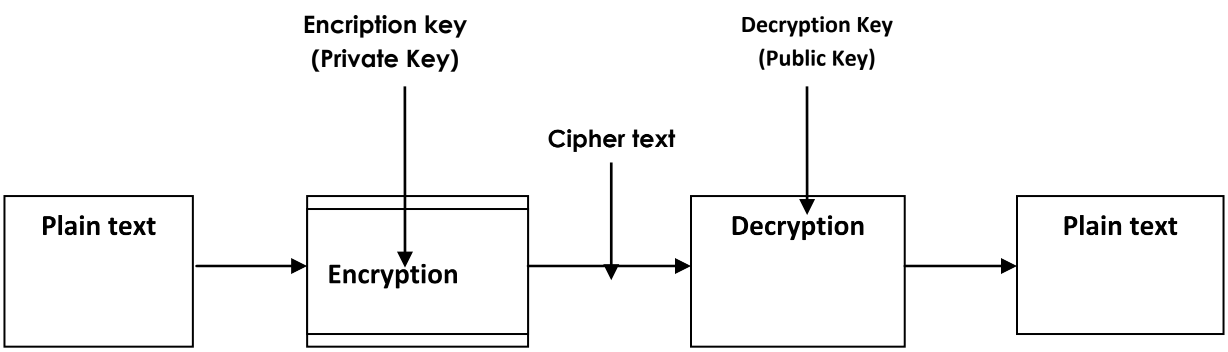
Section 2 contains some of the important terms that are defined below:

(a) "**Access**" means gaining entry into, instructing or communicating with the logical, arithmetical or memory function resources of a computer, computer system or computer network.

(b) "**Addressee**" - A person who is intended by the originator to receive the electronic record but does not include any intermediary.

(c) "**Affixing Digital Signature**" - Adoption of any methodology or procedure by a person for the purpose of authenticating an electronic record by means of digital signature.

Cryptography involved in Digital Signature



(d) "**Appropriate Government**" - Central Government except in the following two cases where it means the State Government.

- in the matters enumerated in List II of the Seventh Schedule to The Constitution.
- relating to any state law enacted under List III of the Seventh Schedule to The Constitution.

(e) "**Asymmetric Crypto System**" means a system of a secure key pair consisting of a private key for creating a digital signature and a public key to verify the digital signature.

(f) "**Computer**" - Any electronic, magnetic or optical or other high speed data processing device or system which performs logical, arithmetic, and memory functions by manipulations of electronic, magnetic or optical impulses, and includes all input, output, processing, storage, computer software, or communication facilities which are connected or related to the computer in a computer system or computer network.

(g) "**Computer Network**" - The interconnection of one or more, computers through

(i) The use of satellite, microwave, terrestrial line or other communication media and

(ii) Terminals or a complex consisting of two or more interconnected computers whether or not the interconnection is continuously maintained.

(h) "**Computer Resource**" - computer, computer system, computer network, data, computer data base or software.

(i) "**Computer System**" - A device or collection of devices including input and output support devices and excluding calculators which are not programmable and capable of being used in conjunction with external files, which contain computer programmes, electronic instructions, input data and output data, that performs logic, arithmetic, data storage and retrieval, communication control and other functions.

(j) "**Data**" - A representation of information, knowledge, facts, concepts or instructions which are being prepared or have been prepared in a formalized manner, and is intended to be processed, is being processed or has been processed in a computer system or computer network, and may be in any form (including computer printouts magnetic or optical storage media, punched cards, punched tapes) or stored internally in the memory of the computer.

(k) "**Digital Signature**"- Authentication of any electronic record by a subscriber by means of an electronic method or procedure in accordance with the provisions of Section 3.

(l) "**Electronic Form**" with reference to information means any information generated , sent, received or stored in media, magnetic, optical, computer memory, micro film, computer generated micro fiche or similar device.

(m) "**Electronic Record**" - Data, record or data generated, image or sound stored, received or sent in an electronic form or micro film or computer generated micro fiche.

(n) "**Function**" - In relation to a computer, includes logic, control arithmetical process, deletion, storage and retrieval and communication or telecommunication from or within a computer.

(o) "**Information**" includes data, text, images, sound, voice, codes, computer programmes, software and databases or micro film or computer generated micro fiche.

(p) "**Intermediary**" with respect to any particular electronic message means any person who on behalf of another person receives, stores or transmits that message or provides any service with respect to that message.

(q) "**Key pair**", in an asymmetric crypto system, means a private key and its mathematically related public key, which are so related that the public key can verify a digital signature created by the private key.

(r) "**Originator**" - A person who sends, generates, stores or transmits any electronic message or causes any electronic message to be sent, generated, stored or transmitted to any other person but does not include an intermediary.

(s) "**Prescribed**"- Prescribed by rules made under this Act.

(t) "**Private Key**" - The key of a key pair used to create a digital signature.

(u) "**Public key**" - The key of a key pair used to verify a digital signature and listed in the Digital Signature Certificate.

(v) "**Secure system**" means computer hardware, software and procedure that

- Are reasonably secure from unauthorized access and misuse.
- Provide a reasonable level of reliability and correct operation.
- Are reasonably suited to performing the intended function and
- Adhere to generally accepted security procedures.

(w) "**Verify**" - In relation to a digital signature electronic record on public key with its grammatical variations and cognate expressions means to determine whether

- The initial electronic record was affixed with the digital signature by the use of private key corresponding to the public key of the subscriber.

- The initial electronic record is retained intact or has been altered since such electronic record was so affixed with the digital signature.

(C) Powers of Central Government to make rules: Section 87 of the Information Technology Act, 2000 confers on the Central Government the power to make rules by notifying in the Official Gazette and the Electronic Gazette, in respect of certain matters, some of which are:

➢ Manner in which
  - any information or matter may be authenticated by means of digital signature under section 5;
  - electronic records shall be filed, created or issued and the method of payment;
  - digital signature may be affixed under section 10;
  - the adjudicating officer shall hold enquiry under section 46.

➢ (Electronic) Form in which
  - electronic records shall be filed, created or issued;
  - Digital signature may be affixed under section 10;
  - an application for licence may be made;
  - application is made for renewal of licence under section 23;
  - application for issue of a digital signature certificate may be made;
  - appeal may be filed .

➢ Prescribing fee
  - payable along with application for license;
  - for renewal of a license under section 23;
  - (late) payable under proviso to section 23;
  - to be paid to certifying authority for issue of digital signature certificate;
  - for filing an appeal.

➢ Prescribing salary, allowances and other conditions of service of the
  - Presiding Officer under section 52;
  - Officers and employees.

➢ Prescribing procedure
  - for security, for the purpose of creating secure electronic record and secure digital signature under section 16;
  - For investigation of misbehavior or incapacity of the Presiding Officer .

➢ Prescribing
  - standards to be observed by the Controller ;
  - requirements which an applicant must fulfill ;
  - period of validity of license granted ;
  - documents which shall accompany an application for license;
  - qualification and experience which the adjudicating officer shall possess;
  - any other power of the civil court;

- Matters relating to the
    - type of digital signature under section 10;
    - Any other.

Every notification made by the Central Government shall be laid, as soon as possible after it is made, before each House of Parliament, while it is in session, for a total period of thirty days. This period may be comprised in one session or in two or more successive sessions. If before the expiry of the session immediately following the above period, both Houses agree in making any modification, the rule will thereafter have effect only in the modified form. Similarly, if both Houses agree that the rule should not be made, the notification shall have no effect, thereafter.

Amendment Act 2008:

Being the first legislation in the nation on technology, computers and ecommerce and e-communication, the Act was the subject of extensive debates, elaborate reviews and detailed criticisms. There were some conspicuous omissions too resulting in the investigators relying more and more on the time-tested (one and half century-old) Indian Penal Code even in technology based cases with the I.T. Act also being referred in the process and the reliance more on IPC rather on the ITA. Thus the need for an amendment a detailed one was felt for the I.T. Act. The Information Technology Amendment Act 2008 was placed in the Parliament and passed without much debate, towards the end of 2008. This Amendment Act got the President assent on 5 Feb 2009 and was made effective from 27 October 2009.

Some of the notable features of the Information Technology Amendment Act are as follows:

- Focusing on data privacy
- Focusing on Information Security
- Defining cyber café
- Making digital signature technology neutral
- Defining reasonable security practices to be followed by corporate
- Redefining the role of intermediaries
- Recognizing the role of Indian Computer Emergency Response Team
- Inclusion of some additional cyber crimes like child pornography and cyber terrorism
- Authorizing an Inspector to investigate cyber offences (as against the DSP earlier)

Offences and Penalties:

Section 43: This section deals with Penalties and Compensation for damage to computer, computer system etc. Where a body corporate, possessing, dealing or handling any sensitive personal data or information in a computer resource which it owns, controls or operates,

- is negligent in implementing and maintaining reasonable security practices and procedures and
- Thereby causes wrongful loss or wrongful gain to any person, such body corporate shall be liable to pay damages by way of compensation to the person so affected.

Section 65: This section deals with Tampering with Computer source documents. Knowingly or intentionally concealing, destroying, altering or causes to conceal, destroy or alter any computer source code when the same is required to be kept or maintained by law is an offence punishable with opt Three Years imprisonment or up to Two Lakh Rupees or with both.

Section 66: This Section deals with Damage to Computer and Computer system. Data theft stated in Section 43 is referred to in this Section. Dishonestly or fraudulently, doing any act stated in Section 43 attracts imprisonment up to Three Years or a fine of up to Five Lakh rupees or both. Earlier hacking was defined in Sec 66 and it was an offence.

Section 66A: This section deals with sending

- offensive messages through computer resources causing annoyance/ inconvenience etc, or

- sending an email to mislead or deceive the addressee or recipient about the origin of such messages (commonly known as IP or email spoofing), or
- any information that is grossly offensive or has menacing character

Punishment for these acts is imprisonment up to three years or fine.

Section 66B: This section deals with Dishonestly receiving or retaining any stolen computer resource or communication device knowingly or having reason to believe the same to be stolen.

Punishment is imprisonment up to three years or one lakh rupees as fine or both.

Section 66C: This section deals with Identity theft. Fraudulently or dishonestly making use of Electronic signature, password or any other unique identification features of any other person is punishable offence.

Punishment is upto three years imprisonment or fine upto one lakh rupees.

Section 66D: This section deals with Cheating by Personation using computer resource or a communication device. Punishment is imprisonment of either description for a term which extend to upto three years and shall also be liable to fine which may extend to one lakh rupee.

Section 66E: This section deals with Privacy Violation. Knowingly or intentionally capturing, publishing or transmitting private area of any person without his or her consent constitutes violating privacy of that person.

Punishment is upto three years imprisonment or upto two lakh rupees fine or both.

Section 66F: This section deals with Cyber Terrorism. Intent to threaten the unity, integrity, security or sovereignty of the nation and denying access to any person authorized to access the computer resource or knowingly/ intentionally attempting to penetrate or access a computer resource without authorization. Acts of causing a computer contaminant (like virus or Trojan Horse or other spyware or malware) likely to cause death or injuries to persons or damage to or destruction of property etc come under this Section. Punishment is life imprisonment.

Section 67: This section deals with publishing or Transmitting Obscene Material in electronic form. Publishing or transmitting obscene material in electronic form is dealt with here. Whoever publishes or transmits any material which is lascivious or appeals to the prurient interest or if its effect is such as to tend to deprave and corrupt persons who are likely to read the matter contained in it, shall be punished with first conviction for a term upto three years and fine upto five lakh rupees and in second conviction for a term upto five years and fine upto ten lakh rupees.

Section 67A: This section deals with publishing or transmitting of material containing sexually explicit act in electronic form. Publishing or transmitting or causes to publish or transmit in e-form any material which contains sexually explicit act or conduct is punishable with - first conviction for a term upto five years and fine upto ten lakh rupees and in second conviction for a term upto seven years and fine upto ten lakh rupees.

Child Pornography has been exclusively dealt with under Section 67B. Depicting children engaged in sexually explicit act, creating text or digital images or advertising or promoting such material depicting children in obscene or indecent manner etc or facilitating abusing children online or inducing children to online relationship with one or more children etc come under this Section. Punishment for the first conviction is imprisonment for a maximum of five years and fine upto ten lakh rupees and in the event of subsequent conviction with imprisonment upto seven years and fine upto ten lakh rupees.

Section 67C deals with preservation of information by intermediaries. It fixes the responsibility to intermediaries that they shall preserve and retain such information as may be specified for such duration and in such manner as the Central Government may prescribe. Non-compliance is an offence with imprisonment upto three years or fine.

Section 68 deals with non-compliance with Controller's directions. Intentionally or knowingly not complied with directions issued by the Controller of Certifying Authorities is punishable with imprisonment upto two years or fine upto one lakh rupees or both.

Section 69 deals with failure to assist in information decryption. Failure to assist the agency to extend facilities to intercept, monitor or decrypt information as required in this section is punishable with imprisonment upto seven years and fine.

Section 69 A deals with failure to comply with Central Govt. direction. Failure by intermediary to comply with direction issued for blocking any information through Computer resource to public access is punishable with imprisonment upyo seven years and fine.

Section 69 B deals with failure to assist in online access to computer resource. Intentionally or knowingly intermediary fails to assist agency in online access is punishable with imprisonment upto three years and fine.

Section 70 deals with securing access to protected system. Securing access or attempting to secure access to a protected system in contravention of this section is punishable with imprisonment upto ten years and fine.

Section 70B deals with failure to provide information. Failure to provide information called for and comply with direction issued by Indian Computer Emergency Response Team is punishable with imprisonment upto one year or fine upto one lakh rupees or both.

Section 71 deals with misrepresentation. Making any misrepresentation to, or suppresses any material fact from the Controller or Certifying authority for obtaining licence or ESC is punishable with imprisonment of two years or fine of one lakh rupees or both.

Section 72 deals with breach of confidentiality and privacy. Securing access to any e-record, book, register, correspondence, information, document pr other material and disclosing them without consent of concerned owner is punishable with imprisonment for a term upto two years or a fine upto one lakh rupees or both.

Section 72 A deals with disclosure of information in breach of lawful contract. While providing services under terms of lawful contract, has secured access to any material containing personal information about another person, with the intent to cause or knowing that he is likely to cause wrongful loss or wrongful gain discloses, without the consent of person concerned, or in breach of a lawful contract, such material to any other person. Punishment is imprisonment upto 3 years or fine upto five lakh rupees or both.

Section 73 deals with publishing false ESCs. Publishing an ESC which is not issued by the competent Certifying Authority, or is not accepted by the subscriber, or the certificate has been revoked or suspended is an punishable ofence under this section. Punishment is imprisonment upto two years or fine upto 1,00,000 rupees or both.

Section 74 deals with publication for fraudulent purpose. Whoever is knowingly creates, publishes or otherwise makes available an ESC for any fraudulent or unlawful purpose is punishable with imprisonment up to two years or with fine up to one lakh rupees or both.

Section 75 applies for offences outside India. This Act shall apply to an offence or contravention committed outside India by any person, irrespective of his nationality, if the act or conduct constituting the offence or contravention involves a computer, computer system or computer network located in India.

Section 76 Confiscation – Any computer, computer system, floppies, compact disks, tape drives or any other accessories related thereto, in respect of which any provision of the Act, rules, orders or regulations, has been or is being contravened, shall be liable to confiscate.

Section 77 Other punishments – No compensation awarded, penalty imposed or confiscation made under this Act shall prevent the award of compensation or imposition of any other penalty or punishment under any other law for the time being in force.

Section 78 A police officer not below the rank of deputy Superintendent of Police shall investigate any offence under this Act.

Cyber Appellate Tribunal

Cyber Appellate Tribunal has been established under the Information Technology Act under the aegis of Controller of Certifying Authorities (C.C.A.). It is established by the Central Government in accordance with the provisions contained under Section 48(1) of the Information Technology Act, 2000.

The Cyber Appellate Tribunal has, for the purposes of discharging its functions under the I.T. Act, the same powers as are vested in a civil court under the Code of Civil Procedure, 1908. However, the procedure laid down by the Code of Civil Procedure, 1908 applies but at the same time the Tribunal is guided by the principles of natural justice. The Cyber Appellate Tribunal has powers to regulate its own procedure including the place at which it has its sittings.

Constitution

The composition of the Cyber Appellate Tribunal is provided for under section 49 of the Information Technology Act, 2000. Initially the Tribunal consisted of only one person who was referred to as the Presiding Officer who was to be appointed by way of notification by the Central Government. Thereafter the Act was amended in the year 2008 by which section 49 which provides for the composition of the Cyber Appellate Tribunal has been changed. As per the amended section the Tribunal shall consist of a Chairperson and such number of other Members as the Central Government may by notification in the Official Gazette appoint. The selection of the Chairperson and Members of the Tribunal is made by the Central Government in consultation with the Chief Justice of India. The Presiding Officer of the Tribunal is now known as the Chairperson.

Jurisdiction

Any person aggrieved by an order made by the Controller or by an Adjudicating Officer appointed under the Information Technology Act, 2000 can prefer an appeal before the Tribunal within 45 days of receiving a copy of the order of the Controller or the Adjudicating Officer.

The Central Government may by notification in the Official Gazette appoint a Controller of Certifying Authorities, and also Deputy and Assistant Controllers whose qualifications, experience and terms and conditions of service may be prescribed by the Government, for discharging the functions provided under section 18 of The Act. The Act empowers the Central Government to appoint an officer not below the rank of a Director to the Government of India or an equivalent officer of a State Government to be an adjudicating officer to hold an enquiry as to whether any person has contravened any provisions of the Act or any rule, regulation or direction or order made there under which renders him liable to pay penalty or compensation. The adjudicating officer appointed under the Act can exercise jurisdiction to adjudicate matters in which the claim for injury or damages does not exceed rupees 5 crore. In respect of claim for injury or damage exceeding rupees five crores, the jurisdiction shall vest with the competent court.

9.2 E-COMMERCE

Introduction

Traditional communication channels like posts and telegraphs have played an important role in the spread of commerce all over the world. Use of telephones further fast-forwarded the whole process of business transactions. As the business became more and more complex it was realized that in order to remain competitive in the business world, one needed faster processing of business information.

The question was not only how to bring speed in the whole process of business transactions but also to overcome the lack of standardization in the information format among the trading partners. The answer case in the form of development of a “paperless” approach to various business processes such as inquiries, purchase orders etc. this "paperless" approach is often referred to as Electronic Data Interchange (EDI). EDI replaces human-readable paper or electronic based documents with machine-readable electronically coded documents.

EDI was in fact nothing but the beginning of e-commerce. The problem with EDI was that of its scale; it came out as a business tool adopted and perfected by large companies. For small and medium sized businesses it was a costly proposition to adopt EDI.

The Internet changed all that. It opened up EDI to a wider range of business opportunities in the form of B2B, B2C, C2B, C2C ai).d P2P (peer-to-peer) market places. EDI proprietary systems gave way to Internet-based electronic market places. Thanks to Internet, the progression from EDI supported business transactions to E-markets has been exponential. It has been able to create that 'mass' electronic market culture which goes beyond buyer-supplier relationship. Today, Internet supports not only sector specific market places (verticals or vortals) but also collaborative market places (horizontals or hortals).

E-Commerce in its present form may be referred to as the 'Internet enabled EDI'. It is here to stay. The demise of *I* dot corns' has a positive effect in the sense that it has given way to revenue models rather than technology pure play. It should not be forgotten that it was the *1*dot corns' that made e-commerce a household phenomenon globally. Moreover, it led to the adoption of 'digital signatures' as a means to secure electronic transactions.

"….. in a loose sense, [e-commerce] means doing business over the internet, selling goods and services which are delivered offline as well as products which can be "digitized" and delivered online, such as computer software[1]".

E-commerce

Basically EDI was beginning of E-commerce but actually the electronic commerce came into force in the 1990s. E-commerce in the present form can be referred as Internet enabled EDI. Further, dot com(.com) has played very important role in E-commerce because it has given way to revenue model and it has made E-commerce a household phenomenon globally.

Definition of E-commerce

Basically E-commerce means doing business over Internet, selling goods and services which are delivered offline as well as the products which can be digitized and delivered online such as computer software.

Different definition of E-commerce as quoted according the UN Report of Electronic Commerce and Development are:

1. "E-commerce is the carrying out of business activities that led to an exchange of value across telecommunication networks".
2. "E-commerce simply is the commercial transaction of services in an electronic format".
3. "E-commerce refers to generally to all forms of transactions relating to commercial activities including both organizations and individuals that are based upon the processing and transmission of digitized data including text, sound and visual images".
4. "E-commerce is about doing business electronically, it is based on the electronic processing and transmission of data including text, sound and video, it encompasses many diverse activities including electronic trading of goods and services".

   Further, IBM defines E-commerce as "the transformation of key business processes through the use of internet technologies. E-commerce is about using technology to streamline business models, creating savings and increasing efficiency. It is about lowering cost and establishing, closer, more responsive-relationships with your customers, suppliers and partners".

   According to another jurist E-commerce has different definitions depending upon in which perspective it is used. For example,—

- From a communications perspective, E-commerce is delivery of information, products/service or payment via telephone line or computer network or any other mean.
- From a business process perspective, E-commerce is the application of technology toward the automation of business transactions and work flows.
- From a service perspective E-commerce is a tool that addresses the desire of firms, consumer and management to cut service costs while improving the quality of goods and increase the speed of service delivery.
- From an online perspective E-commerce provides the capability of buying and selling products and information on the internet and other online services.

Therefore, electronic commerce, commonly known as E-commerce or E-business consists of the buying and selling of products or services over electronic systems such as the internet and other computer networks. The amount of trade conducted electronically has grown extraordinarily with widespread Internet usage. The use of commerce is conducted in this way, spurring and drawing on innovations in electronic funds transfer, supply chain management, Internet marketing, online transaction processing, electronic data interchange (EDI), inventory management systems, and automated data collection systems. Modern electronic commerce typically uses the World Wide Web at least at some point in the transaction's lifecycle, although it can encompass a wider range of technologies such as E-mail as well.

Online business is different from conventional business: Business done through computer and internet is known as online business and such business may be operated from a business office or home office but its primary existence is in cyber space. It is different from conventional business where in-person contact between customer and product/service provider is essential. Practically an online based business could be operated from anywhere by someone using a computer to access and maintaining a site which is hosted by an independent ISP as there are many types of traditional businesses. Therefore, there are different types of virtual businesses. However, in virtual business, the primary communication between business operator and potential customer is done online.

Main Goals of E-commerce:

It helps in achieving following goals

(i) Reach new markets.

(ii) Create new products or services.

(iii) Build customer loyalty.

(iv) Enrich human capital.

(v) Make the best use of existing and emerging technologies.

(vi) Achieve market leadership and competitive advantage.

Main Reasons for the Spread of E-commerce:

(i) Digital convergence, i.e., it means that due to digital revolution almost all digital devices can communicate with one another.

(ii) Today's E-commerce is available to anyone, anywhere in the world, anytime 24/7 (24 hours a day, 7 days a week).

(iii) It helps in bringing about positive changes in an organization.

(iv) People are now having a widespread access to IT and Personal Computers (PCs).

(v) E-commerce helps in reducing operating costs and increasing profit margins due to global operations.

(vi) Demand for customized products and services is increasing.

E-commerce has Several Advantages:

- **Businesses without the barriers of time or distance:** E-commerce plays very important role in allowing people to carry out businesses without the barriers of time or distance. One can log on to the Internet at any time, whether day or night and purchase or sell anything at his desires.
- **Lower cost-of-sale:** As there is no human interaction (wholeseller, retailer etc.) during the on-line electronic purchase order process, therefore, the direct cost-of-sale for an order taken from a web site is lower than through traditional means. Further, electronic selling also eliminates processing errors, and is also more convenient for the visitor.
- **Cheapest means of doing business:** Another important benefit of E-commerce is that as compare to paper based commerce it is the cheapest means of doing business.
- **Advantages to buyer:** From the buyer's perspective also E-commerce offers a lot of advantages.
  - (a) Reduction in buyer's sorting out time.
  - (b) Better buyer decisions;
  - (c) Less time is spent in resolving invoice and order discrepancies.
  - (d) Increased opportunities for buying alternative products.
- **Less delivery time, labour cost etc.**: A significant benefit of E-commerce is that it helps to reduce the delivery time, labour cost and the cost incurred in the following areas:
  - (a) Document preparation;
  - (b) Error detection and correction;
  - (c) Mail preparation;
  - (d) Communication;
  - (e) Data entry;
  - (f) Overtime for completing the work; and
  - (g) Supervision expenses
- **Price fixation:** The day-to-day pressures of the marketplace have played their part in reducing the opportunities for companies to invest in improving their competitive position. A mature market, increased competitions have all reduced the amount of money available to invest. If the selling price cannot be increased and the manufactured cost cannot be decreased then the difference can be in the way the business is carried out. E-commerce has provided the solution by decimating the costs, which are incurred.

Disadvantages of E-commerce

Following are main disadvantages of E-commerce:

- **Few people are using E-commerce:** Because of technology phobia entrust only few people are using this mode of commerce. Therefore, one important disadvantage of E-commerce is that the Internet has still not touched the lives of a great number of people, either due to the lack of knowledge or trust. A large number of people do not use the Internet for any kind of financial transaction. Some people simply refuse to trust the authenticity of completely impersonal business transactions, as in the case of E-commerce. Many people do not want to disclose personal and private information for security reasons therefore, may not fulfilling the requirement of E-commerce. Further, many times, the legitimacy and authenticity of different E-commerce sites have also been questioned.
- **Unable to personally examine the product:** Buying products through the Internet do not allow physical examination of products. Only images of the products may be available for viewing,

but there is a risk involved in the uncertainty of the quality of the product that the consumer is purchasing.

- **Special hardware and software:** There are specific hardware and software that are essential to start an E-commerce company, which are bulky and costly.
- **Maintenance of website:** Website must be maintained and updated regularly which leads to extra labour costs.
- **Training and maintenance:** It is important to have well skilled and trained workers to create and maintain E-commerce facilities of a company.
- **Security:** An E-commerce business exposes itself to security risks and may be susceptible to destruction and disclosure of confidential data, data transfer, and transaction risks (as in online payments) or virus attacks. Possibilities of stealing credit card numbers are the real threats in E-commerce activity.
- **Not suitable for perishable commodities:** Another limitation of E-commerce is that it is not suitable for perishable commodities like food items. People prefer to shop in the conventional way than to use E-commerce for purchasing food products. So E-commerce is not suitable for such business sectors.
- **Delivery time:** The time period required for delivering physical products can also be quite significant in case of E-commerce. A lot of phone calls and E-mails may be required till you get your desired products.
- **Returning the product and getting a refund:** where consumer is not satisfied with a particular product then returning the product and getting a refund can be even more troublesome and time consuming than purchasing.
- **Problems of E-record:** Last but not the least, main problem in E-commerce is problems of Electronic record or message when transmitted during e-transaction i.e. integrity, authentication, confidentiality and privacy.

Present Trends in E-Commerce:

Electronic Commerce has started a new revolution that is changing the way business houses buy and sell products and services. E-commerce refers to the paperless exchange of business information using Electronic Data Interchange, Electronic Mail, Electronic Bulletin Boards, Electronic Funds Transfer and other network-based technologies.

Significantly, E-commerce has got a fillip with the US Government's announcement that all federal purchases would be made paperless. In the last few years, organizations have started conducting EC over the Internet because it has proved to be a low-cost alternative. However, E-commerce standards are still under development.

However, Electronic Data Interchange (EDI) is still the proven application for E-commerce, although it is only one of the ways' of doing electronic commerce.

Electronic Data Interchange

EDI is the system where data is transferred electronically in machine readable or processable form. Here, moment any message is sent through EDI then it would be immediately processed by receiving computer without any human intervention or interpretation or rekeying.

How does EDI Work?

Before EDI following steps were involved in commerce:

Step I: Creation of purchase order (PO) by the customer.

Step II: PO is sent by the customer (sender of the message) using post office, fax, telex and so on.

Step III: PO is received by the supplier (receiver of the message).

Step IV: PO is interpreted by the supplier (receiver).

After EDI following steps were involved in commerce:

Step I: Customer's computer system creates and sends the electronic PO.

Step II: PO is received by the supplier (receiver of the message) and places the order directly into his system and he acts accordingly.

Uses of EDI

EDI is used in following ways:

1. EDI is used to electronically transfer documents such as purchase order, invoices, shipping notices, receiving advises and other standard business correspondence between the trading partners.
2. EDI can also be used to transmit financial information and payment in electronic form. However, where EDI is used for effecting payment it is commonly known as financial EDI or electronic funds transfer.

Benefits of EDI

EDI has following benefits:

1. The use of EDI eliminated many problems associated with traditional information flow such as the delay associated with making of documents.
2. As data is not repeatedly keyed (typed) therefore the chances of error are reduced.
3. Time required to re-enter data is saved.
4. As data is not re-entered at each step in the process, therefore labour costs are reduced.
5. As time delays are reduced therefore more certainty in information flow is there.
6. EDI generates functional acknowledgement that the EDI message has been received by the recipient and is electronically transferred to sender. Therefore this acknowledgement which is sent electronically by the recipient to sender, states that the message has been received.

Drawback of EDI

Initially EDI was very costly and only big business houses could adopt it. However, Internet removed this drawback by adopting different versions of EDI so that it could be used by middle or small business houses also.

Securing E-commerce: Adoption of Digital Signatures

It has been realized that Internet being a public network would never be secure enough and there would always be a fear of interception, transmission errors, delay in deletion, authenticity or verification of an electronic message using Internet as a medium.. Hence the goal was to protect the message, not the medium.

The idea was to adopt a technology that makes communications or transactions legally binding. The *functional equivalent* approach extended notions such as "writing", "signature" and "original" of traditional paper-based requirements to a paperless world. That is, in order to be called legally binding all electronic communications or transactions must meet the fundamental requirements, *one* authenticity of the sender to enable the recipient (or relying party) to determine who really sent the message, *two* message's integrity, the recipient must be able to determine whether or not the message received has been modified *en route* or is incomplete and *third,* non-repudiation, the ability to ensure that the sender cannot falsely deny sending the message, nor falsely deny the contents of the message.

It led to the acceptance of cryptography, a data encryption technique, which provided just that kind of message protection. Based on the nature and number of keys cryptography has evolved into Symmetric (private key cryptographic system) and Asymmetric (public key cryptographic system) cryptography. In symmetric1 cryptography a single secret key is used for both encryption and decryption of a message, whereas in asymmetric cryptography encryption and decryption is done involving an asymmetric key pair consisting of a public and a private key.

As the name suggests public key is meant for public consumption and private key is to be kept confidential. The owner of the key pair must guard his private key closely, as sender authenticity and non-repudiation are based on the signer having sole access to his private key. In an asymmetric crypto system, a private key is mathematically related to public key and it is computationally impossible to calculate one key from the other. Hence the private key cannot be compromised through knowledge of its associated public key. Although many people may know the public key of a given signer and use it to verify that signer's signatures, they cannot discover that signer's private key and use it to forge digital signatures. This is sometimes referred to as the principle of "irreversibility".

Digital signatures are based on asymmetric, or public key cryptography and are capable of fulfilling the demand of burgeoning E-commerce by not only providing message authentication, integrity and non-repudiation function but also making it highly scalable. Another important feature is the involvement of a trusted third party, "Certifying Authority", to issue digital signature certificate.

Digital signature means authentication of any electronic record by a subscriber by means of an electronic method or procedure.

The digital signature is created in two distinct steps. First the electronic record is converted into a message digest by using a mathematical function known as "hash function" which digitally freezes the electronic record thus ensuring the integrity of the content of the intended communication contained in the electronic record. Any tampering of the contents of the electronic record will immediately invalidate the digital signature. Secondly, the identification of the person affixing the digital signature is authenticated through the use of the private key which attaches itself to the message digest and which can be verified by anybody who has the public key corresponding to such private key. This will enable anybody to verify whether the electronic record is retained intact or has been tampered with since it was so fixed with the digital signature. It will also enable a person who has a public key to identify the originator of the message.

Section 5 of Chapter III provides for legal recognition of Digital Signatures where any law requires that any information or document should be authenticated by affixing the signature of any person, then such a requirement can be satisfied if it is authenticated by means of Digital Signatures affixed in such manner as may be prescribed by the Central Government.

Duties of Certifying Authority:

1. According to Section 30 of the Information Technology Act, 2000, Certifying Authority shall follow certain procedures in respect of Digital Signatures as given below:
   - Make use of hardware, software and procedures that are secure from intrusion and misuse.
   - Provide a reasonable level of reliability in its services, which are reasonably suited to the performance of intended functions.
   - Adhere to security procedures to ensure that the secrecy and privacy of the digital signatures are assured and
   - Observe such other standards, as specified by the regulation.
2. Every Certifying Authority shall ensure that every person employed by him complies with the provisions of the Act, or rules, regulations or orders made thereunder.

3. A Certifying Authority must display its licence at a conspicuous place of the premises in which it carries on its business. A Certifying Authority whose licence is suspended or revoked shall immediately surrender the license to the Controller.

4. Every Certifying Authority shall display its Digital Signature Certificate, which contains the public key corresponding to the private key used by that Certifying Authority and other relevant facts.

Digital Signature Certificate: A digital signature certificate is a mechanism for authenticating and securing the information that is transmitted between the two parties. It is an authoritative identification about a person or a company. It is simply a public key, along with some identifying information, that has been digitally signed by a certificate authority. It identifies the subscriber, certification authority, and its operational period and contains the subscriber public key. The certificate is thus protected so that it cannot be altered without detection. It is like an electronic passport that authenticates identity of an entity. The identifying information in the certificate can be trusted because the digital signature is cryptically strong.

Legal recognition of digital signature, electronic records and authentication is necessary in an electronically formed contract. The Information Technology Act provides legal status on the use of the electronic records and signatures. Authentication and non-repudiation are secured through the mechanism of digital signature. The digital signature certificate ensures that the purported sender is in fact the person who sent the message. By certifying that a particular public key does indeed belong to a specific person, it authenticates and makes digital signature conclusive. For verification of such signature, the verifier must have the signer's public key and have an assurance that it corresponds to his private key. Digital certificate associates a particular person to that pair. Its basic purpose is to serve the need of the person seeking to verify a digital signature who would want to know that:

- The public key corresponds to the private key used to create the digital signature;
- Whether the public key is identified with the signer.

Section 35 of the Act deals with the issue of the digital certificate by the Certifying Authority, on an application being made in the prescribed form.

Digital Signatures & Public Key Infrastructure

The basic problem with the aforesaid digital signature regime is that it operates in online, software driven space, without human intervention. Sender sends a digitally signed message; recipient receives and verifies it. The only requirement is that both sender and the recipient to have digital signature software at their respective ends. How about authenticity? Suppose A sends to B a digitally signed message, how would B make sure that it is the message indeed originated from A? Now to authenticate that the message was from A only, and not from A1 or A2?

This calls for a participation of a trusted third party (TTP) to certify for individuals' (subscribers) identities, and their relationship to their public keys. The trusted third party is referred to as a Certifying Authority (CA). The function of a CA is to verify and authenticate the identity *of* a subscriber (a person in whose name the Digital Signature Certificate is issued).

A digital signature certificate securely binds the identity of the subscriber. It contains name of the subscriber, his public key information, name of the certifying authority who issued the digital signature certificate, its public key information and the certificate's validity period. These certificates are stored in an online, publicly accessible repository maintained by the Controller of Certifying Authorities or in the repository maintained by the CA. Every CA has to maintain operation as per its certification practice statement (CPS). The CPS specifies the practices that each CA employs in issuing digital signature certificates.

PKI Processes

Public Key Infrastructure (PKI) is about the management and regulation of key pairs by allocating duties between contracting parties (Controller/CA/Subscribers), laying down the licensing and business norms for CAs and establishing business processes/ applications to construct contractual relationships in a digitized world. The idea is to develop a sound public key infrastructure for an efficient allocation and verification of digital signatures certificates.

Step 1- Subscriber applies to Certifying Authority (CA) for Digital Signature Certificate.

Step 2 - CA verifies identity of Subscriber and issues Digital Signature Certificate.

Step 3 - CA forwards Digital Signature Certificate to Repository maintained by the Controller.

Step 4 - Subscriber digitally signs electronic message with Private Key to ensure Sender Authenticity, Message Integrity and Non-Repudiation and sends to Relying Party.

Step 5 — Relying Party receives message, verifies Digital Signature with Subscriber's Public Key, and goes to Repository to check status and validity of Subscriber's Certificate.

Step 6 - Repository does the status check on Subscriber's Certificate and informs back to the Relying Party.

Electronic Financial Transaction (EFT) refers to a process by which money is transferred from one person's bank account to another person's account electronically rather than using a check or transferring cash. Of course, these electronic transfers are also available to governments and businesses.

The individuals or governments or businesses using them authorize these electronic transactions in writing. The transactions are processed through the Automated Clearing House (ACH) Network. Organizations using the network have formed an association, National Automated Clearing house Association.

Types of Electronic Financial Transaction (EFT)

Direct Deposits

Perhaps the most common example of this type of electronic financial transaction is requesting your employer to deposit your paycheck directly into your bank account. You must sign a form in which you tell your employer the name of the bank and the number of your account in which you want the employer to deposit your paycheck. Your employer typically notifies your bank and tests the transaction to make sure there is no problem on the date of the transaction (this is called a pre-note). You can withdraw your authorization at any time.

Most often everyone involved is happy with this arrangement. The employer saves money because direct deposits take less time to create and cost less to process through the banking system. The employee likes it because the money is automatically in the bank on payday without having to pick up the check and getting it to the bank.

Direct Payments

Instead of writing a check to pay your bills, you pay bills by transferring money directly from your bank account to your creditor's bank account. In many instances, your creditor prefers this arrangement because your creditor will not have to open the mail and process the check when receiving your payment. In fact, creditors frequently will give discounts to customers who pay their bills electronically.

In some instances, you can also authorize your creditor to come into your bank account and take money from your account whenever you owe the creditor money. Why would you ever allow such an arrangement, which is called an ACH debit? Usually, creditors will give even greater discounts to customers authorizing ACH debits. The primary reason the creditor likes ACH debits is the creditor is assured of receiving payment at an exact time chosen by the creditor. In this way, the creditor can more accurately predict the creditor's cash position, and more efficiently manage and invest cash resources. ACH debits are most common in the commercial world. However, you frequently see them used by consumers when repaying bank loans, such as car loans and second mortgages. Frequently, the bank will offer a lower interest rate, or perhaps extend a greater amount of credit to borrowers who agree that the monthly payment can be automatically withdrawn from the borrower's bank account on a date certain.

Online banking (or **Internet banking** or **E-banking**) allows customers of a financial institution to conduct financial transactions on a secure website operated by the institution, which can be a retail or virtual bank, credit union or building society. It may include of any transactions related to online usage.

To access a financial institution's online banking facility, a customer having personal Internet access must register with the institution for the service, and set up some password (under various names) for customer verification. The password for online banking is normally not the same as for telephone banking. Financial institutions now routinely allocate customer numbers (also under various names), whether or not customers intend to access their online banking facility. Customer numbers are normally not the same as account numbers, because a number of accounts can be linked to the one customer number. The customer will link to the customer number any of those accounts which the customer controls, which may be cheque, savings, loan, credit card and other accounts.

To access online banking, the customer would go to the financial institution's website, and enter the online banking facility using the customer number and password. Some financial institutions have set up additional security steps for access, but there is no consistency to the approach adopted.

Future Prospects

Although the total value of goods and services traded using electronic media is insignificant today, it is expected to pick up in the next five years. According to projections, the value of worldwide goods and services traded electronically grew at a rate of 36% annually from US$ 130 billion in 1995, to US$ 610 billion in the year 2000.

But, experts maintain that the main reasons due to which people are still reluctant to use E-commerce are:

(i) Lack of security,

(ii) Lack of reliability,

(iii) Bandwidth constraints.

Commerce Net

Commerce Net is a consortium of companies which is promoting the use of internet for E-commerce. Sponsored by Silicon Valley vendors and US government agencies, it was launched in 1994 with the aim of creating infrastructure for business-to-business transactions on the internet.

Today, it has over 120 members and helps companies to streamline their procurement and development cycles by performing transactions online, overcome impediments to e-Commerce by making new interfaces, security mechanisms and indexing tools.

Taxation Difficulties in E-commerce

Tax is always an important area of concern in commerce. Moreover in the knowledge Society of Twenty First Century it has become more complex in E-commerce. There are various tax difficulties in E-commerce. A few such difficulties are:

(i) Problem of Tax collection: Tax collection is not easy in case of online transactions and depends on the location of the e-merchants business, the location of the buyer, the types of goods for sale, etc. Whether income derived from online taxation qualifies for source taxation or not depends upon whether the entity that earn the income has some presence in the source country?

(ii) Problem of Sales Tax: Another important controversial issue under e-commerce is sales tax. The sales tax law differs from country to country. Also, each country has different sales taxes and different jurisdictions.

Most governments would like to increase tax revenues by taxing e-commerce. Since the e-commerce is also using the conventional channels of trade and business, governments and tax authorities would like to tax online trade. But the fear is that taxation of e-commerce in its early years might affect its growth, causing a much greater loss for everyone concerned in the long run. Some experts say that there is a possibility of E-commerce going away from a region with high taxes thus leaving it behind in the global race for E-commerce.

(iii) The Problems of Tax Jurisdiction and Enforcement:

As many online transactions involve parties residing and operating in different legal and tax jurisdictions therefore moot question is which authority has the necessary tax jurisdiction and it is not clear in many situations. Similarly, enforcement of tax laws on the Internet is equally difficult. For this Tax authorities need to frame common tax policies to avoid such problems.

(iv) Whether Web Server or ISPs Constitute Permanent Establishment in the Cross-Border transaction?

Traditionally profits are taxed on two basis:

(a) Tax payer's residence basis i.e. country where tax payer resides.

(b) Source of profit basis i.e. a country where transaction took place.

However, with the spreading of E-commerce these two distinctions are getting blurred. **For example:** Mr. A of India enters into online transaction and earns income in Canada. Now question is whether India or Canada would impose tax on such income earned by Mr. A. Here India may impose tax on Mr. A as A is resident of India and Canada may impose tax on the basis of source of income Therefore, in such situations there are chances of double taxation. Lets take another complex problem where Mr. A resident of China places an order to British Company online. This British company having headquarters in UK and its server operating in USA may actually transfer goods from its Australian warehouse to the customer in China. Here important question is which country is the source of profit and which country is residence country whether it is actually a British company as it has its headquarter in UK or US company as its web server is located in the US?

In the physical world to avoid double taxation on such cross border of transaction concept of Double Taxation Avoidance Agreement (DTAA) has been evolved. It is significant to mention here that at international level for avoiding double taxation on such cross border transactions we have two important model tax treaties:

(a) OECD Model Tax Treaty

(b) United Nations Model Tax Treaty

These model tax treaties act as model for the current international tax rules and customary terms of agreement between signatory states and are also foundation of double taxation avoidance agreements. The member states are allowed to use or modify such model tax treaties to suit their means and desires in dealing with other countries. So based upon model tax treaties member states enter into agreement between them to decide incidence of tax in such cross border transactions.

(a) OECD Model Tax Treaty

This treaty uses the concept of Permanent Establishment (PE) to determine whether the entity that has earned income has some presence in source country. Further Permanent Establishment in general means a place of management, a branch, an office, a factory, a workshop, a mine, a quarry, or other place of extraction of natural resources, a building site, assembly project which exists for more than a certain period (6 to 12 months) and in certain circumstance an agent or a permanent representative. However, under Article 5 of the said treaty, permanent establishment has been refined and it involves three conditions:

- Existence of a business place i.e. facility such as premises or in certain cases any machinery or equipment.

- This business place must be fixed i.e. it must be established at a particular place with a certain degree of permanence.
- The business of the entity must be carried out through this fixed place of business.

This definition refers to a physical location of business at a particular place with a certain degree of permanence. The commercial activity must be done through some connection with the fixed place of business in that country.

(b) The United Nations Model Tax Treaty

This treaty is based upon the principle that the developing countries are generally net importers therefore they must be given priority in taxation of cross border transactions. This UN Model Tax Treaty is based upon OECD Mode, Treaty. However, the UN Model Tax Treaty provides more scope than OECI Model Tax Treaty for the country in which income has its source to assume the sole or prior right to tax that income. Under this treaty source of income generally forms the basis of taxation whereas the concept of Permanent Establishment mentioned in OECD Model Tax Treaty includes expended list of activities. Due to this, though these two treaties are identical in many aspects but there are certain differences also. Therefore, Permanent Establishment in a country makes any entity liable to be taxed by the government of that country on the basis of source of income. In the virtual world moot question is whether web server or ISPs constitute Permanent Establishment?

Whether web server can act as Permanent Establishment?

Earlier it was a controversial issue that whether in cyber space the web server act as permanent Establishment. However, this controversy was solved in 2001 when the working party of OECD had agreed upon considering the server as Permanent Establishment for taxing e-transactions. According to OECD the server on which website is stored and through which it is accessible is a piece of, equipment having a physical location which constitute a fixed place of business of the entity that operates that server. However, for the server or other compute! equipment to constitute a Permanent Establishment following conditions must be fulfilled:

1. It must be owned or leased by that entity.
2. It must be in a fixed location.
3. Business must be wholly or partly carried on in the jurisdiction where that server or other equipment is located and the activities carried on through the server must be core and not merely preparatory or auxiliary.

Therefore, now it is settled law that existence of a web server in a country is enough to act as Permanent Establishment.

Whether ISP can act as Permanent Establishment?

It is significant to mention here that Internet Service Providers (ISPs) creating web pages for their clients do not automatically create "Permanent Establishment" of these clients in its country.

Article 5 of Model Tax Treaty provides that for an agency to constitute a Permanent Establishment there must be a relationship whereby the foreign enterprise relies on the domestic agent to conclude binding contracts. It means that principal agent relationship agent must be there. Now question is whether IISP acts as an agent of Business entity to whom service is provided by him?

An ISP merely provides technical services to websites like the telephone exchange and does not in any way participate in the business activities of the websites hosted by it. Further under the OECD Model Tax Convention, a dependent agent in a country can constitute a Permanent Establishment in the country where the agent has, and habitually exercises, the authority to enter into contracts on behalf of the foreign company. However, no Permanent Establishment is created where the hosting company is an independent agent.

The Global Information Infrastructure Commission (GIIC) has also stated that tax authorities should clarify that an ISP which is economically and legally independent of the enterprise, is not a dependent agent and thus would not constitute a permanent establishment. The GIIC has clearly provided that an ISP generally, have no authority to enter into binding contracts on behalf of a customer. He only provides technical services and are economically as well as legally independent of their customers. He is like telephone companies who provide the technological medium of communication and hence cannot be called agents. The relationship of an enterprise with its ISP is only a contract for services to be provided to the enterprise and not to act on behalf of the enterprise as a legal agent.

Further some jurist believe that Permanent Establishment concept has become obsolete in the virtual world and it needs to be modified for E-commerce. Some jurists also feel that Permanent Establishment is a deceptive concept when applied in virtual world to cross border e-transactions. It deviate the attention from business activity in a place to web servers, ISPs and other equipments which have no connection with business activity. Web servers may be located or relocated at any place irrespective of the place where the business activity has actually taken place. Therefore Permanent Establishment principle is not relevant to the modes of doing business in virtual world. Business activity will be carried on in any place without any Permanent Establishment in such a place. Further developing nations are also likely to lose revenue under this concept of Permanent Establishment in the virtual world and it may also lead to tax evasion.

(v) Problem of Under-Reporting of Online Transactions

Because of all the above problems, very little taxes are actually paid for online transactions around the world, largely because governments are hesitant to impose taxes and tariffs on the online transaction and partly because businesses and individuals alike find it easy to get away with under-reporting of their online transactions.

Legal Aspects of E-commerce

Due to the new and different type of activities in E-commerce, various legal aspects have come up. These legal disputes and case law are attracting attention of industries and governments around the world. A few legal aspects in E-commerce are:

(i) E-security.

(ii) Integrity,

(iii) Authentication,

(iv) Jurisdiction,

(v) Contracts,

(vi) Liability,

(vii) Warranties,

(viii) Taxation,

(ix) Copyrights,

(x) Patents,

(xi) Trademarks and Domain Names.

Moreover these and other legal aspects still remain a serious problem in E-commerce not only in one country but all over the globe. Further many of the legal problems and questions that arise in E-commerce remained unanswered due to lack of specific laws or legal guidelines.

Lets briefly analyse these legal aspects:

E-commerce Jurisdiction:

In E-commerce the legal issue of jurisdiction, meaning the legitimate scope of government power, still remains a major legal aspect that is yet to be sorted out satisfactorily. A court must have jurisdiction over the litigants and the claims before it entertains a lawsuit. In the context of e-commerce, this issue arises when there is a dispute between business houses from different states in a country. For example, in India, a customer in New Delhi may be required to travel to Bangalore to defend against a Company that is suing him for breaking a ales agreement.

Generally, under the present law of physical jurisdiction, the Court will have jurisdiction over commercial litigant if his business is located in that area. However, in the cyber space the place where the Web server or the business is located would determine the rights of the customer to file a suit. Unfortunately, it is not always clear where the server is located, especially when the e-merchant has multiple Web servers in different countries. Perhaps, the only thing that count is the country where the e-merchant is located and the location determines the jurisdiction on the Internet.

For example, in 1999, a serious legal issue had come up in E-commerce about products that are available in one country but are restricted in the country from which the customer is ordering. At that time, the online book store Amazon.com was criticized by Germany's Simon Wiesenthal Center for selling books like Mein Kampf, which are banned in Germany. While Amazon.com's German subsidiary does not offer these books on its Web site, the U.S. Website does. Therefore, Legal Issue is if the product is confiscated in Germany, what recourse does the customer have to recover the product?

Therefore, For all these problems of E-commerce in virtual world, we do not have separate Laws. However wider interpretation could be given to the existing laws of physical world to answer such legal issues.

Liability under Law of Contract and Internet:

There are several kinds of legal problems or disputes in E-Commerce specially in B2C Model covered under Law of Contract such as:

- The e-merchant delivers, but the customer does not admit that he or she ever received the merchandise.
- The e-merchant delivers, but the customer refuses to pay. His or her 14-year old ordered the product using a parent's VISA card without authorization. The customer pays for the goods and the e-merchant fails to deliver.
- The customer pays in full, but receives either the wrong merchandise or a partial order.
- The customer does not like the goods, but the e-merchant has no procedure for accepting returned goods.
- The customer does not like the goods but the e-merchant refuses to accept returned goods or give credit to settle the dispute.
- The customer receives the goods, but it arrives damaged. The carrier denies responsibility, the e-merchant claims it is the carrier's responsibility, and the vendor is located overseas.
- The customer receives the goods but it does not operate properly. The e-merchant asks the customer to ship the product to the manufacturer at the customer's expense. The manufacturer has no in-house service center.

Here important question is whether Law of Contract would be applicable to solve such problems?

It is significant to mention here that to recently the Information Technology Act, 2000 has been amended by the Information technology (Amendment) Act. 2008 by which Section 10A was introduced so as to confer confers validity on E-contract which reads as under:

Validity Of Contracts Formed Through E-Form [Section 10A]

Where in a contract formation, the communication of proposals, the acceptance of proposals, the revocation of proposals and acceptances, as the case may be, are expressed in electronic form or by means of an; electronic record;

then such contract shall not be deemed to be unenforceable solely on the ground that such electronic form or means was used for that purpose.

It is important to note that Section 10A confers validity on e-contract. Therefore, where the proposals, the acceptance of proposals and the revocation of proposals or acceptances are made in e-form then such contracts shall be valid under the Indian Contract Act 1872 and shall not be unenforceable solely on the ground that such electronic form or means was used for that purpose.

Liability under Law of Tort and Internet

Basically tort is a civil wrong which involves civil liability and civil action. Most of the cases relating to fraud, negligence, misrepresentation, false advertisement, and IPRs infringement are covered under it.

- Strict liability: A product that produce the wrong solution, causing injury to others, fall under laws of strict liability or negligence. The basis of liability involves product liability and is covered under tort law. Therefore the moot question is that if such product is purchased online causing injury to another person whether rule of liability would be applicable?
- Fraud: If an e-merchant gives false advertisement on the website or sells wrong products or a customer gives an unauthorized credit card over the Internet, whether he or she will be liable for fraud?
- Suppose a product is bought online but consumer finds it defective. Again here question is of liability. Here depending upon how liability is worded liability is of the manufacturer. Generally in such situation every person involved in transaction (manufacturer, e-merchant and seller) would be liable.

E-commerce and Taxation

Like other areas there are various taxation difficulties in E-commerce which still remained unanswered. However, by giving wider interpretation to the existing Taxation Laws such problems could be solved.

Copyright and patent infringement and Internet

The copyright and trademark violation that come under intellectual property law are also is also a big issue. Copyright law gives the author of a tangible product the right to exclude others from using the finished work. Similarly patent law gives the inventor of a product or process the right to exclude others from using such invention. A moot question is if there is infringement of IPRs (copyright and patent) online whether it is covered under IPRs laws?

Trademarks and Domain Names

Trademarks infringement in digital medium and Domain Names Disputes are other areas which need attention.

Whether a Website is a product or a service?

There are different opinions about whether a Website is a product or a service. If a Web site is considered a product, according to law, proving negligence is unnecessary to hold the developer liable. But if a Website is a considered a service, then the contract law of the state in question would apply.

Ethics in E-commerce

The problems relating to ethics in e-commerce also cannot be ignored as it generally has legal implications. One may lead to or imply the other although an unethical act is different and not the same as an immoral or an illegal act. Ethics basically is fairness, justice, equity, honesty, trustworthiness, and equality which are also important in E-commerce.

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