OPERATIONS MANAGEMENT

(DBUS22)

(MBA 3Years)

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BLOCK 1 OPERATIONS MANAGEMENT —AN OVERVIEW

This block comprising one thematic unit introduces the subject of operations management which is equally applicable to products and services. The block explains the objectives of operations management and tries to develop an understanding of scientific approach to industrial engineering. It gives a birds' eye view of managerial functions involved in operations management.

UNIT 1 OPERATIONS MANAGEMENT — AN OVERVIEW

Objectives

Upon completion of this unit, you should be able to:

- know the production/operation function as process of value addition
- recognise the distinction between products and services
- comprehend all organisations as conversion systems whether in manufacturing or service sectors
- understand the systems concepts in operations management
- appreciate the purpose and objectives in operations management
- identify various problems of decision-making in operations management
- distinguish various structures of production systems and their associated problems
- appreciate the role of materials management
- know the concepts in systems life-cycle
- appreciate the role of scientific approach of industrial engineering/operations research in the management of production/service systems
- understand the basic theme of the subject and be familiar with the conceptual scheme we will follow in this text
- have a brief idea of the historical profile of the development of operations management

Structure

1.1 INTRODUCTION

In this unit you will learn about the aspects of management of production and service organisations. For long the term 'production' has been associated only with a factory like situation where goods are produced in the physical sense. Factory has been defined as ".....any premises in which persons are employed for the purpose of making, altering, repairing, ornamenting, finishing, cleaning, washing, breaking, demolishing or adopting for sale, any article".

However, by generalising the concept of production as the "process through which goods and services are created" we can include both manufacturing and service organisations within the purview of production management. Thus the essential features of the production function are to bring together people, machines and materials to provide goods or services thereby satisfying the wants of the people.

Inclusion of services within the scope of production enables us to look at the problem of production management in a much wider perspective. This brings a number of seemingly non-manufacturing sectors of economy such as transport, energy, health, agriculture, warehousing, banking etc. within the scope of production systems. That is why the terms production and operations management or operations management have been suggested by many to indicate the general applications of the techniques of management of machines and materials.

This broad concept of production is kept in mind throughout this book although the apparent emphasis may be on techniques used in the context of manufacturing organisation but you should always be able to extend and apply these management techniques to all types of service organisations as well.

The Value Added Process

Perhaps a more general concept of 'operations' instead of 'production' will better include both manufacturing as well as service organisations. Operations—either in manufacturing or in service—are purposeful activities of an organisation. Operations function is the heart of and indeed the very reason for an organisation to come into being. All operations can be said to add value to some object thereby enhancing its usefulness. We may formally define an operation as "the process of changing inputs into outputs and thereby adding value to some entity; this constitutes the primary function of virtually every organisation".

Now let us consider how value can be added to an entity by performing an 'operation function. There are four major ways:

a) **Alter:** This refers to change in the form or state of the inputs. This change may be physical as in manufacturing, or sensual or psychological such as the feeling of comfort or satisfaction after getting cured from an illness.

b) **Transport:** The entity gets value added through transport because it may have more value if located somewhere other than where it currently is. Entity may include people, goods or garbage.

c) **Store:** The value is enhanced if the entity is kept in a protected environment for some period of time, such as potatoes in cold storage or foodgrains in warehouses.

d) **Inspect:** The value of an entity may be enriched through an inspection as we better understand its properties and can therefore take more informed decisions regarding their purchase, use, repair etc.

Thus we see that the value may be added to an entity through a number of different means. It may directly change in space, in time or even just in our mental image of it All these processes can be called 'operations'. Thus almost every organisation—manufacturing, transportation, warehousing, health-care, education etc. come within the purview of operations management.

Products and Services

The output of an operations (or production) system may be in terms of end-product—physical goods such as automobiles or rendering a service such as in transportation, hospitals, educational institutions, cinema-halls etc. Rendering a service may involve physical goods (or facilitating goods) such as dentist making a set of false teeth while rendering dental care. Thus services can be considered as bundles of benefits, some may be tangible and others intangible (such as reduced waiting, courteous calls, convenient location etc.) and these may or may not be accompanied by facilitating goods. Based on this grouping it is possible to segregate organisations producing goods or services or both.

The Conversion Process

From the foregoing description, it should now be clear that all production or operation functions are essentially a part of the conversion process which transforms entities in shape, size, form, location, space, time and state. Hence every organisation can be considered essentially as a conversion system which converts inputs into outputs through the conversion process (or operations). This aspect is further highlighted in the next section

1.2 SYSTEMS CONCEPTS IN OPERATIONS MANAGEMENT

A system may be defined as "a purposeful collection of people, objects and procedures for operating within an environment". Thus every organisation can be represented as a system consisting of interacting sub-systems. The features of a system are that these have inputs and outputs. The basic process of the system converts the resource inputs into some useful form of outputs. Of course, depending upon the efficiency of the conversion process we may have undesirable outputs too—such as pollution, scrap or wastage, rejections, loss of human life (in a hospital) etc. Using the generalised concept of production (which includes services) we can call such systems as production systems.

Figure I: Conceptual Model of A Production/Operation System

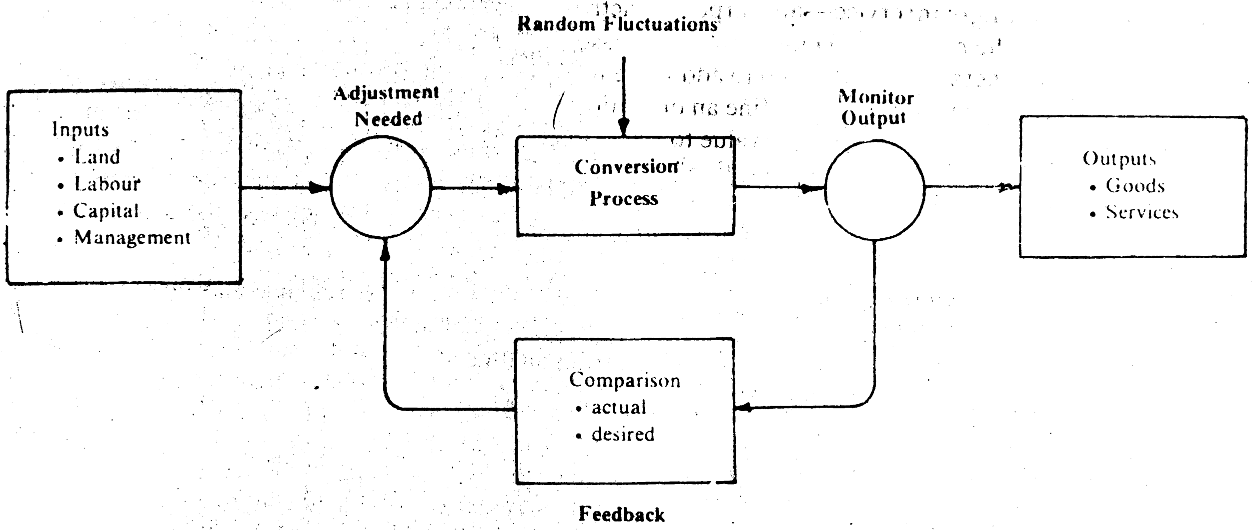


Figure I describes a generalised concept of production system. It takes resource inputs and processes them to produce useful outputs in the form of goods or services.

Inputs and Outputs

Inputs to the system may be labour, material, equipment (machines), facilities, energy, information and technology. Thus machines and materials, which constitute the main focus of this book are the resource inputs required by the production system. Other inputs to operating system can be—customers in a bank, patients in a hospital, commuters to a public transport system, files and papers to an office situation, and programmes to be run in a computer centre etc.

Similarly outputs from a system may be in terms of finished products, transported goods, delivered messages, cured patients, serviced customers etc.

Productivity of Conversion Process

Now we come to the main question of how we know that we are managing our system operations well. This concerns the efficiency with which we are converting the inputs into outputs. This conversion efficiency can be roughly gauged by the ratio of output/input; a term which is generally known as 'productivity' of the system. It is obvious that productivity can be improved by maximising the desirable form of outputs from the system for a given level of resource inputs or alternatively by requiring a minimum amount of resource inputs for a given level of output from the system.

Thus

$$\text{Productivity (P)} = \frac{\text{Output (O)}}{\text{Inputs (I)}}$$

Management of production systems is essentially concerned with the management for productivity. An alternate way of looking at the concept of productivity is to look at the amount of waste generated in the system. If waste is 'unnecessary input' and 'undesirable output' from a system, then productivity can be improved by reducing wastefulness (or wastivity) of the system.

Thus a simple way to look at the productivity improvement is to attack wastes of all types of resources—materials, labour, capacity of machines, time, space, capital etc.

If you look a bit deeper into what is happening inside the conversion system—you could find only two mutually exclusive things happening. Either, the resources are being processed (operation) taking it nearer to the completion stage or nothing useful is happening to the resource inputs. For example materials may be waiting in the form of inventory in stores, waiting to be loaded on the machine. Job orders may be waiting to be processed. In a hospital a patient may be waiting to be attended to etc. All these forms of waiting, delays in inventories are non-productive events and any drive to improve productivity must aim at eliminating or at least reducing such idle time, waiting etc. Thus if you wish to improve your system operations, try to attack such non-productive elements in the total throughput time of the entity in the system.

Manufacturing and Service Systems

As stated earlier, the generalised model of production system includes both manufacturing systems as well as service systems. Examples of manufacturing systems are: Manufacturing of fertilisers, cement, coal, textile, steel, automobiles, machine tools, blades, televisions, furnitures etc. Examples of service systems include a post office, bank, hospital, municipal corporation, transport organisation, university, supply office, telephone exchange etc.

Although basic structure of service systems is amenable to same analysis as manufacturing systems, service systems do have some salient features making the management of such systems slightly more difficult. Some of these characteristics are:

a) Output from the system is non-inventoriable. You cannot generally produce to stock.
b) Demand for the service is variable.
c) Operations may be labour-intensive.
d) Location of service operation is dictated by location of users.

1.3 OBJECTIVES IN OPERATIONS MANAGEMENT

Every system (or organisation) has a purpose, certain objectives and goals to achieve. Since the objectives of an organisation have hierarchical structure, sub-goals lead to accomplishment of goals which contribute to the achievement of objectives and eventually the purpose or mission of an organisation. It is very important that these objectives should be unambiguously identified, properly structured and explicitly stated.

In general terms, the objectives of an organisation may be to produce the goods/or services in required quantities and of quality as per schedule and at a **minimum cost.** Thus quantity, quality and time schedule are the objectives that determine the extent of customer satisfaction. If an organisation can provide for these at a minimum cost then the 'value' of goods created or services rendered enhances and that is the only way to remain competitive. Thus various objectives can be grouped as—performance objectives and cost objectives.

Performance Objectives

The performance objectives may include:

a) **Efficiency** or productivity as output per unit of input.

b) **Effectiveness:** It concerns whether a right set of outputs is being produced. Where efficiency may refer to 'doing things right', effectiveness may mean 'doing the right things'.

c) **Quality:** Quality is the extent to which a product or service satisfies the customer needs. The output has to conform to quality specifications laid down before it can be accepted.

d) **Lead times:** Manufacturing lead time or throughput time is the time elapsed in the conversion process. Minimisation of idle time, delays, waiting etc. will reduce throughput time.

e) **Capacity utilisation:** Percentage utilisation of manpower, machines etc.

f) **Flexibility:** If the conversion process has the flexibility of producing a combination of outputs, it is possible to satisfy a variety of customer needs.

Cost Objectives

Attaining high degree of customer satisfaction on performance front must be coupled with lower cost of producing the goods or rendering a service. Thus cost minimisation is an important systems objective. Costs can be explicit (visible) or implicit (hidden or invisible). These could be tangible in economic terms or intangible in social cost terms—such as delayed supplies, customer complaints etc. While managing production systems we must consider both the visible and invisible, tangible and intangible costs. Some examples of these costs are:

a) Explicit (visible) costs:
- Material cost
- Direct and indirect labour cost
- Scrap/rework cost
- Maintenance cost

b) Implicit (invisible/hidden) costs:
- Cost of carrying inventory
- Cost of stockouts, shortages, back-logging, lost sales
- Cost of delayed deliveries
- Cost of material handling
- Cost of inspection
- Cost of grievances, dissatisfaction
- Downtime costs
- Opportunity costs

For the purpose of managerial decision-making, we should consider the total relevant systems costs including visible and invisible. A longer term cost implications rather than only short-term will help in arriving at better decisions.

1.4 OPERATIONS MANAGEMENT DECISIONS

Operations Management is essentially a function concerning decision-making with respect to a production/operation system so as to render the necessary customer satisfaction at lowest cost.

The Process of Management

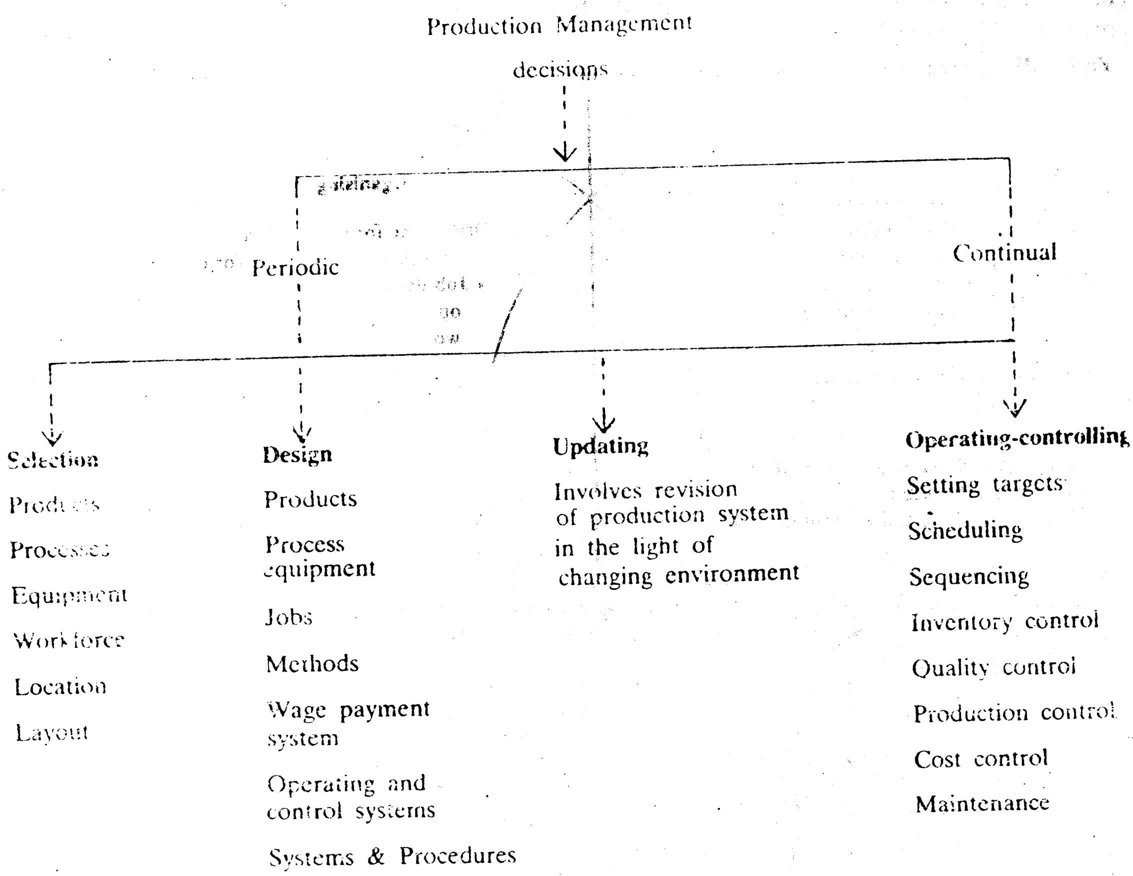
Essentially management can be considered as a process of planning, organising, coordinating and control.

There are different ways in which the production management functions can be grouped for the sake of discussion. For instance, all the decisions concerning the production system could be divided as:—

a) **Periodic decisions** which include selection, design and updating of resources, structures, systems and procedures.

b) **Continual decisions** which are required in day-to-day operation and control of production systems.

Figure II: A classification of Production Management Decisions



Source: Chase, R.B. and N.J. Aquilano, 1973, Production and Operations Management: A Life-cycle Approach, Richard D. Irwin: Homewood

Figure II shows a listing of some of the decisions according to this scheme of functional classification. It may be seen that decisions in (a) above are generally strategic decisions having long-term implications while in (b) we have operational (short-term) decisions.

And yet another way of looking at these decisions may be:

i) Planning and Design of Production Systems.

ii) Operations and Control of Production Systems.

The major topics covered in this book will be grouped according to the above mentioned classification.

A third way to group these decisions could be:

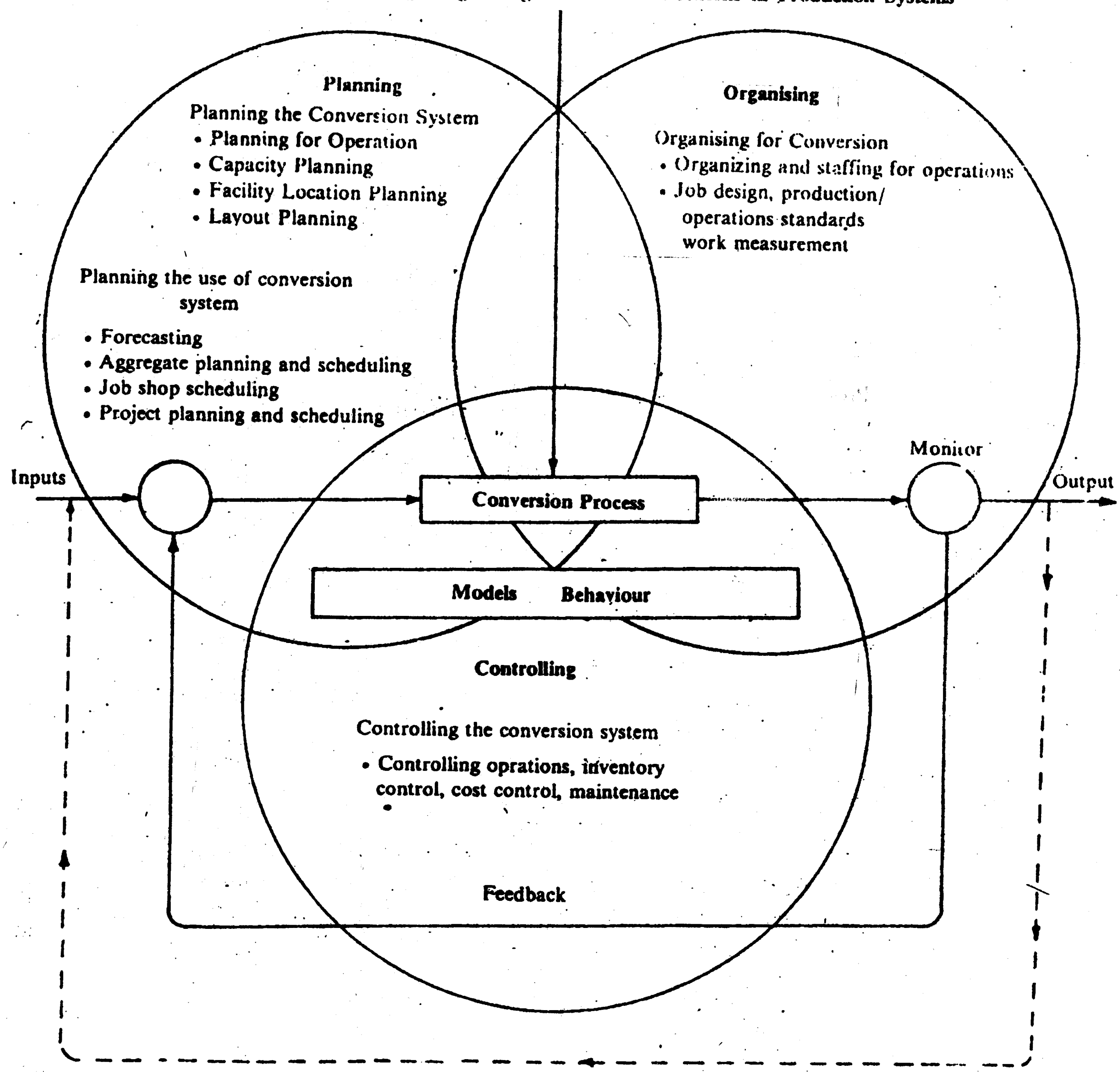
I Planning Decisions — Planning the conversion systems
Planning the use of the conversion systems

II Organising Decisions —
- Organising for conversion
- Structuring of operations
- Staffing
- Job and work-design
- Production/operation standards

III Controlling Decisions — Monitoring and control of conversion systems on aspects of
- Quantity
- Quality
- Time
- Inventory
- Cost
- Maintenance.

Figure III shows schematically a listing of production management decisions according to this classification.

Figure III: A Framework of Planning, Organizing and Control Decisions in Production Systems



Source: Adam Jr., E.E. and R.J. Ebert, 1978. Production and Operations Managerial Concepts: Models and Behaviour, Prentice-Hall-Inc., Englewood-Cliffs.

Strategic (long-term) Decisions

A decision is said to be strategic if it has a long-term impact; influences a larger part of the system and is difficult to undo once implemented. These decisions in the context of production systems are essentially those which deal with the Design and Planning (long-range or intermediate range) aspects. Some examples of these decisions are:

a) **Product selection and design:** What products or services are to be offered constitute a crucial decision. A wrong choice of product or poor design of the product may render our systems' operations ineffective and non-competitive. A careful evaluation of product/service alternatives on the multiple objective basis can help in choosing right product(s). Techniques of value engineering can be useful in creating a good design which does not incorporate unnecessary features and can attain the intended functions at lowest costs.

b) Process selection and planning: Choosing optimal (best under the circumstances and for the purpose) process of conversion systems is an important decision concerning choice of technology, equipment and machines. Process planning pertains to careful detailing of processes of resource conversion required and their sequence. Included in such decisions are the aspects of mechanisation and automation.

c) Facilities location: It concerns decision regarding location of production system its facilities. A poor location may spell operating disadvantages for all times to come. Therefore it is important to choose a right location which will minimise total 'delivered-to-customer' cost (production and distribution cost) by virtue of location. Evidently such a decision calls for evaluation of location alternatives against multiplicity of relevant factors considering their relative importance for the system under consideration.

d) Facilities layout and materials handling: Facilities layout planning problems are concerned with relative location of one department (activity centre) with another in order to facilitate material flow, reduce handling cost, delays and congestion, provide good house-keeping, facilitate coordination etc. A detailed layout plan gives a blueprint of how actual factors of production are to be integrated. The types of layout will depend upon the nature of production systems. Most of the concepts used in layout planning models are based on the importance of locating departments close to each other in order to minimise the cost of materials handling. Proper choice of the material handling equipment such as fork-lift truck, conveyors etc. is a related decision in layout planning. There are large number of computer packages develope such as CRAFT (Computerised Relative Allocation of Facilities Techniques), CORELAP (Computerised Relationship Layout Planning) etc. to help in layout planning for process based layouts. Balancing the production or assembly line and line-design including provision of inter-stage storage capacity are some relevant issue in the product-based layouts.

Newer technologies, particularly computer-based, are significantly altering the traditional concepts in layout planning. More recently the concepts in Group Technology (GT), Cellular Manufacturing Systems (CMS) and Flexible Manufacturing Systems (FMS) have influenced the layout planning and material handling policies significantly.

e) Capacity planning: It concerns the acquisition of productive resources. Capacity may be considered as the maximum available amount of output of the conversion process over some specified time span. Capacity planning may be over short-term as well as on a long-term basis. In service systems the concept of capacity and hence capacity planning is a bit more difficult problem. Long-term capacity planning includes expansion and contraction of major facilities required in conversion process, determination of economics of multiple shift operation etc. Break even analysis is a valuable tool for capacity planning. Other techniques like learning curves, linear programming and decision tree are also useful tools in capacity planning.

The above mentioned five decision areas will be described in detail in the units immediately following this one.

Operational (short-term) Decisions

Operational level decisions deal with short-term planning and control problems. Some of these are:

a) Production planning, scheduling and control: In operation scheduling we wish to determine the optimal schedule and sequence of operations, economic batch quantity, machine assignment and despatching priorities for sequencing. Production control is a complementary activity to production planning and involves follow up of the production plans.

b) Inventory planning and control: This problem deals with determination of optimal inventory levels at raw material, in-process and finished goods stages of a production system. How much to order, when to order are two typical decisions involving inventories. Materials requirement planning (MRP) is an important upcoming concept in such a situation.

c) **Quality assurance:** Quality is an important aspect of production systems and we must ensure that whatever product or service is produced it satisfies the quality requirements of the customer at lowest cost. This may be termed as quality assurance. Setting standards of quality, control of quality of products, processes are some of the aspects of quality assurance. Value engineering considerations are related issues in quality assurance.

d) **Work and job design:** These are problems concerning design of work methods, systems and procedures, methods improvement, elimination of avoidable delays, work measurement, work place layout, ergonomic considerations in job design, work and job restructuring, job enlargement etc. Design and operation of wage incentives is an associated problem area.

e) **Maintenance and replacement:** These include decisions regarding optimal policies for preventive, scheduled and breakdown maintenance of the machines, repair policies and replacement decisions. Maintenance of manpower scheduling and sequencing of repair jobs; preventive replacement and condition monitoring of the equipment and machines are some other important decisions involving equipment maintenance. Maintenance is extremely crucial problem area particularly for a developing economy such as ours because it is only through a very effective maintenance management that we can improve capacity utilisation and keep our plant and machinery productive and available for use.

f) **Cost reduction and control:** For an on-going production system the role of cost reduction is prominent because through effective control of total cost of production, we can offer more competitive products and services. Cost avoidance and cost reduction can be achieved through various productivity techniques. Value engineering is a prominent technique available for cost reduction. Concepts like standard costing and budgetary control help in monitoring and controlling the costs of labour, material etc. and suggest appropriate follow up action to keep these costs within limits.

Monitoring and Feedback Control

In every system, the actual accomplishment of objectives may not be as planned for various reasons. It is therefore very important to monitor the actual performance by measuring the actual output or some performance indicators. Basic elements of monitoring and feedback control—be it control of quantity, quality, time, inventory or cost—are:

1 Establish standards of performance or outputs.
2 Measure actual performance.
3 Compare the difference between the actual and planned.
4 Take appropriate remedial actions by changing inputs revising plans, changing priorities, expediting the progress etc.

Design of an appropriate feedback control system is therefore vital for all production/operations management problems. Control is complementary to planning. Without monitoring and control, planning may not be effective; without planning, control may not be effective. Thus planning and control are two sides of the same coin.

In the design of control systems, we should consider cost-benefit aspect of control in mind. If cost of control exceeds its benefits, it becomes counter-productive. Thus selective controls must be exercised employing the exception principle or Pareto's Law. A more effective control could be self-control or cybernetic or steering control but it may be difficult to design such controls in a large and complex organisation.

Need for Updating and Review of Decisions

When we plan or design our production system, the process of planning assumes certain external and internal environment or work. In a dynamic system there may be changes in the environmental parameters which make our previous decisions out of date and irrelevant. In such a situation, we need to review, revise and update our decisions. For example, we may switch over to group technology layout from existing process type; we may add or delete our product lines; we may revise the product design in the light of newer types of materials that have developed or on the basis of feedback from customers etc.

It is a good practice to incorporate periodic reviews and updating as a part of our system so that our decisions are relevant to the prevailing circumstances and are compatible with the external environment. Thus, we should be able to revise all the previously stated decisions should the contingency of the situation so demand.

1.5 TYPES OF PRODUCTION SYSTEMS

Looking from a different point of view, the entire problem of production/operations management can be visualised as that of managing the 'material' flow into, through, and out of the production system. If we try to detail out the flow characteristics inside the conversion systems, we shall find that some systems have very smooth and streamlined flow; some others may have more complex flow characteristics. In general, the more complex the flow characteristics inside the system, the more difficult it becomes to manage the system. On the basis of material flow characteristics, the production system can be grouped into the following four categories:

a) Mass production or flow line production system

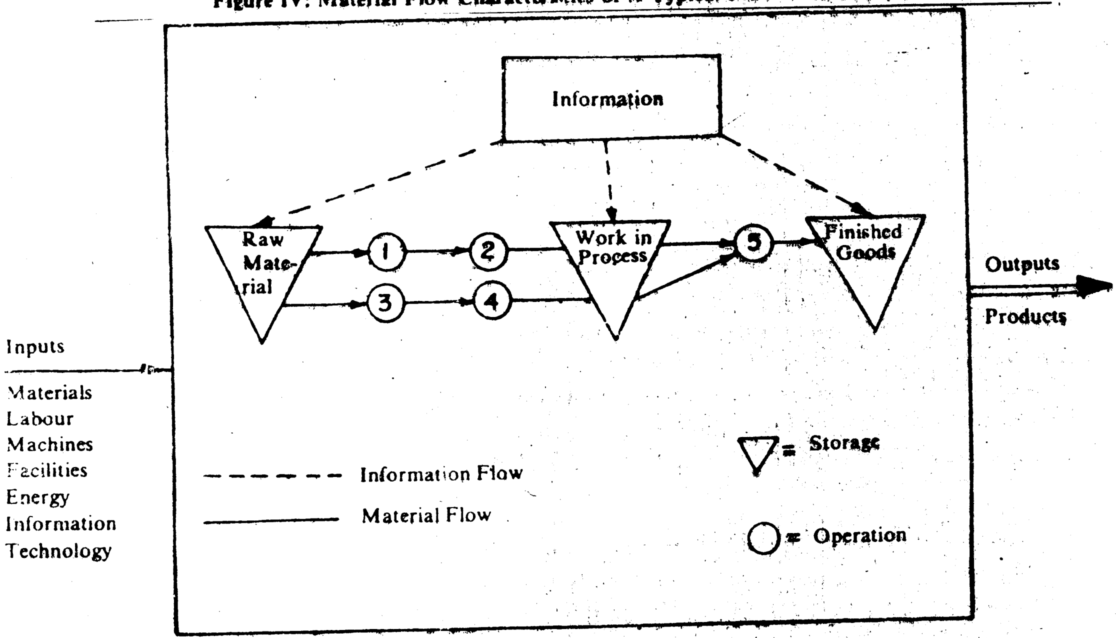
b) Batch production system

c) Job shop

d) Unit manufacture of projects.

The main focus of production management problems will therefore depend upon the type of the system. Problems which are very crucial for mass production may not be relevant for batch production and vice-versa. It is therefore very important to identify the type of systems we are managing and then focus on main problems of planning and control relevant to that system. A brief description of these problems are given in the following sub-sections. Figure IV shows the flow characteristics of a typical production system.

Figure IV: Material Flow Characteristics of A Typical Production Process



Source: Menipaz, E. 1984. Essentials of production and Operations Management, Prentice-Hall Inc.: Englewood-Cliffs.

Mass Production or Flow Line Production Systems

These systems have simplest flow characteristics constituting straight line flow. Facilities are arranged according to sequence of operations where the output of one stage becomes input to the next stage. The whole system is cascaded.

Major production management problems in mass production systems are—balancing of production/assembly lines, machine maintenance and raw materials supply. In a production line consists of the series of production centres, if workload is unbalanced, then the most bottle-necked production stage will govern the whole output rate. This will result in increased throughput time and poor capacity utilisation thus contributing to low productivity. Hence a production or assembly line should be designed such that its workload is as evenly balanced as possible. Maintenance becomes important because if any production stage is under breakdown it will block the whole line unless quickly restored back into operational effectiveness. Raw material to first stage is important to avoid shortage and subsequent starvation of the whole line.

There are methods and techniques available to attend to the above mentioned problem areas. Some of these will be discussed in a later unit on operations planning and control aspect of mass production system.

Batch Production System

If a variety of products are made with relatively small volume of production, it may not be possible to layout a separate line for each product. In such cases, batch production concept is adopted when a product is made in a certain quantity called as 'batch quantity' on a machine, and after a while it is discontinued and another product is scheduled in a certain batch quantity. Thus various products compete for the share of a machine. The machines are for general purposes. Material flow in such systems is more complex than in mass production systems. Accordingly, the planning and control aspects are relatively more difficult. Some prominent problem areas are:

a) Optimal layout planning for the production system;

b) Aggregate production planning to absorb demand fluctuations economically;

c) Machine-job allocation problem;

d) Determination of economic batch quantity; and

e) Scheduling and sequencing of operations.

Production control assumes significance in such systems as the status of progress of various products must be chased up and effectively monitored.

Job Shop

A job shop does not have its own standard product but accepts whatever customer orders come in. Thus it is essentially a group of facilities and processes a wide variety of customer orders in varying batch sizes. Each order may be a new order requiring process planning, tooling and sequencing. Material flow in job shop like situation is quite complex. A dynamic job shop where even customer orders come in a random fashion is a very difficult system to analyse at least from the point of view of production, planning and control. The main problem is despatching priority rule to determine the sequence in which various waiting job orders are to be processed on manufacturing facilities. For example, a production manager may sequence the job orders on the basis of the short processing time (SPT) rule. The job requiring smallest operation time gets top most priority in order-scheduling. From analytical point of view a job shop can be treated as a network of queues and the waiting line models or simulation techniques can be used to analyse it.

Unit Manufacture or Projects

Suppose we want to make a ship. Obviously due to large size of the product, the entire concept of material flow should change. In the previous three cases the manpower and facilities were fixed and product (or material) was moving from place to place. Here product remains fixed and manpower facilities put work on it some chosen sequence. Since such products are not made in large number and have long throughput time, we can treat each product as a project. Thus project planning, scheduling and monitoring techniques based on network models such as PERT/CPM can be used for planning and control of such production systems.

1.6 MANAGEMENT OF MATERIALS IN PRODUCTION SYSTEMS

As mentioned previously, problems of production management essentially concern management of material flow into, through and out of the system. This makes materials management a vital subject. Since materials constitute an extremely important and costly resource to a production system, an improvement in materials productivity will lead to overall improvement in systems performance and cost reduction.

Role of Materials Management

Materials in Indian context constitute more than half the total cost of production in most industries and projects. In some industries 60-70% of total production cost is due to materials. This makes materials management the biggest single area having tremendous potential for cost reduction. A well coordinated materials management programme may lead to 15-20% cost reduction.

If inventories are taken as an index of materials management effectiveness, then there is so much that can be done to cut inventories in Indian industries. If inventory is viewed as 'usable but idle resource' then we can also call it a 'necessary evil'. Our materials planning system should be such that we are able to ensure adequate supply of materials to meet anticipated demand pattern with the minimum amount of capital blocked in inventories in a non-productive manner.

Need for Integrated Approach to Materials Management

To be most effective, our desire to maximise materials productivity must aim at getting most out of every rupee invested in materials. This calls for a well coordinated and integrated approach towards various problem areas involving decision-making with respect to materials. It can be seen for example that the inventory in the system can be lessened by reducing uncertainties in demand and supply, by reducing procurement lead time, by reducing excessive material varieties through standardisation, codification and variety reduction programmes. Thus development of reliable sources of supplies to have 'just in time' supply will reduce inventories substantially.

Other important areas to improve efficiency on materials management front are:

a) **Value analysis, purchase price analysis:** In this we want to put right kind of material through competitive prices to reduce the material bill. Value analysis aims at getting the required function performed at minimum cost and therefore value analysis technique has a major role in materials related cost reduction.

b) **Materials handling:** Materials handling provides place (location) utility only. Otherwise it does not add to functional or esthetic value of materials but is an element of cost. Thus our aim should be to design systems of production and storage to minimise the costs associated with movement and handling of materials.

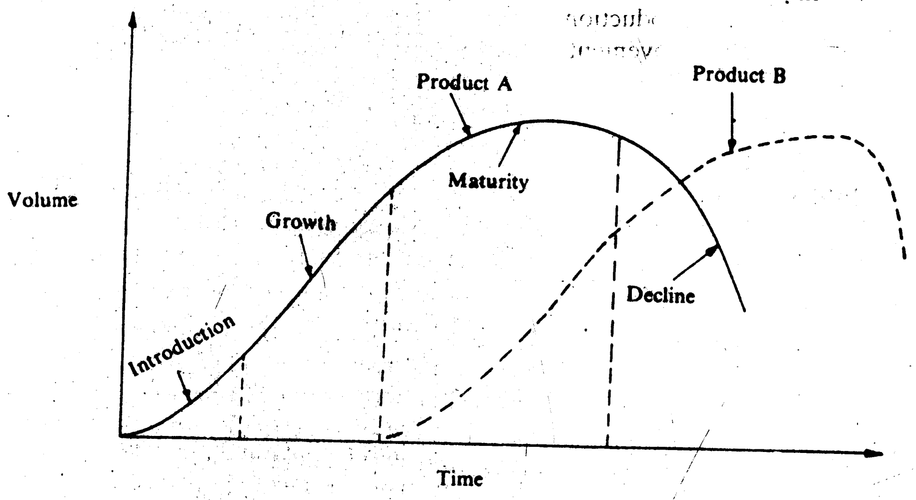
c) **Inventory control:** Here we try to plan our procurement actions so that we can get the demand satisfied reasonably well without having to stock (in inventory) too much of materials. This is a very well discussed problem area in literature on materials management.

d) **Stores management:** Stores function looks after physical custody of materials. By proper planning of layout, storage materials and issuing policies we can ensure faster service so that items demanded by production can be supplied without delay. Avoidance of pilferage, wastage and storage losses are also important aspects of stores management.

e) **Waste management:** Materials waste must be minimised if not eliminated. Waste can also be considered as a barometer of materials productivity. If materials waste is minimum, productivity of materials improves.

An integrated approach to materials management must look at all the above mentioned problem areas in a coordinated manner with a view to maximise materials management effectiveness.

Figure V: Product Life-Cycle



1.7 CONCEPTS IN SYSTEMS LIFE-CYCLE

The life-cycle concept or 'womb to tomb' concept draws analogy from living organisms. It assumes that every system (product) has a definite life-cycle and it passes through growth, maturity, saturation and decline phases. Figure V shows a typical life-cycle of a product. Similar pattern could exist for the entire production systems. Life-cycle concept enables us to understand various decisions and their inter-dependence in a better perspective. For example if some of the strategic decisions like product selection or plant location, which are made at the early stages of systems life-cycle are wrong, then these would continue to influence day-to-day operations planning and control decisions adversely and no amount of day-to-day effectiveness will be able to undo the damage done by poor decisions at initial stages of life-cycle.

This concept also enables us to be alert to the external environment and start phasing out a dying product and substitute it with a new product well in time so that continued survival of the organisation can be planned. Figure V shows how introducing new product well in time can cause long-term survival of the organisation even if individual products follow life-cycle pattern. Life span of a product may vary from few months (such as fashion goods) to few decades.

Stages in Systems Life-cycle

Figure VI shows the eight stages of the system life-cycle along with the associated key decisions to be made at each stage. Some of the initial decisions like product selection, technology selection, location and layout selection are of strategic importance. Once the system has achieved steady state—most on-going organisations we work in are probably at that stage—then most problems of operations management are of tactical or operational nature. Short-term planning and control and cost reduction strategies are the main focus at that stage. The steady state experiences minor perturbations due to external and internal factors. Moderate level changes can be accommodated by updating and revising of the previous decisions. When the system cannot adjust to even major revisions due to extreme changes in external environment, then the systems must come to end-through liquidation or through sale or merger. Termination or phasing out of operations may be sometimes deliberate.

Life-cycle Costing

A very important concept in costing has emerged in recent years—that of life-cycle costing. It says that when we evaluate the cost implications of our decisions we should not consider the short-term cost alone but the entire costs during the life-cycle of the system and equipment. Thus long-term cost repercussion must be examined rather than immediate short-term alone. Such a concept may change our perspectives and

Figure VI: Stages of Life-cycle and key-decisions involved

Stage	Key-decisions
1 Birth of the system	1 Identification of corporate goals; selection of the product
2 Production design and process selection	2 Technological design of product, selection of manufacturing technology sequence of manufacturing
3 Design of the production system	3 Facility location/layout, Design for quality, Demand forecasting
4 Manning the system	4 Job structuring allocation, assignment methods design, work measurement, payment systems
5 System start up	5 How to overcome initial problems, how to achieve full capacity
6 System in steady state	6 Operational decisions, cost reduction studies, improving system performance to look after day-to-day problems
7 Revision of the system	7 Updating various decisions in the light of external changes
8 Death of the system	8 How to phase out, salvage resources, sustain by starting new product etc.

Source: Chase, R.B. and N.J. Aquilano, 1973. Production and Operations Management: A Life-cycle Approach, Richard D. Irwin: Homewood.

seemingly good decisions may not remain attractive if life-cycle costs are computed. For example while purchasing a machine, the short-term cost may mean only initial purchase price and we may be tempted to buy a cheaper equipment or machine. It may however require too much repair, maintenance and operating expenses. If all these costs including initial costs are compared during the life-cycle of the machine, we may find that an expensive machine with very little maintenance repair and operating cost may be preferred alternative over initially inexpensive but 'costly-to-maintain' machine. Thus while making important decisions regarding design and planning aspects of production systems we should consider life-cycle costs. These could even be converted to present values by discounted cash flow techniques, accounting for the time value of money.

1.8 ROLE OF SCIENTIFIC METHODS IN OPERATIONS MANAGEMENT

Methods and techniques of scientific management have tremendous role to play in helping us to make rational and logical decisions in the context of production and operations management. Through scientific methods, tools and techniques of industrial engineering and operations research along with **behavioural science** we can look at all facets of the problems and evaluate the consequences of our actions before arriving at a decision. These techniques thus reinforce the subjective or intuitive judgement and contribute to better management.

The Role of Industrial Engineering

Indian Institution of Industrial Engineering (IIIE) has adopted the following definition of Industrial Engineering:

"Industrial Engineering is concerned with the design, improvement and installation of integrated systems of men, materials and equipment. It draws upon specialised knowledge and skills in mathematical, physical and social sciences together with the principles and methods of engineering analysis and design to specify, predict and evaluate the results to be obtained from such systems."

It can therefore be seen that industrial engineers are designers of management systems and industrial engineering approach integrates various approaches such as operations research, systems analysis, behavioural science etc. towards the integrated design of organisations. In this book many industrial engineering techniques will be used in various units which helps us in better management of production systems.

The Role of Models

Models are representation of systems with a view to explain certain aspects of system's behaviour. Generally a mathematical model is preferred in decision-making because it tries to explain system's objectives and function in terms of decision variables subject to our control as well as non-controllable parameters due to environment or resource constraints etc. Thus a simplified form of a model is:

$$E = f(x_j, y_i)$$

Where E = Measure of effectiveness or objective function

x_j = Controllable (decision) variable, $j = 1 \ldots n$

y_i = Non-controllable parameter, $i = 1 \ldots m$

Thus a model provides us a cause-effect relationship so that we can evaluate our alternative courses of action on the basis of our objectives and choose an optimal (best under the circumstances) strategy to maximise our effectiveness. Thus models provide a valuable tool to compare our options and thus improve the quality of decisions and provide us a better insight into our decision process. However, it must be noted that models are a means to achieve an end (better decisions) and not an end in itself. We must choose a simple, valid and logical model of the decision situation. A large number of model based techniques have been developed in the subject called 'Operations Research' (OR) which help in mathematical conceptualisation of many decision-making problems relevant to production/operations management. Some very versatile and powerful techniques like linear programming, queuing theory and simulation have been applied extensively to study various problem areas in production management. Some of these will be described, though briefly, in appropriate units in this book.

The Role of Computers

In a large sized problem, a computer becomes a very efficient tool in problem solving and evaluation of alternatives. A big size linear programming or simulation problem can be efficiently solved on computers. Due to fast developments in computering facilities and application software, many OR models can be implemented via computers. Computers also have tremendous role in management information systems to provide useful, relevant and timely information for planning, monitoring and control of production systems—thus providing decision support through information.

The Role of Behavioural Science

Since people are integral part of our production system, understanding of human behaviour is very important so that managers can evaluate the consequences of their actions on human relations, morale, motivation and productivity. Supervisor's relationship with his subordinates, organisation structure, individual and group behaviour, work habits and attitude, incentives, participation in decision-making performance appraisal systems have impact on worker morale and motivation. Behavioural science provides us some insight on these aspects and therefore has a role to play in production and operations management.

1.9 BRIEF HISTORY OF OPERATIONS MANAGEMENT

Historically speaking, the field of operations management has evolved in a very short span of time. Its roots, however go back to the concept of 'division of labour' advocated by Adam Smith in his book "The Wealth of Nations" in 1776. In 1832, Charles Babbage, a mathematician extended Smith's work by recommending the use of scientific methods for analysing factory problems.

However, the era of scientific management as it is now known started with the work of F.W. Taylor in 1878 who subsequently came to be recognised as the 'Father of Scientific Management'. Taylor is credited with recognising the potential improvements to be gained from analysing the work content of a job and designing the job for maximum efficiency. His experiments conducted on the shop floor brought

of scientific management in the following way:

a) Development of a science for each element of a man's work thereby replacing the old rule of thumb methods.

b) Selection of the best worker for each task and then training and developing the workman on individual basis.

c) Striving for cooperation between management and the workers to simultaneously obtain both maximum production and high worker wages.

d) Dividing the work between management and workers so that each is working on what they are most proficient in doing.

Taylor described his management philosophy in a book "The Principles of Scientific Management" published in 1911. This event, more than any other, can be considered as the beginning of the field of Operations Management. The colleagues, contemporaries and followers of Taylor were many and included the following people.

Frank Gilbreth and his wife Lillian Gilbreth are recognised for their contributions to motion study. Gilbreth developed the concept of 'Therbligs' and 'Chronocyclegraphs' for motion study in 1911. Lillian Gilbreth wrote her book 'The Psychology of Management' which was one of the earliest works concerning the human factor in organisations.

In 1913, Henry Ford developed the concept of mass production and arranged work stations into an assembly line with moving belt. In 1913 also, Henry Gantt made his best known contribution in charting the production schedules using a visual-diagrammatic tool which is popularly known as 'Gantt-Chart' and is an effective practical tool even today.

In 1913, Harrington Emerson applied Taylor's ideas to develop organisation structure and suggested the use of experts in organisations to improve efficiency.

Wilson developed the concept of Economic Order Quantity (EOQ) in 1928 which is still recognised as the classical work in the scientific analysis of inventory systems and works of subsequent researchers were essentially further refinements of Wilson's lot size formula.

In 1931, F.H. Dodge, H.G. Roming and W. Shewhart developed the concept of sampling inspection and published statistical tables. Earlier in 1924, W. Shewhart pioneered the concept of statistical quality control and developed control charts for monitoring the quality of production processes.

In 1933, Elton Mayo conducted his famous experiments at Western Electric's Hawthorne plant looking into human and social aspects of work. This paved the way for the 'behavioural school' of management. Mayo felt that scientific management often emphasised technical skills at the expense of adaptive skills. Some other notable developments in these lines include the concept of 'managerial grid' developed by a Robert Blake and Maslow's hierarchy of needs and Doughlas McGregor's Theory X and Theory Y in management.

In 1937, L.H.C. Tippett developed the concept of work sampling to gauge the level of machine and manpower utilisation and for setting work standards.

In and around 1950 two major developments that influenced operations management were the emergence of techniques of 'Operations Research' beyond military context and developments in engineering offered by L.D. Miles. The OR is application of scientific methods to study and devise solutions to managerial problems in decision-making. Using mathematical models and the systems approach OR has helped solve resource allocation, scheduling, processing, inventory, location, layout and control problems. Techniques of value engineering helped in efficiently identifying the unnecessary costs so that products and systems could perform their function at minimum costs.

Developments in computers led to computerised applications of Industrial Engineering and OR techniques to production management problems. Development in MIS and DSS (Decision Support Systems) provided a further fillip to the developments in operations management. In 1958 the concepts of CPM and PERT

were developed for analysis of large projects and since then a number of network based techniques of project management have been developed.

In the late 1950s scholars and researchers in the field began to generalise the problems and techniques of manufacturing management to other production organisations such as petroleum, chemical and other process industries leading to the emergence of the concept of 'production management' as a functional management discipline. In the late 1960s the concept of 'Operations Management' expanded to include the service sectors as well. Only recently the service sector has received as much attention as production sector from the point of view of scientific management of systems operations.

Systems approach taking a holistic (integrated) look at the problems of operating systems emerged in the 1970s which considered the inter-play of various sub-systems in organisations. Developments in the computer simulation of integrated production-inventory systems are some of the current thrusts in modelling of production management problems.

In the more recent past there has been a major thrust on the adoption of Japanese management techniques like the 'just in time (JIT) system' or 'Kanban system' for production scheduling and inventory control and the concepts in quality circles (QC). These concepts have apparently done well in Japanese context but should be cautiously adopted in other situations only if external work/environment and work ethos make them appropriate elsewhere too. Other notable developments in recent past have been group technology (GT) or cellular manufacturing systems (CMS), flexible manufacturing systems (FMS), computer-aided design/manufacturing (CAD/CAM) etc. Thus future of operations managements looks bright.

1.10 SUMMARY

This unit has attempted to give a general overview of operations management. A systems approach treating each operation as a value addition process has been described. The concept of operations management includes both the production of goods as well as services. Operations as the conversion process have been identified to be central function of virtually every organisation. Value is primarily added to entities by changing them directly in space, in time or in our minds. The important characteristics of conversion process have been identified as its efficiency, effectiveness, quality, lead times, capacity and flexibility. Objectives of operations management may be in terms of customer satisfaction or performance objectives as well as cost objectives.

Various decision areas have been categorised as strategic or operational decisions, periodic or continual decisions and various problem areas have been listed under each group. Management of production systems depends upon the structure of the systems and complexity of material flow and accordingly the production systems can be classified as mass, batch, job shop and project production systems. The characteristics of each of these systems together with the relevant production management problems have been highlighted. Role of materials management becomes crucial as materials are responsible for more than half the total cost of production systems. An integrated approach involving coordinated efforts to attempt various problems of materials management is emphasised.

Life-cycle approach to products and systems provides a good insight into the key decisions at every stage and concepts in life-cycle costing provide new perspectives to decision-making. Role of scientific techniques of industrial engineering, operations research together with behavioural science and computers is outlined. A brief unit-wise overview of the plan of the book is given so that the relevance of various units to the common theme of the book can be linked.

Finally, a brief historical profile of the subject from the era of Taylor to modern times including modern Japanese management techniques provides a synoptic view of the growth and development of the subject.

Behavioural science: Systematic study of human behaviour.

Batch production: A production system between mass and job shop. A number of products are made in batches on the manufacturing facility.

Control: A management function aimed at ensuring that actual performance is in accordance with the plans formulated to achieve its objectives.

Conversion process: Transformation of inputs to outputs thereby leading to value addition.

Ergonomics: Branch of technology concerned with the problems of the mutual adjustment between man and his work.

External environment: Comprises external surroundings in which an organisation functions and which has an impact on its performance.

Feedback: The process of comparing the actual performance and the planned one in order to initiate action for control purposes.

Inputs: All types of resources required by the conversion process for producing goods or services.

Inventory: Usable but idle resource.

Job shop: Manufacturing of varieties of products in small batch sizes according to customer orders.

Lead time: Total manufacturing (procurement) time in completing the production after initiating the work. It is a measure of how quickly the output can be produced.

Life-cycle: The cycle of birth-growth-maturity and decline of a product or a system.

Management: The process of planning, organising, directing and control.

Mass production: Making of a single product in very large quantities so that facilities can be arranged according to sequence of operations for the product.

Model: A representation of reality intended to explain some aspect of it.

Monitoring: Process of measuring actual performance or progress of work for the purpose of control.

Operations: The process of changing inputs into outputs. It is a purposeful function vital to virtually all organisations.

Operations research: Application of scientific methods, tools and techniques to the problems of decision-making in order to find optimal solution to problems.

Organising: Allocating human and material resources in appropriate combination to implement action plans. It defines tasks, structures and then allocate resources.

Output: Final product or rendering ot a service.

Planning: Determining what is to be achieved, setting goals and identifying means to achieve them.

Production: The process of creating goods and services (synonymous to operation).

Productivity: The efficiency of conversion process expressed as output per unit of input.

Project: A set of tasks having sequential dependence with a definite starting and ending point.

Quality: A composite of characteristics that determines the extent to which a product or service satisfies the customer needs.

Schedule: A time table of production system indicating the time when a particular job will be processed on a particular machine.

Sequence: The order in which waiting jobs are to be processed on a machine or a facility.

Service: A bundle of benefits, some may be tangible and others intangible.

Simulation: A technique which feigns systems on paper or on computer in order to describe system behaviour

Systems: A purposeful collection of people, objects and procedures for operating within an environment.

Strategic decisions: Important decisions having long-term impact.

Value engineering: A systematic procedure to identify and eliminate unnecessary costs to provide equivalent function at lowest costs.

1.12 SELF-ASSESSMENT EXERCISES

1 Identify the inputs, transformation process and outputs in the following operations systems:

a) Manufacture of television sets

b) Bank

c) Hospital

d) Warehouse

e) Educational institution

2 At what stage of product life-cycle will you put the following?

a) Steam locomotive

b) Colour television

c) Bicycle

d) Computer aided manufacture

e) Automated warehousing

3 Identify the main objectives relevant to the performance of the following operating systems:

a) Transportation system in a metropolitan city

b) Post office

c) Factory making cotton textiles

d) Insurance company

e) Construction of a house

4 Write True or False against the following statements:

a) Location of a plant is an important strategic decision

b) Mass production system is suitable for products with large variety and small volume of production.

c) Efficiency and effectiveness are synonymous terms.

d) Productivity is a ratio of output/input.

e) Feedback control is not needed if you plan your operations.

5 Describe four activities performed by the Operations Manager.

6 Does external environment affect the performance of a system?

7 List five symptoms of a poorly managed transport corporation.

8 List five symptoms of a soundly managed hospital.

9 Why is it more difficult to increase productivity of a service system as compared to a production system?

10 Consider the following situation:

You have been asked to look into the operations of a company which is in the business of repairing and overhauling automobiles. Current practices have led to an extreme amount of customer dissatisfaction due to very high waiting time, discourteous behaviour of work force with the clients, poor quality of workmanship and high cost of repairing automobiles. As a result the customers have started getting their services elsewhere. The owner is very keen to improve the situation but he finds that his people are not motivated by a spirit of service basically because of poor wages and indifferent supervision. This operation is located in an environmentally alert community and they have also been complaining to the local municipal authorities

that the nasty way in which operations are handled and waste water disposed off, is causing lot of inconvenience in the locality. The owner-manager wants your help in improving the effectiveness of systems operations.

How will you analyse the situation? What further information you may need? Prepare a short working paper outlining your suggestions to improve the systems operations.

1.13 FURTHFR READINGS

Adam Jr., E.E. and R.J. Ebert, 1987. *Production and Operations Managerial Concepts: Models and Behaviour*, Prentice-Hall Inc: Englewood-Cliffs.

Buffa, E.S. 1983. *Modern Production/Operations Management* (7th edition), John Wiley & Sons: New York.

Chase, R.B. and N.J. Aquilano, 1973. *Production and Operations Management: A Life-cycle Approach*, Richard D. Irwin: Homewood.

McClain J.O., and L.J. Thomas 1985. *Operations Management: Production of Goods and Services*, Prentice-Hall Inc.: Englewood-Cliffs.

Menipaz, E: 1984. *Essentials of Production and Operations Management*, Prentice-Hall Inc.: Englewood-Cliffs.

Meredith J.R. and, T.E. Gibbs 1980. *The Management of Operations* (2nd Edition), John Wiley & Sons: New York.

Riggs J.L. 1976. *Production Systems: Planning, Analysis and Control* (3rd edition), John Wiley & Sons: New York.

BLOCK 2 FACILITIES PLANNING

This block on Facilities Planning has five units dealing with different aspects impinging on facilities planning. Facilities here refer to production plants and other facilities for service institutions like hospitals, colleges, canteens, airports etc. The first stage for facilities planning is selection of Product. The issues concerned with product selection are thus discussed in the very first unit of this block (Unit No. 2). After product (or type of service) selection has been made, one has to select the process (discussed in Unit No. 3). Where the facility should be located becomes the next question. There are a lot of considerations which impinge on this question which are discussed in detail in Unit No. 4. Once the facilities location has been decided, the layout of facilities has to be done which has been discussed in Unit 5. A mention is also made of different materials handling equipment. Finally in Unit 6, capacity planning is discussed. The related issues of demand forecasting and capacity forecasting are also discussed. A number of quantitative or operations research techniques have been referred to in this block. These techniques are not discussed fully since their details would be handled in Course MS-7 and other courses to follow.

UNIT 2 PRODUCT SELECTION

After going through this unit, you should be able to:

- recognise that all outputs of any organisation are services
- appreciate Product Selection as one of the key strategic decisions of any organisation, wherein the organisation attempts to match its production with changes in environment, changes in consumer taste and changes in technology
- learn the concept of producibility and its effect on product selection
- identify the various stages involved in the product selection process
- have a brief idea of the new product mortality curve and the message it conveys about reducing research costs
- know the issues involved in screening a new product idea
- identify the trade offs involved in product design
- understand the impact of product design on process design.

Structure

2.1 INTRODUCTION

We have looked at operations as the process of converting inputs into outputs and thereby adding value to some entity. This concept of value addition is very important for effective management of the operations function. Although the 'conversion' takes place inside the organisation, the addition of value occurs only when it is perceived to have done so by the customers of the product or service in the market place. This concept changes the orientation of an operations manager from totally inward looking to one who is alert to the needs of the customers. As we go on to discuss the strategic decisions in operations management in the next couple of units, this issue will come up again and again and it is not out of place to remind ourselves once more that it is not enough to produce a product or service but it has to be produced so that there is an added value as perceived by the market.

Although we differentiated a product from a service above, this differentiation becomes very hazy and confusing. For example, if we are selling a computer, we are selling a product of course. However, instead of selling the computer if we start leasing it to our customers—what are we selling now—a product or a service? On the other hand, so far as the customer is concerned—he is using the computer exactly in the same manner in both these cases. The difference is only in terms of payment and the legal ownership of the asset. Similarly, even when the computer is sold outright, we are also selling after-sales service and other customer support services along with the computer. Thus, we start seeing that so far as the customer is concerned he is only buying some benefits in all these cases and these benefits are services. Services are bundles of benefits, some of which may be tangible and others intangible, and they may be accompanied by a facilitating good or goods. If there are no accompanying facilitating goods, e.g. getting a haircut, we will refer to these services as pure services.

All outputs of an organisation are services and in this unit we would take a deeper look at output selection. Thus, although we have titled the unit as **product selection,** we would like to pursue it as **output selection** keeping in view the service nature of any organisation that we presented above. In what follows, the term product is thus used in its generic sense and is meant to include services.

A Strategic Decision

Product selection is a strategic decision for any organisation. Such decisions are long term decisions and the organisation commits itself to the product/products selected for a long time to come. What products to produce—in what form and with what features—is very important because many other decisions—for example, the technology used, the capacity of the productive system, the location of the production facilities, the organisation of the production function, the planning and control systems, etc. are dependent on this. The competitiveness and profitability of a firm depend in part on the design and quality of the products and services that it produces, and on the cost of production. The design of a product or service may make it expensive to produce and a change in design may make it possible to produce the same in a less expensive way. Similarly, one design of a product or service may require large and expensive additions to capacity of some process whereas a change in design may make it possible to produce the same with existing capacity.

Product selection is a strategic decision, thereby involves other functional areas like marketing, research and development and as well also the top management therein. The operations management function provides vital inputs regarding the production of the product or service in these decisions making.

Producibility

The product selection process is a highly integrative process. Thus product function, cost, quality and reliability are some of the inputs to this decision. The producibility of a product/service measures the ease and the speed with which the output can be produced.

The specialised equipment, specialised skills and specialised toolings, facilitate in switching production from one product to another etc. and are thus important factors to assess producibility. It is also important to look at the complete range of products produced because a new product may either use the capacity of processes/sub-processes already established or may require the establishment of capacity of some processes/sub-processes. A family of similar products is much simpler to produce than a family of dissimilar products.

2.2 THE PRODUCT SELECTION PROCESS

Product selection is an ongoing process in any organisation. In fact, as the environment changes, as new technology is developed and as new tastes are formed, the product should benefit from these developments; otherwise what is perceived to have added value today may not be perceived as such tomorrow. For example, jute has been in use as a packing medium for a long time. However, with changes in technology and consumer taste, the same product is no more perceived to have added value and therefore, its demand has reduced.

Product Selection Stages

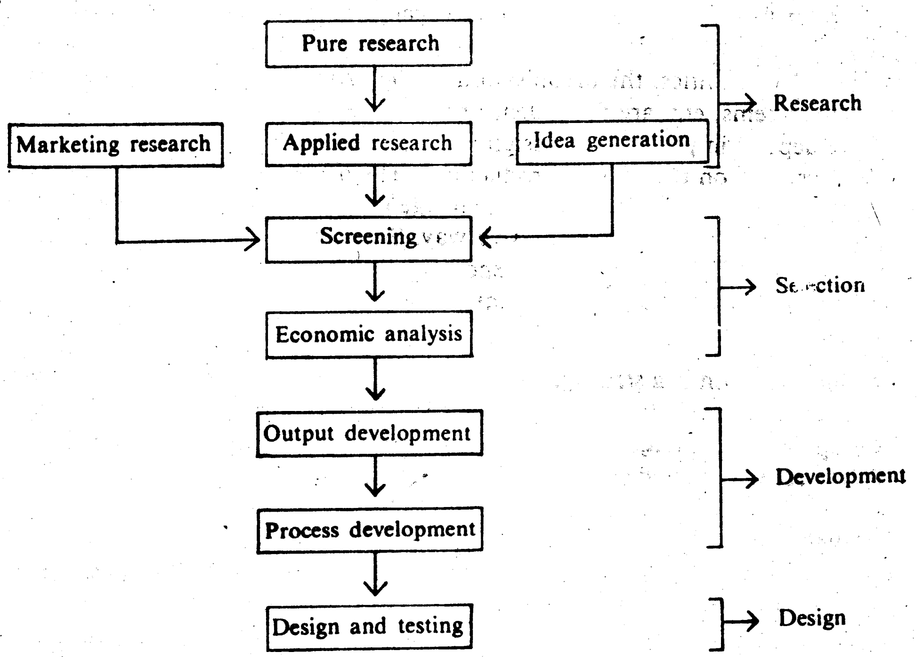
The process of creating, selecting, developing and designing the output of an organisation is shown in Figure 1. We will follow the same sequence in our discussion as well. Output possibilities are generated from many sources:

a) From the field itself through market research. This can take the form of consumer surveys, dealer surveys, opinion polls etc.

b) From research laboratories. This can be due to a breakthrough achieved by pure research or applied research in developing new knowledge.

c) From conscious and formalised attempts to generate new ideas for products or services. These ideas can be generated by using techniques like brainstorming, panel discussions, scenario building, technology forecasting etc.

Figure I : Stages of Bringing A New Output to Market



Source : Adapted from Meredith & Gibbs, 1984, *The Management of Operations*, John Wiley, New York, p. 55.

The output ideas thus generated are then screened where their match with corporate objectives and policies is studied and their market viability is established. A detailed economic analysis is then performed to determine the probable profitability of the product or service. For non-profit organisations, this takes the form of a cost-benefit analysis. This is followed by development of the product or service from a concept to a tangible entity and finally by design and testing.

No Smooth Sequence

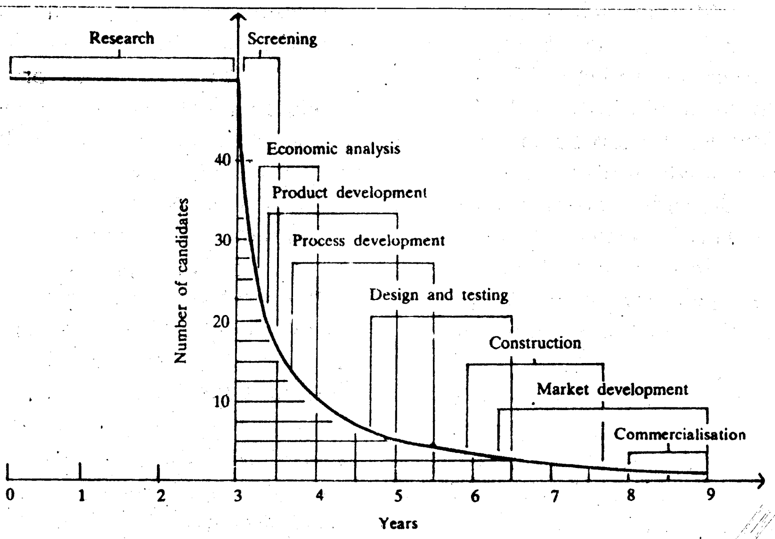
Although Figure I depicts product selection as a sequential process where one stage follows another, in reality, the process may not be so smooth as shown. Thus, economic analysis may have to be done after output development if reliable cost estimates are not available at the earlier stage. Similarly, new product features may be added at any of the above stages, thereby initiating a whole new cycle. Finally, as product selection is an ongoing process, there is no finality to the process since as some new product ideas are being processed, still new ideas enter the output selection process and this may go on and on. The product selection process therefore ensures a continuous match between what is demanded and what is produced.

In some cases, the production process has also to be designed along with the product or service. This has to be done, for example, when the market viability of the product depends on low cost and so the production process has to be decided along with the product design. Or take the case of another product where it is felt imperative to obtain a large market share right from the initial launch. It may become necessary to establish a large capacity for the production process right from the beginning. The production process has to be designed along with the product in such a case.

New-Idea Mortality Curve

The previous section highlighted the fact that an output possibility has to cross several hurdles before it enters the market as a commercial product or service. The new idea mortality curve presents the same in a graphical manner. Figure II shows the mortality curve for a hypothetical group of fifty chemical product-ideas. Although the product ideas are hypothetical, still the stage-wise mortality as well as the time frame shown is quite indicative. Figure II assumes that after three years of research, fifty potential chemical product-ideas are available for consideration. Initial screening reduces this number to about half and after economic analysis, by the end of year four, the number of potential products decreases to nine. The mortality of ideas continues over time and by the end of five-and-a-half years, at the completion of the product and process development stages, the number has already fallen to about five. Design and testing reduces this further to about three and by the end of construction, market development and commercialisation, just about one successful product is left. Figure II is based on international experience, and situation in India has not been tested empirically. Thus, the mortality curve should be treated as an indicative proposition in the Indian context.

Figure II : New Idea Mortality Curve From Research To Commercialisation For Chemical-Product Ideas



Source : Adapted from Meredith & Gibbs, 1984. *The Management of Operations*, John Wiley, New York, P.57

The curve also shows that converting product ideas into marketable products is a slow process. For chemical products, on an average it takes six years to commercialise a product after the initial research has been completed, as is shown by Figure II. At the end of it all, a product commercially launched may not turn out to be successful and the mortality may extend to the product as well.

The actual figures in Figure II are only indicative and within an industry firms differ in the speed at which they can convert a product idea into a commercial product. Some organisations are more innovative than others and they are always ahead with more new product ideas. Similarly, some organisations are more risk-taking than others and attach a high priority to being a pioneer with new products than others who are relatively risk-averse and would like to do a more thorough job of screening, economic analysis, product development, design and testing and would perhaps also wait-it-out to see how some others have fared with similar products.

Activity A

In the context of your own organization, study the pattern regarding new idea mortality curve. Though not mandatory, we would welcome if you send your analysis to the IGNOU School of Management Studies.

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Cost of New Product Ideas

The new idea mortality curve also points to another fact by implication. The cost of pursuing different new product ideas till their abandonment is also to be borne by the few successful products. This significantly increases the cost of new product development and justifies the rationale of collaborative research. The research and development for a product is carried out at one place and later on the knowledge gained is made available to the collaborating organisations, which are then free to make independent product developments of their own. A similar concept holds for our industrial research institutions in the government sector. For example, in the early stages of development of the television industry in India, Central Electronic Engineering Research Institute, Pilani (CEERI) developed an indigenous design of a black and white television set and made it available to television manufacturing organisations for a fee.

Activity B

Generate at least three new output ideas your organizations.

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2.3 SELECTION OF THE PRODUCTS

At the research stage, the priority should be generation of new ideas. In fact, it is better not to start the screening process till a reasonable opportunity has been provided to generate all new ideas. This is because different thought processes are required for generation of new ideas and for a rational analysis of the same. Consideration of one new idea may generate a better idea whereas an evaluative analysis introduced early in the process may hamper the creative process of idea generation. Some techniques for idea generation, for example, brainstorming, explicitly prohibit any analysis or criticism (based on analysis) of suggested ideas at the idea generation stage.

Once a number of potential new product or service ideas have been generated, the process of screening them to evaluate and select the 'best' idea is set in motion. This can perhaps be discussed in two phases—a qualitative phase where the new product idea is studied in terms of its match with the corporate objectives and the corporate strategies of the organisation. The second phase is more quantitative in the sense that potential costs and revenues (or benefits) generated by new product are quantified and an economic analysis is performed to establish the economic viability of the new product or service idea.

Screening

The new product or service idea is assessed to establish its market viability as well as to find out if it is in the larger corporate interest of the organisation to add this new product or service to the current outputs of the organisation.

A product or service has to have sufficient demand or else it may not make much sense to produce it at all. Of course, what is considered sufficient by one organisation may be considered to be grossly insufficient by another. Also the demand for a product or service is dynamic and although the current demand for a product or service may be assessed to be low, an organisation may still decide to

retain the new output idea for further analysis if it assesses that the demand will grow in future. For example, vacuum cleaners are still in the introduction phase of their product life-cycle in India and an organisation may select this as its product if it assesses that sales will grow in the near future.

Activity C

Identify some products of your organization which are in the growth stage. What are the criteria followed in your organization to decide about new product/service introductions.

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Each organisation has some corporate strengths and weaknesses. New product or service ideas should capitalise on the strengths and should attempt to reduce the weaknesses to the extent possible. On the other hand, if one of the determinants of success for a new product or service idea is already perceived to be a corporate weakness, such a product or service does not have a good 'fit' with the strength and weakness profile of the organisation. For example, if strong design capability is identified as a corporate strength of an organisation then adding heat exchangers to its list of products—which have to be custom designed and built is trying to exploit a corporate strength. On the other hand, another organisation which has identified design capability as one of its weaknesses would perhaps select centrifuges which are standard products and offered off-the-shelf.

It is important to realise that strengths and weaknesses are relative and also perceptive. The same feature can be perceived to be a strength by one organisation and as weakness by another. For example, low investment in capital assets can be considered to be a strength since this gives the organisation greater flexibility in product selection and adjusting to changes in demand whereas the same can be perceived to be a weakness when capacity cannot be hired from outside or the quality of jobs got done from outside is unsatisfactory. What is important is to ensure that there is a close match between the strengths and weaknesses of the organisation and the requirements for the product or service to succeed.

In product selection, many organisations try to get synergistic results by exploiting one or more of the following four factors:

i) Familiarity with similar products or services
ii) Familiarity with the same or similar production or transformation process to produce the product
iii) Familiarity with the same or similar markets or market segments
iv) Familiarity with the same or similar distribution channels.

Thus, it is perhaps natural for a firm manufacturing ceiling fans to include heat convectors in its product list, wherein it can benefit from its familiarity with similar production process, similar market segments and even the same distribution channel. On top of it, it can also reduce its weakness of having a highly seasonal capacity utilisation.

The above discussion also highlights the fact that any new idea for a product or service has also to be seen in relation to the effect on the existing products or services. A new product may find a market for itself by cannibalising one of the existing products. A new brand of a biscuit may create its market by a corresponding reduction in demand of another brand from the same firm unless the two are carefully targeted at different segments.

We have referred to the strengths and weaknesses of an organisation as relative, but relative to what? Of course, relative to the competition. If there is no competition, which is very unlikely, there is no need to match the product requirements with the relative strengths of an organisation. For totally new products or services, even if there is no competition presently, very soon competition will perhaps develop and it is the desire to remain ahead of the competition that provides the motivation for continuous inflow of new product ideas. Whatever be the relative strengths and weaknesses of any organisation, it is very unlikely that an organisation can be successful if its strengths are only in marketing, finance and other non-operational areas. In fact for long-term success, it is almost imperative that sound operations management is one of the strengths of the organisation.

Sometimes a new product or service idea having very poor match with the existing strengths and weaknesses of the organisation is consciously adopted. This can happen if the organisation feels that the existing products or services have reached the decline phase of their product life-cycles either on their own or due to some changes in the environment e.g. government policy, introduction of better and cheaper substitutes, changes in prices of some inputs etc. For example, when ITC Ltd. decided to diversify into hotels, this new service idea did not exploit any of the four familiarity factors which could have given some synergistic results.

Economic Analysis

An economic viability of a new product or service idea ties up most of the concepts that we have talked so far in quantitative terms to the extent possible. What this means is that the economic value of the returns must exceed the economic value of the costs incurred to produce the output. For commercial organisations, the measurement of the returns and costs is relatively straightforward and economic analysis in a way becomes synonymous with profitability analysis. The cash flows generated as well as consumed, if the new product or service idea is implemented, have to be estimated for the life of the project. However, since there is a time value of money these cash flows cannot be directly added or subtracted. So, the cash flows are discounted to take care of the time value of money and the net present value of all cash flows is obtained—or else the cash flows are used to find an internal rate of return. The details of how to discount cash flows are discussed in the course MS-4.

Non-Profit Organisations

For non-profit organisations, there may not be a cash inflow at all, or else the cash inflows may occur at externally fixed prices. For such organisations economic analysis generally means a cost benefit analysis, which is similar to the cash flow analysis mentioned earlier but now the net present value of all benefits less that of all costs is used as an indicator of economic viability. The benefits imply an addition of real resources to the society as a whole whereas the costs imply using up real resources as a result of implementation of the new product or service idea. These items of cost and benefit are valued so that they reflect the social willingness to pay for the same. Wherever free market conditions exist, the market prices can be used to value the costs and benefits. On the other hand, economic prices are first estimated and then used to value those costs and benefits for which free market conditions do not exist.

Economic analysis is, therefore, much more difficult for non-profit organisations than for organisations having a profit motive.

Activity D

For a non-profit organization like a hospital, consider the ways in which the services can be costed or priced?

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Activity E

Screen the ideas generated in activity B by you, considering the likely dermand and the desirability of adding these out puts.

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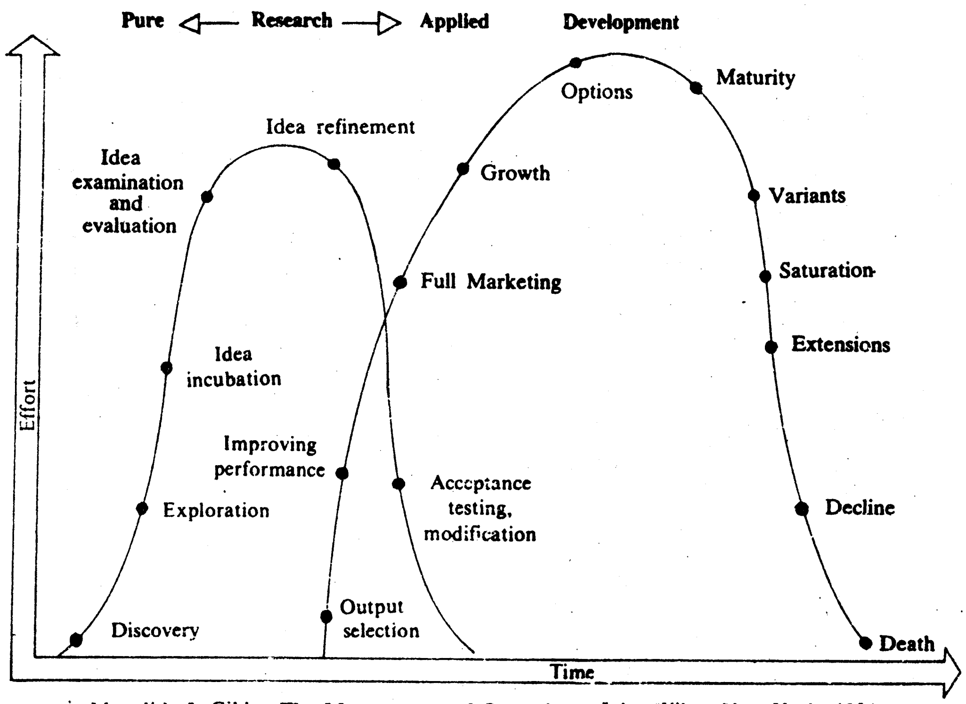
2.4 PRODUCT DEVELOPMENT

Product development concerns itself with modifications or extensions provided to ideas so as to improve the functioning, the cost, the value-for-money of the product. Development effort improves the performance of the product, adds options and additional features and even adds variants of the basic product. On the whole, development effort is innovative vis-a-vis research which is more inventive—the thrust being on developing new product ideas, technologies and processes.

Development Efforts

Figure III charts the development effort over time for a typical product. The figure also shows the effort made for research to show the rel tive magnitude of effort as well as the timing of the two. Development starts after research has established an idea which has been examined, evaluated and even refined. The development effort rises initially as the performance of the product or service is improved and as the product itself graduates to the growth phase of its product life-cycle. The development effort still continues to rise but now the result is mainly providing options. As the product reaches its maturity, the development effort has peaked and thereafter gradually starts reducing. In this phase, product variants are developed and offered so as to lengthen the life cycle. This is followed by extensions of the product and Figure III highlights the fact that product development is an ongoing process which starts as the product is launched in the market and continues till it is withdrawn from the market.

Figure III : The Development Effort Through The Product Life-Cycle of A Product



Source : Meredith & Gibbs, **The Management of Operations**, John Wiley, New York, 1984, p. 66

What is more important—research or development? Development can start only when research has produced a product or service idea which is technically feasible and economically viable. However, greater effort is expanded on development as compared to research in most parts of the world today than it was, say 30 years ago. This is partly because the new products e.g. colour television, are more complex and require longer to debug and to improve their performance. This could also be true because research has become very expensive and organisations are under pressure to commercialise research as early as possible, even before the product or service ideas have been refined and debugged. But one possible consequence of this shift away from research is that organisations make themselves vulnerable to technological breakthroughs which can give rise to a whole new generation of the product or service itself. The tradeoff between research and development is an important strategic decision for most organisations.

2.5 PRODUCT DESIGN

At the design stage, detailed specifications are provided so that manufacturing can produce what has been designed. This means not only providing dimensional specifications but even specifications regarding capacity, horse power, speed, colour etc. are laid down and the task of manufacturing is to convert the design into physical entities.

Product Variety

There are two distinctly different priorities that can affect the design of a product or a service. The higher the standardisation, the greater will be the ease in producing. On the other hand, customers have different needs and by adding variety, one can satisfy more customers. Standardisation attempts reduction in variety and better use of productive facilities, thereby achieving lower unit costs. If the demand for the product or service is strong when the price is low, organisations will try to minimise unit costs through standardisation and most of the competition will be based on prices. There are other cost-related advantages due to standardisation. It simplifies operational procedures and thus reduces the need for many controls. The organisation can buy raw materials and components in bulk and thus get quantity discounts. It enables steady flow of materials through work centres and thus reduces the number of production set-ups related to change in flow. It reduces the total inventory of raw materials, work-in-process and finished goods. Finally, since the effective volumes become larger as the variety is reduced, high-volume production methods become viable thus giving economies of scale in production itself.

Standardisation is a very useful concept but production needs have been given the highest priority in this scheme of things. This may be a very good approach to product design as long as cost is the primary basis of competition. Otherwise, one can design a product to suit the diverse needs and tastes of the customer. All watches are meant to display the right time but still a company like HMT has hundreds of models of watches with different movements, dial shapes, sizes and other features. By adding variety, an organisation attempts to satisfy the varied needs and tastes of its customers and competes on non-price considerations as well.

One method used to obtain variety or perceived variety and yet hold down cost is through modularisation. A product is designed using modules or sub-assemblies that are interchangeable and each different combination of modules gives a new variety of the product. For example, two different movements, three dial shapes, two dial sizes for each shape and three different colours will give 2x3x2x3 i.e. 36 varieties of watches, yet making large quantities of standard modules.

Design simplification attempts to simplify the design so that the product or its parts become simpler to produce. This might mean combining two or more parts into one so that some assembly operations are eliminated. In some other situation, this might involve replacing screw fastened parts by parts which can be snapped tight in place without any fasteners. Design simplification gives pay-offs in terms of lower production costs and in some cases by lower material costs as well.

Activity F
From the experience of your own organizations or your general experience identify some products which follow a modular design approach.

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Structuring of Options

Options provide variety to a product increasing its attractiveness to a spectrum of users while retaining operations as simple as possible. We can see optioned products everywhere—from computers and office furniture to automobiles and machine tools. Even services have options built-in, for example in vehicle insurance.

Structuring the options is a major part of making a product line competitive when not competing on costs alone. However, options bring in their own complications as well. For example, pricing becomes much more complicated since each option may not have the same margin. A lot of sales effort is required explaining options or determining what the customer wants and it complicates the customer's choice. Options also give the customers an opportunity to change their mind and this creates additional difficulties where the product is made-to-order. All options are not used to the same extent and low-usage option parts become hard to plan and control when mixed with a high-usage option part.

CAD/CAM

A part can be computer designed (computer-aided design) and its fabrication instructions can be generated by computer-aided manufacturing (CAD/CAM). This has the advantage that the manufacturing equipment is not tied up for long periods during setting up time. Practically all the preparation time is in programming where detailed instructions regarding the physical task to be performed and the sequence in which these have to be performed are written into a programme which can be read and executed by a computer having the machine tool or any other manufacturing equipment under its control. This then allows for very small batch sizes without losing on economy. Finally, because information regarding the design and the manufacture of the product and component is available on computer files, it is possible to use the data together with other information on materials, tools, etc. for production planning and control purposes thus achieving computer-integrated manufacturing (CIM) that has great importance for the future. CIM is not yet a reality, but is certainly the direction toward which manufacturing in some industries is proceeding.

Design Characteristics and Tradeoffs

By now it should be quite clear that there are many product features which can be affected by product design. In fact, Operations Management normally has a major role to play while final product characteristics are set.

The **kev elements** to be considered **in product design** are:
a) Function: the new design must properly meet the recipient's need and perform the function for which it is designed.
b) Cost: the total cost incurred in producing the new design should not be excessive, else that will affect its demand.
c) Quality: the quality of the new design should be as high as possible, within the constraints of the cost. Quality can cost money and excessive quality will increase the cost and reduce demand, whereas inadequate quality will affect the performance and lead to complaints and fall in demand.

d) Reliability: the new design should function normally without failures for the expected duration. This is more important for complex designs involving many elements and the design must provide for redundancies and high reliability of elements so that high system reliability can be obtained.

The other elements which are also important in a product design, perhaps to a lesser degree are:

e) Appearance: if the new design can be made more attractive, without sacrificing on the other attributes, that is only likely to improve the demand. The relative importance of appearance varies from product to product and in many industrial equipment, it may have a relatively small effect.

f) Environmental Impact: the new design should not degrade the environment.

g) Product Safety: the new design should not pose a hazard to the recipient.

h) Productivity: the new design should be producible with ease and speed.

i) Maintainability: this is particularly applicable to consumer durables and industrial equipment. If a failure occurs in the equipment, it should be easily repairable with a minimum of down time.

j) Timing: this is particularly relevant for design of services. The service should be available when desired by the recipient.

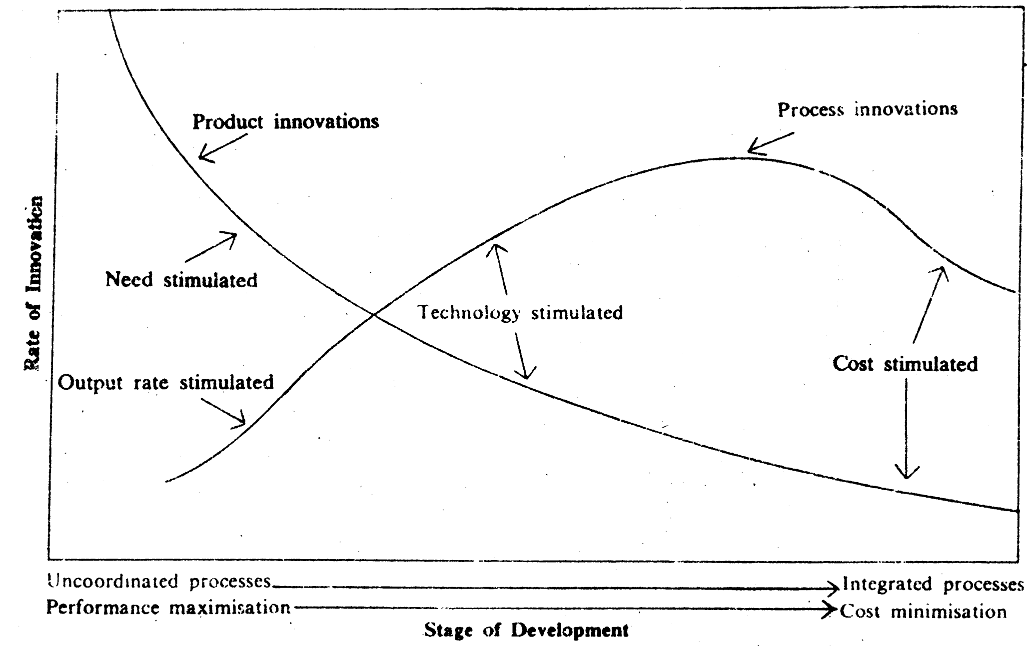
k) Accessibility: this element is also applicable to services. The recipient should be able to obtain the service without difficulty. The last two factors are important for design of services since services cannot be inventoried.

In both product and service design, many alternatives usually exist that will meet the basic function of the output. The design task is to recognise the major characteristics of the demand and to carry out a detailed analysis of the tradeoffs available among the various design alternatives, so as to meet the needs of the recipients as closely as possible. Sometimes, when the needs of the recipients are diverse, design will produce different models or versions of the same basic product to satisfy the needs of different segments of the market. This can be seen from the various models of television produced by almost every television manufacturer or the economy and the executive classes of air travel offered by Indian Airlines.

The Impact of Product Innovation on Process Innovation

The design of a product or service has very close linkages with the design of the process required to produce it. In some cases, the product design itself becomes feasible only because of technological innovations. Throughout the product life-cycle, the process of product development goes on and we have looked into this aspect in section 4.4. It has been found that similar innovations take place in process design as well and this is shown in Figure IV below.

Figure IV : Product And Process Innovations in the Life-Cycle of a Typical Product



Source : Buffa E S, *Modern Production/Operations Management*, Willey Eastern, New Delhi, 1983, p. 107

Figure IV shows that in the first stage, product innovations are primarily need-stimulated and the emphasis is on maximisation of product performance.

The process is typically uncoordinated in this stage and process innovations are primarily output-rate stimulated. Product innovations are gradually decreasing while process innovations pick up at this stage.

In stage two, both product and process innovations are technology-stimulated. The productive system design emphasises cost minimisation as competition in the market begins to emphasise price. Process innovations start dominating over product innovations as they yield greater reduction in cost.

The product or service has reached maturity and saturation by the third stage and innovations are stimulated primarily by cost considerations. The productive processes become highly integrated and product-focused operations try to achieve economies of scale by having integrated plants of large capacities.

2.6 SUMMARY

We have looked at the processes of bringing new product and services to the market in this unit and the role of operations in that process. We identified all outputs of an organisation as services, sometimes along with a facilitating good and sometimes without that. Product selection is a strategic decision for the organisation and the top management as well as functions like marketing, R & D and engineering have a role in the making of product selection decisions.

We looked at the stages involved in bringing new output from an idea stage into a tangible entity in the market. New product ideas are generated through market research, research laboratories themselves or conscious, formalised attempts. These ideas have a very high mortality and the new idea mortality curve showed that hardly 1 or 2 per cent of all new ideas are carried through to the market.

New product ideas are first screened for market viability and their fit with corporate strengths and weaknesses. These are then subjected to an economic analysis. New product ideas are then developed, features are added or dropped, variations introduced and the product is finally designed and tested for a commercial bunch.

Product designs attempt to introduce a product having characteristics as close to what is desired by the customers as possible and this involves tradeoffs between elements like the function, cost, quality, reliability and others like producibility, maintainability, product safety, environmental impact, etc. Finally, we found that product innovations and process innovations are closely linked to the life-cycle of the product itself.

2.7 KEY WORDS

Producibility of an output refers to the case and speed with which the output can be produced.

New-Idea Mortality Curve shows in a graphical form the number of output ideas surviving after each of several hurdles till the ideas get converted to outputs and enter the market.

Product Development refers to modifications or extensions provided to ideas so as to improve the functioning, the cost, the value-for-money of the product.

Standardisation attempts reduction in variety and better use of productive facilities thereby achieving lower unit costs.

Modularisation involves designing the output using modules that are interchangeable and each different combination of modules gives a new variety of the output.

Product is used here in its generic sense and is meant to include services; same as output

Output Ideas refer to ideas regarding possible new outputs which, after refinements and modifications, could result in some outputs offered in the market.

Screening the process of establishing the market viability of a new output idea as well as to find the desirability of adding the new output to the outputs of the organisation.

2.8 SELF-ASSESSMENT EXERCISES

1 There are many stages involved in bringing a new output to the market. Why can't the stages be performed in a smooth sequence?
2 Give examples of some organisations where you feel the new-idea mortality rates would be low. Why?
3 Can services be standardised? Should they be standardised?
4 How should an organisation balance the different design characteristics in a new product?
5 What are the important factors to be considered while finding the 'fit' of an output to an organisation?
6 Explain the Product Selection and stages involved therein.
7 What is producibility? How does it affect product selection?
8 "Product development and design is basically a research and development activity". Elaborate the statement with suitable examples.
9 Explain Product design. How does it influence the Process Design?

2.9 FURTHER READINGS

Adam, E.E. and R.J. Ebert. 1982. *Production and Operations Management* (2nd edition); Prentice-Hall: Englewood-Cliffs.

Buffa, E.S. 1983. *Modern Production/Operations Management* (7th edition); Wiley Eastern: New Delhi.

Hall, R.W. 1987. *Attaining Manufacturing Excellence,* Dow-Jones Irwin: Homewood.

Meredith, J.R. and T.E. Gibbs. 1984. *The Management of Operations* (2nd edition); John Wiley & Sons: New York.

Wild, R. 1985. *Essentials of Production and Operations Management* (2nd edition); Holt, Rinehart and Winston: London

UNIT 3 PROCESS SELECTION

Objectives

After going through this unit, you should be able to:

- identify the various tradeoffs involved in process selection
- know the issues involved in the general transformation process selection procedure
- learn the four forms of transformation processes—their characteristics, advantages and disadvantages
- know about the new technologies that are applicable to the transformation processes
- understand the concept of Process Life-cycle
- learn the use of break-even analysis in choosing the least cost process
- appreciate the need to maintain focus in all production operations.

Structure

3.1 INTRODUCTION

The transformation process that converts inputs into outputs with added value is the core element in the operations function. The selection of the process is therefore a strategic decision for most organisations. The process selected will, to a very large extent, determine both the quality and quantity of men and women to be employed as well as the amount of capital required for the production of goods and services. In fact, many organisations are slowly coming round to the view that operations has been the missing link in the traditional approach of formulating a corporate strategy wherein the production or operations function is expected to play a supportive role to marketing.

Undoubtedly, marketing has to establish what is to be produced to satisfy the needs of the customers. However, the traditional approach is partly based on the view that "PRICE = COST + PROFIT". Looked at this way, the price of a product or service is obtained by adding a profit element to the cost incurred in producing the same.

This view of looking at profit and price may not have any serious problem if the environment is less competitive. But as markets become more competitive, the customers have more choice in terms of product attributes like design, functions, ease of use, performance, quality and cost.

The transformation process, therefore, has to be so selected that it can provide the desired product attributes and at the same time remains cost-effective. This can be best achieved by taking a strategic view of the production/operations function and by integrating the operations function including process selection while formulating the corporate strategy of the firm.

In this unit, we shall discuss the major factors involved in the selection of the transformation process, the various alternative process forms available and the process involved in selecting an appropriate transformation process.

Process Selection as an Adaptation

The major considerations in any process selection e.g. capacity, flexibility, lead time, efficiency in using resources are so interdependent that changing the process to alter one will almost invariably alter the others as well. There are numerous tradeoffs available while selecting a process—between different materials, between requirements of labour and capital, between volume and variety, between cost of production and flexibility and so on. It is important to know the consequences of every such tradeoff.

The transformation process selection is a complex decision because of the existence of so many tradeoffs, many of which are also interdependent. Generally speaking, there is no concept like the best process for a particular conversion. Rather, many times it is an attempt to find a process which produces acceptable levels of attainment on many objectives some of which are incongruent. For example, we want a process which is flexible as well as instrumental in producing outputs with least cost. Obviously, we cannot have both and so our attempt will be to select a process which has acceptable levels of flexibility and cost. One can give similar examples from the other tradeoffs mentioned earlier. Such a situation only highlights the need to integrate these decisions while formulating the corporate strategy of the firm.

By now it should be clear that any change in the host of factors mentioned above will have a profound effect on the process selected. For example, with the passage of time, if the volume or the variety of the products/services produced undergoes a change, a different process form might become more appropriate. Therefore, the process selection continues to remain an adaptive process.

Process Selection and the Environment

As a strategic decision, the process selection decision is influenced by the environment to a very great extent. With newer materials are becoming available such as a different transformation process which might become more appropriate. This phenomenon can be seen very clearly wherever plastics are being used as newer substitutes of some natural material. Metal containers giving way to plastic containers mean a totally different transformation process for the company manufacturing containers. New synthetic packaging materials have caused significant changes in the process involving packaging of consumer products.

Similarly, development of new technology may render a process obsolete as the new technology is more economical, uses cheaper material or produces goods with a higher quality level. Bolts can be made by machining hexagonal rods. However, with the development of cold forging, the material wastage involved in metal cutting can be totally eliminated giving rise to a process which is not only more economical but faster as well. Not only the manufacturing technology, but the technology involved in organising the operations function also has an effect on the process selected. This can be seen when concepts like Group Technology or Autonomous Working are used and we shall discuss these concepts later in this unit.

The competitors might also affect the process selected for a transformation. For example, when the competitors can deliver the product or service much faster than us, this may lead to a review of the form of process selected for our operations function. Similarly, when we want to compete on non-price factors like quality, custom-made product designs, shorter lead times or easier availability, the transformation process has to be geared to the combination of such factors that we consider to be important.

3.2 FORMS OF TRANSFORMATION PROCESS

Process selection is actually a generic decision and in practice this refers to the selection of sub-processes and sub-sub-processes depending on the type of output that is produced. If the output is a product then, following the design of the

product, this can be broken down into sub-assemblies and sub-sub-assemblies till we reach an elemental level of components which cannot be broken down further. Now, for each of such components we have to decide whether to produce it ourselves or to buy from outside. If it has to be produced by us, then the process selection decisions concern the technology to be used, the sequence of operations to be performed, including in process storage and transportation from one work centre to another, equipment required for the transformation, staffing, the detailed work place layout, design of special tools, jigs and fixtures and so on. If the product requires an assembling of components and sub-assemblies, then the assembly process has also to be selected and designed appropriately. In fact, there may be no best way to produce a product or service; rather it may always be possible to improve both the output and the process selected to produce it.

Establishing the Volume and the Variety

One of the major considerations for process selection is knowing where we want to peg our organisation on the volume/variety continuum. The volume/variety continuum can be conceived of as an imaginary straight line, one end of which refers to very high product variety implying each product to be different from each other, consequently having very low volume viz., only one of each product. As we shall see later in this unit, such high variety requires the use of highly skilled labour, general purpose machines and in general, detailed and complex operations, planning and control systems.

The other end of the continuum refers to very low product variety implying a single standard product that is produced in very high volumes. Such a combination enables us to use highly automated, mass production processes using special purpose machines and simple production planning and control systems.

Produce-to-stock or Produce-to-order

A related consideration for process selection is whether the product is to be produced and stocked in our warehouses to be sold as and when the demand occurs, or is to be produced only on receipt of an order from the customer. It is a related consideration because, usually standard products with less variety are produced in batches and as sales proceed, we draw the products from the inventory. When the inventory level touches a predetermined minimum level, a fresh batch of the product is produced and such a cycle goes on. In this system, goods are produced in anticipation of sales orders and the customer gets immediate delivery and does not have to wait. However, such a system can work only with inventoriable products and the shorter the shelf life of a product, the higher the risks undertaken by the producer. For example, newspapers have a very short shelf life and so the risks of overproducing as well as underproducing are high.

When we produce-to-order, the production process starts after receiving the sales order in quantities dictated by each sales order. All custom-made products are produced-to-order since the exact specifications are known only after receipt of the order. In such a system the customer has to wait while his products are being produced and so the longer the lead time for production, the longer the waiting period.

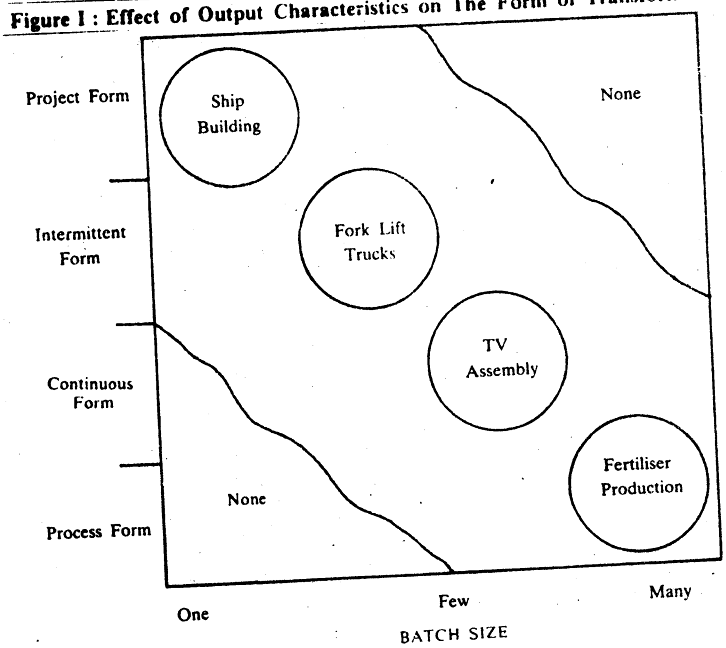
Services, by their very nature, cannot be inventoried and so services have to be produced to order. The transformation process in such a system has to be so selected and designed that the waiting time for a customer is not excessive.

Finally, we can have a combination of both these systems as well. For example, where a large number of options are provided on the product, the components and sub-assemblies might be produced to stock whereas the final assembly is carried out on order. In restaurants, food is semi-cooked in batches i.e. produced to stock and the final dish is prepared on receipt of a customer order i.e. produced-to-order.

Effect of Output Characteristics

In the previous sections we have said that the form of the transformation process depends to a large extent on output characteristics like volume/variety and whether produced-to-stock or produced-to-order. Figure I illustrates these comments by showing the relationship in a diagrammatic form.

Figure I : Effect of Output Characteristics on The Form of Transformation Process



Source : Adapted From Hayes, R.H. et al., "*Link Manufacturing Process and Product Lift Cycles*," Harvard Business Review, Jan-Feb. 1979

The horizontal axis which shows the output characteristics is represented in terms of the batch size. On one extreme we have products produced in batches of size one, i.e. each product is different from the other. On the other extreme we have products produced in infinitely large batch sizes. These are products with no variety and have the characteristics of a commodity like fertiliser, sugar, cement etc.

The form of transformation process is similarly represented on the vertical axis. The top end represents the project form where each project is followed by another project—no two projects are exactly alike and detailed planning, scheduling and monitoring has to be performed to keep the project costs and durations under control. As we go down the vertical axis the flow of materials becomes more smooth and uniform. These can be categorised as batch production or interrupted form, mass production or continuous form, and finally, as the name implies the processing form wherein there is no interruption in the flow of materials at all, as in a petroleum refinery or a fertiliser plant. In the subsequent sections we are going to discuss each of these process forms in somewhat more detail.

However, we would like to point out a couple of things in Figure I before we proceed further. First, as is shown in Figure I we would not find any process corresponding to the lower left hand region or the top right hand region of the Figure. That is to say, when the batch size is very small it is not at all advisable to use the continuous or the processing form of transformation. Similarly, when the batch size is really large, it is again inadvisable to use the project or the interrupted form.

The second point that emerges from Figure I is that for any batch size, there is usually a choice available in choosing the processing form. Thus, even in the same industry one may find different competitors using different processing forms and thus trying to create a special niche for themselves. For example, one manufacturer of ceiling fans might choose the interrupted form whereas another might decide to adopt the continuous form of production and both might coexist in the same competitive market.

It is also not difficult to see that Figure I also holds good for services (except that there is no processing form for service). The service provided by a lawyer on a law-suit is almost always of a project form. Services provided by a government agency is usually of the interrupted form whereas for some high volume services the continuous form is employed. In fact, in recent years, as the service sector is growing faster than other sectors, more and more services are gradually being pushed down the vertical axis of Figure I. Fast food service is a typical example of this phenomenon.

3.3 THE PROJECT FORM

Project operations are characterised by complex sets of time-bound activities that must be performed in a particular order. Distinctly different from all other forms of transformation process such that each project has a definite beginning and a definite completion, the project form of transformation is very useful when complex tasks involving many different functional specialisations have to be performed against strict deadlines.

If the output of the transformation process is a product, such products are generally characterised by immobility during the transformation. Such operations are referred to as Fixed Position assembly and can be seen in the production of ships, aircrafts, and construction of buildings, roads, etc. As projects have limited lives, a project team is usually set up to manage a project. Resources such as men, materials and equipment are brought together for the duration of the project. Some materials are consumed in the transformation process, while others like equipment and personnel are redeployed for other uses at the end of the project.

We give below a small list of projects to clarify our understanding of a project:

- setting up a new thermal power plant
- building a hospital
- modernising a textile mill
- constructing roads, bridges, buildings
- organising an annual sales conference
- launching a new product
- punching and delivering a programme like Diploma in Management
- computerising the purchase and the inventory control system
- conducting a two-week training programme.

The number and importance of project operations is growing at a very fast rate in most societies, including ours. We shall now discuss some of the possible reasons for this growth in project operations. The benefits from various development programmes are delivered through projects. With the spread of education and rise in income levels, people themselves organise projects in the areas of community development, travel and tourism, social functions etc. Each knowledge area is getting more and more specialised and on many jobs we now need inputs from different specialisation areas. The project form is very suitable to handle inter-disciplinary specialist groups.

The fast-pace of technological developments is forcing many companies to adapt to the new technologies. Such developments are taking place not only in the manufacturing technologies but also in packaging technology, material handling technology, computer technology and so on. Implementing a change is usually carried out through a project operation. Increased competition, similarly, is forcing companies to launch projects on cost reduction, higher productivity, better methods and so on.

Whenever a transformation process is to be carried out under severe time and cost constraints, i.e. whenever the penalty associated with time and cost over-runs is severe, the project form of transformation is the most suitable. With ever-higher prices of equipment and labour, the cost of delay in many activities is becoming intolerably high and that is another reason for the speedy growth in project operations.

Choosing the Project Form

There are many situations in which the project form of the transformation process is the most appropriate. Obviously, if the tasks involved are for a limited duration, there is perhaps no alternative to using the project form of operations to carry out the tasks within the time frame prescribed.

The project form also offers extremely short reaction times to changes—both internal and external. Thus, if the outputs belong to high technology areas where the product design and/or the process technology is changing at a very fast pace and the operations have always to be kept abreast of the latest developments, again the project form may be found useful. For example, the project form of operations is used very often when we are selling chemical plants.

When a transformation process requires inputs from many specialisation areas, the project form of organisation is known to perform well. This is because the project form draws upon a mixed complement of personnel from different functional specialisations (e.g. mechanical engineers, civil engineers, chemical engineers, technicians, marketing and financial specialists etc.). However, the same feature of mixed complement of personnel does not allow the project form to advance high technology areas. Another process form where operations are organised by functional specialisations may be more appropriate if advances in high technology areas is one of the desired objectives. In the latter form, a group of specialists help in developing a process related to their field of specialisation. Such a group usually has access to specialised manpower as well as equipment which also contributes towards advancing technology. In the project form, generalised resources (staff and equipment) which are usually used as specialised resources will have a poor utilisation.

When the tasks involved are of very large scale involving many inter-dependent activities, the project form of operations is typically chosen. This is because the project form is better suited for detailed planning, monitoring and control of a large number of inter-related activities many of which are performed by different agencies.

Activity A

Can you choose an area or activity in your organization where project from of organization ma be more suitable compared to existing organization from?

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Characteristics of Project Processes

Project operations are different from other forms of transformation process in the way resources are organised and deployed as also in the planning and control of various activities that constitute the project. In the following sub-sections we discuss some of these characteristics of project operations.

Short Life-cycle

Projects are designed to have a definite beginning and a definite end. Project processes are therefore different from all other forms of transformation processes in that they have a specific completion. At the end of one project, resources from this project could be redeployed elsewhere in other project processes or other operations. In fact, even during the life of a project, resource requirements are not uniform. Thus in the initial phase, resource requirements including manpower, are at a low level. But there is a fast build-up during which more and more resources are absorbed in the project. This build-up, however, gradually levels off and then there i a cutting back as the project nears its completion. However, the resource requirements in terms of a particular skill (e.g. design engineer, high pressure welder etc.) or a particular equipment (e.g. concrete mixer, pile driver etc.) may vary more unevenly and so resource levelling remains one of the major difficulties in project planning and scheduling.

Consequent Personnel Problems

This phenomenon of a fast build-up, a levelling off and final cut back in resource requirements can give rise to two related personnel problems.

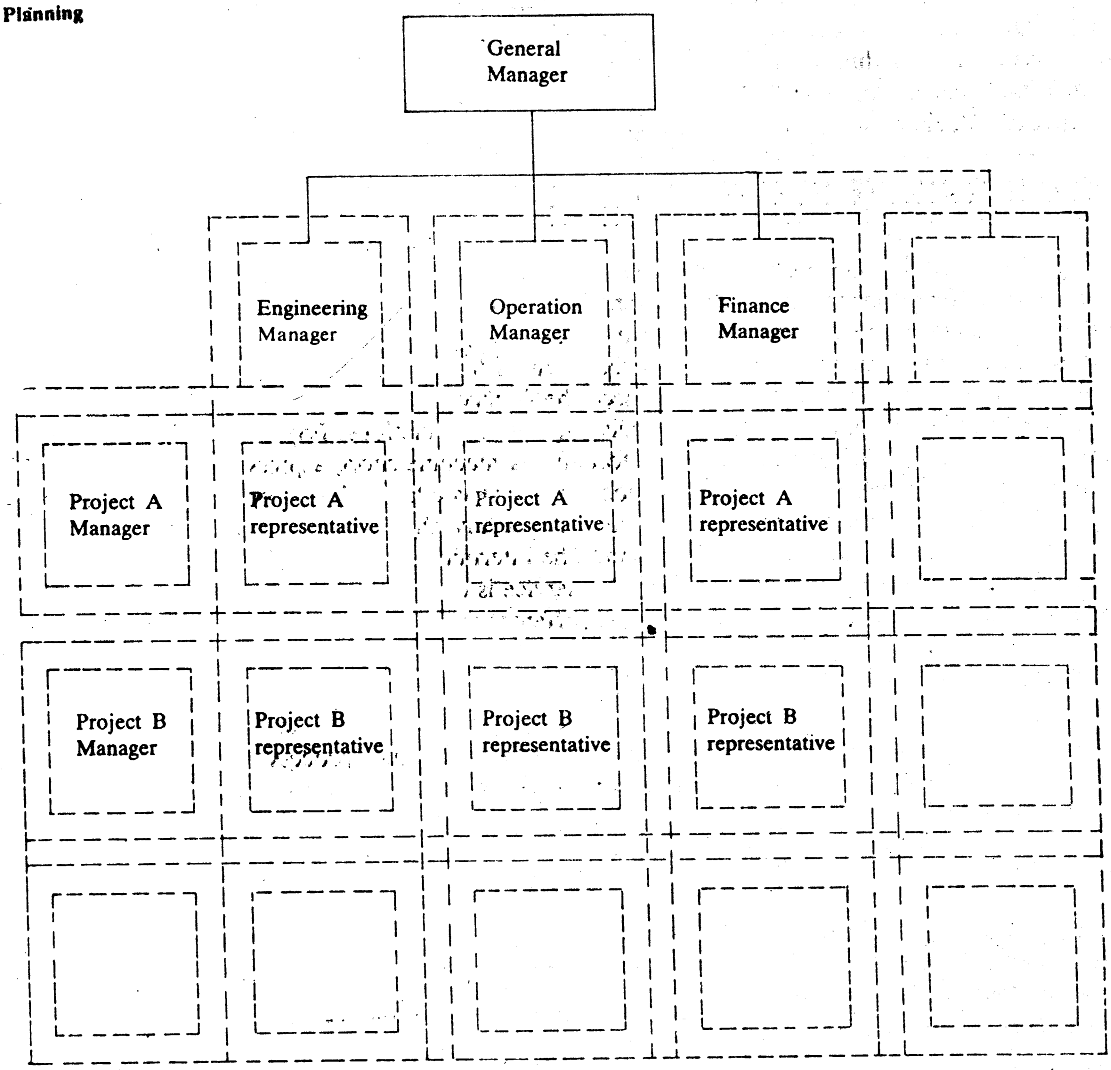
When there is a fast build-up, staff is generally borrowed from other departments and also some are hired for a short duration. Thus, they may have limited loyalty anc short-lived interest in the project. This is further compounded by the fact that the staging area or the site for many projects could be in a different and relatively undeveloped geographical region and that causes some dislocations in the normal life of the persons involved. Finally, the persons may have limited experience with the special tasks involved in the project.

As each project has a limited duration and as the end of the project draws near, the staff may start spending more time getting prepared for the next job. This is especially true if they are hired for the project and have to look for alternate jobs once the project is over. In the process, the project may get dragged beyond its scheduled date of completion.

Matrix Organisation

When multiple project operations are under way, a matrix organisation structure is generally used. In a matrix organisation, project representatives for each project are designated by different functional areas. As shown in Figure II there are project representative from Engineering, Operations, Finance and so on for Project A. There are similar representatives for Project B and other projects. Thus, each functional manager holds the resources and each project manager coordinates the use of designated resources through the project representative concerned. This form of organisation allows coordination across functional departments for better useof resources. However, a major disadvantage of this form of organisation is that an employee has two supervisors—one in the project and another in his "home" or functional department. The need for coordination between functional and project managers is essential so that there are no conflicts in regard to questions such as: Who will evaluate and reward employees? Who is ultimately responsible for the discipline of employees? In the absence of such coordination the project representative may find himself or herself in the unenviable position of having to satisfy two bosses with different priorities.

Figure II: Matrix organisation structure for project management



Activity B

In your experience, have you come across Matrix form of orgainization? From Experiential point of view, what are the advantages disadva tages, Identify some situations where Matrix from would be useful.

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Activity C

Think of a project to which you belonged or you have observed from close quarters. Recall some important characteristics of that project.

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Importance of Scheduling and Control

A project generally involves many tasks—each having its own specialisation and perhaps to be executed by a different agency. However, they have a strict precedence requirement—like one task cannot even begin until two other predecessor tasks have been completed. The cost of delay in completion of the project is also usually very high, many times with explicit penalties being mentioned as well. Because of all these reasons the scheduling and control of various activities in a project assumes great importance. Some network planning techniques like CPM and PERT have been specially designed to resolve these issues.

3.4 INTERMITTENT FLOW PROCESSES

When the output variety is large, each output takes a different route through the organisation, uses different inputs, requires different operations and takes a different amount of time and also sequence, the intermittent form of processing is often used. In this system, each output, or small group of similar outputs (referred to as a batch or a lot), follows a different processing route through the facility, from one location to another. The facilities are organised around similar operations functions. For example, in an engineering organisation there is a foundry, a machine shop, a press shop, a tool room, a paint shop and so on. In a hospital, there is a blood bank, an X-Ray department, a pathological laboratory and so on. The flow through these departments depends on the exact needs of a patient. The intermittent process is especially suited for service organisations because each service is often customised and so each one requires a different set of operations in a different sequence.

Characteristics of the Intermittent Form

Referring to Figure I, the intermittent process form is generally suitable when the variety is large and consequently the volumes are low. The transformation process should be able to take care of this large variety and also in a manner that the cost of the processing is not excessive.

Flexibility

When an organisation wants to produce a variety of outputs using common facilities, it wants to have flexibility in its operations. This is achieved by employing general purpose machines and equipment as well as having staff with a wide range of skills. The facilities are laid out in accordance with the general flow and for specific outputs, there may be a lot of movement as well as backtracking depending on the sequence of operations required. Not only the processing, even the inputs required for different outputs could be quite different.

Even if the final product does not have excessive variety, e.g. in manufacturing of typewriters, the intermittent form is still used for the manufacture of components. This is because a large number of components are assembled into a typewriter and the same facilities could be used in making many different components in batches. One batch of 1000 pinions could be produced this week and the next batch may have to be produced only after one month. By splitting into batches in this manner, a large number of different components can be produced on a common set of machines. All this is possible because the intermittent form of processing is flexible.

Around Standard Operations

The transformation processes are organised around standard operations in the intermittent form. In a bank, this would result in departments like cash, advances, deposits, savings bank accounts and so on. Any customer who wants to deposit or withdraw cash, has to go to the cash department for this purpose.

In such a scheme, each functional group is a specialised group and performs all tasks connected with that specialisation. That is why the workers need to have a width of skills so that they can perform a range of tasks—of course within the specialisation. A machine operator in a grinding shop will not be producing the same output everyday and thus besides skills in operating different types of grinding machines needs the ability to read and interest blueprints and perhaps also the ability to 'set up' grinding machines to perform different jobs.

The amount of specialisation achieved by organising around standard operations enables the organisation to solve complex and specialised problems. Thus, a difficult grinding job is more likely to be carried out by an organisation having a grinding shop than by another having project operations or even continuous flow processing where grinding operations are also being performed.

Material Handling and In-process Inventory

As the grouping of facilities is around standard operations, the partly processed output is to be transported from one standard operation to another. The amount of material handling for an output or a batch of output depends on the number of standard operations to be performed and also the distance between the locations where the operations are performed. For all the outputs of the organisation, therefore, the amount of material handling would depend on the output mix and the layout of different facilities. A great deal of effort is made to design the facilities layout so that the material handling is reduced for a targeted output mix.

Again, as the same facilities are being used for the processing of many outputs, the flow of materials through the facilities is not smooth, but interrupted. After one operation, the partly processed output or batch of outputs may have to wait if the facilities required for the next operation are busy on the processing of another output on batch. Such material is referred to as work-in-process and the consequent in-process inventory is typical in intermittent flow processing.

Difficulty in Management of Resources

Since each output or batch of outputs is different, the planning and control of the operations function is very difficult under intermittent flow processing. Elaborate planning and control procedures are used so that the movement of each output or batch of outputs can be tracked and all the inputs required for a particular output or batch be made available in time. The planning and control becomes more difficult in the absence of accurate time standards as the outputs may not be repetitive.

Advantages of the Intermittent Form

In transformation processes, there is always a trade-off between flexibility of operations and the efficiency of use of resources. Intermittent transformation processes are chosen whenever flexibility is considered more important than mere efficiency.

Variety at Low Cost

The intermittent form of processing is appropriate when we want to respond to demands of small volume and high variety. The primary advantage of this form of processing is, therefore, the ability to produce a wide variety of outputs at a reasonable cost.

The choice of machines and equipment, the skill of the staff, the layout of the facilities and all related decisions emphasise the need to have flexible operations whic are also not very costly. In intermittent flow processing, general purpose machines ar generally used as these are cheaper than special purpose machines, since they are in greater demand and generally available from more suppliers. Also, they are easier an cheaper to maintain and dispose of thus reducing the cost of obsolescence. Because of the diversity in outputs, all the equipment does not have hundred per cent utilisation. The cost of unutilised equipment is low, as the equipment is simple general purpose and not very costly.

High Capacity Utilisation

As facilities are grouped around standard operations, all the outputs requiring a particular operation will have to be sent to the section carrying out that operation. Thus, there will be a high capacity utilisation for equipment grouped around that operation. The cost involved in providing special environmental conditions for some operations e.g. airconditioning, dehumidifying, dust proofing etc. is also minimised as all such equipment is physically close to each other when the organisation is laid out for intermittent form of processing.

Staff Advantages

Each worker performs a complete operation under intermittent processing—e.g. completing an analysis on a form, painting a component or product etc. This, complemented by the fact that the task itself is not repetitive, provides the workers pride of workmanship and increased responsibility. There is usually a high morale in the group when all the group members are similarly skilled and work in the same location.

Disadvantages of the Intermittent Form

The intermittent form will not remain the best form of processing if the volumes for some outputs become high. The in-process inventories could become excessively high and the operations planning and control could get out of hand necessitating the use of expediters.

More Costly for High Volumes

The initial cost for general purpose machines, which are mostly used in intermittent processing, is low. But they are usually slower than special purpose machines and also give lower quality of outputs. The skilled operators are paid more than the semi-skilled or the unskilled. The end result being that although the fixed costs are lower for general purpose machines, the variable costs per unit of output are higher. For low output volumes, therefore, the general purpose equipment could be the cheapest as well. However, as output volumes rise, the advantage in terms of a lower fixed cost is more than compensated by a higher component of variable cost and thus the special purpose machines may offer the least cost alternative.

Complex Operations Planning and Control

As mentioned earlier the planning and control of operations is very complex for the intermittent form. When the number of jobs on the ship floor rises to high levels, it becomes almost impossible to keep track of individual jobs. Over and above the paperwork involved, "expediters" are employed to reorder priorities and track down specific jobs.

The requirement of each output being different, in the absence of such detailed planning and control there may be production bottlenecks on some facilities whereas resources may remain idle at some other facilities. It is easy to see that there may be a host of reasons causing such idling of resources—e.g., machine breakdown, raw material non-availability, delay in a previous operation, absent worker, non-availability of tools etc. etc. It is the job of operations planning and control to ensure that all the inputs required for a particular operation are made available when the operation is planned.

Large In-process Inventory

Intermittent processing would always have some in-process inventory. However, as the variety of outputs and the scale of operations increase, the in-process inventory becomes larger. On top of it, there will be a fast build-up of in-process inventory if there is any laxity in the operations planning and control function. This increases the space requirement of operations and also disturbs the appearance of the operations area at times making it even unsafe.

The material handling equipment used in intermittent operations is generally mobile and is more expensive than the fixed position handling equipment like chutes and conveyor belts. It also requires more space for movement thus adding to the space requirement.

New Technology for Intermittent Flow Operations

There have been quite a few developments towards increasing the efficiency of intermittent flow operations. Many of these developments are based on using the computer for many planning and control activities and some, like group technology, are based on using continuous flow principles for outputs which have a large variety.

Computerised Production and Inventory Control Systems

Many different types of computer packages are available which can link the input and output requirements, check with the inventory at hand and automatically raise purchase orders and also prepare different types of statements for planning and control purposes. Given a schedule of output requirements, the computer can work out the requirement of raw material and other bought out items and can plan the procurement and production of these so that there is no hold up of production due to non-availability of material.

Integrated Computer-Aided Manufacturing

These computer packages tie up the previous systems with mechanical systems that control machinery and material handling equipment. These packages do not carry out manufacturing of parts alone but also process planning, costing, tool design, production planning, material ordering etc. The rate of development in this area is extremely rapid and is also accelerating. Computers are used for both planning as well as execution of the plans.

Manufacturing Resource Planning (MRP II)

If the computerised production and inventory control systems could be linked with other planning and accounting systems of the organisation, it would result in comprehensive computer packages on manufacturing resource planning. Such a system would integrate marketing, finance, personnel, payroll and other systems and can prepare statements on funds requirement, promotional need, capacity planning and so on.

Group Technology

Group technology has developed over the years to become a complete philosophy rather than a single technique. The common thread running through all these techniques is the attempt to find groups which can be used in organising the transformation process. The purpose of grouping is to overcome some of the disadvantages of intermittent flow processing as outlined in 5.4 above and the grouping can be of component parts, machines, equipment and people.

In general, component parts are grouped into families so that the processing required for members of a family is similar. The machines and equipment are also grouped into cells so that the volumes through a cell are higher and the variety smaller. Therefore, the principles used in continuous flow processing can be used for each of these groups.

The benefits expected from group technology are really fourfold:

i) reduced amounts of time and costs because the nature of operations and their sequence is similar for a family of component parts
ii) reduced material handling as the machines and equipment in a cell are physically close to each other
iii) shorter throughput times as the waiting period between operations is minimal
iv) reduced in-process inventories, again because of minimal waiting between operations.

3.5 CONTINUOUS FLOW PROCESSES

As distinct from intermittent flow processes, all outputs are treated alike in this form of processing and the workflow is thus relatively continuous. The production process is therefore geared to produce one output, perhaps with some options added on. The variety is small and volumes are high thus making it worthwhile to focus the transformation process on the output. This would mean arranging the facilities in the sequence in which they are required for the output, using high speed special purpose machines, laying out the facilities to minimise the movement of materials and designing the production system so that there are no bottlenecks as well as no idle time for any of the resources.

Traditionally, services were considered to be too customised for this form of processing. However, we are now finding that by standardising the service and also by increasing the volume of output, it is possible to use continuous processes even for services. One can give the example of fast food joints or periodic servicing of automobiles towards these trends.

Characteristics of Continuous Processes

The continuous process form is characterised by relatively standardised outputs and consequently fixed inputs, fixed sequence of operations and also fixed processing time. As the variation from one output to another is very small, the transformation process is selected and designed to maximise the efficiency of the resources and in the process flexibility of operations is sacrificed.

High Volumes

If an organisation is planning to produce only a small variety of outputs and in high volumes, it will find the continuous processing form a very attractive proposition. Because of high volumes, one can choose those production facilities which are special purpose and perhaps custom-built so that the initial costs are high, but they can produce the output at a low variable cost. The higher the volumes the further these tradeoffs shift towards higher fixed costs and lower variable costs. This is because the variable costs are low and the high fixed costs are spread over a high volume of output thus making the continuous processing form the least cost processing form for high volumes.

Easier Planning and Control

As all outputs follow the same path from one operation to the next, there is no need to keep track of each output for planning and control purposes. In other words, all operations being standardised with standard operation times and no waiting between operations, if the time when processing starts for an output is known, all subsequent operations including the final completion of the output can be predicted quite closely.

This implies that there is virtually no in-process inventory since there is no waiting between operations. Also, as the transformation process is designed specially for this output the amount of movement between operations is minimal. Further, as volumes are high, special purpose fixed position material handling equipment like chutes, conveyors etc. which have low space requirements and operate at low variable costs can be used.

Linear Workflow

All the facilities are arranged in the sequence in which they are required for the production of outputs. The material therefore moves from one facility to another or from one location to another with no backtracking at all. That is why product organisations of this form are often called flow shops.

When the continuous form of processing is used for production of an output, we have, what is called a **product line**. In many product lines we can actually see the material moving on a conveyor and workers removing one unit from the conveyor for processing and putting it back on the conveyor at the end of the operation so that it goes to the next location for the next operation. It is, therefore, important that the work content at each of the locations be exactly equal so that no location has a bottleneck nor does a location have idle time. The rate of output will be governed by the slowest location (referred to as work station in the context of a production line). Sometimes, when there is a large variability in the operation times, a small in-process inventory is allowed to be built up to cushion out the effect of such variations.

When only assembly operations are performed on a line, such a line is called an assembly line. Assembly of many low variety products is carried out using assembly lines—for example automobiles, television sets, domestic electrical appliances etc.

Advantages of the Continuous Form

The continuous form of processing requires a great deal of effort while designing. But once implemented, it offers many simplicities in its operation.

Low Unit Cost

The main advantage offered by continuous process operations is the low per unit cost of production. As discussed earlier, this is achieved by selecting equipment which provides low variable costs of operation perhaps at high initial costs which are distributed over large production volumes. Further cost saving is possible due to bulk purchasing of materials, efficient facility utilisation, low in-process inventories and lower material handling costs.

Lower Operator Skills

The machines used in continuous processes are generally special purpose and so their operation is simpler, with few setups required. The operator skills required are therefore lower which improves the availability of workers with requisite skills and also gives rise to lower labour costs.

However, the special purpose machines are more complex in their design and functions and so are more difficult to maintain. Thus, higher maintenance skills are required and since the experience of working on any of these machines is limited, the time taken for diagnosis and repair is longer. Similarly, spare parts availability itself could be difficult for special purpose machines.

Simpler Managerial Control

As the workflow is streamlined in the continuous form, the planning and control of production is much simpler. With standardised operations and operation times, the predictability of operations is higher. This implies that the performance on meeting delivery dates is better.

In fact, while operating an interrupted processing system, if one of the outputs establishes a high growth in volume, it may be worthwhile exploring the possibility of setting up a production line for this output. Although the component parts are produced using interrupted processing, the final assembly is carried out on an assembly line for many products.

Disadvantages of the Continuous Form

Although the continuous form of processing offers a low cost alternative when volume of production is high and the variety low, there are some disadvantages in organising the production in this form.

Difficult to Adapt

As the whole production process is designed for a particular output, any change in the output characteristics is difficult to obtain. Because of this, important changes in product design are often not made, which can affect the competitive strength of the organisation. Each production or assembly line is designed for a particular rate of production. Sometimes, it is difficult even to change the rate of output. This causes serious difficulty when the demand for the output increases or decreases.

Possibilities of Stoppage of Line

If there is a breakdown at any work station or in the material handling equipment, the whole line may come to a standstill. In the absence of work-in-process, production at all work stations will suffer till the line can be started again.

Balancing the Line

The work content at each of the work stations should be exactly equal to avoid bottlenecks and idling of resources. However, if it is not possible to exactly equalise the work content, the output rate is governed by the slowest work station which implies that workers at all other work stations are less busy. This remains a sore point among the workers.

Low Worker Morale

A worker's task is highly repetitive in the continuous form of processing and for high output rate production lines the task may also be very insignificant and unchallenging. This dehumanising aspect of the workers' role causes boredom, monotony and very soon starts affecting the morale of workers.

High Initial Cost

The special purpose machines and equipment used in continuous form of processing have very high initial cost. It is also costly to service and maintain. Also, such special purpose equipment is very susceptible to obsolescence and it is not easy to find a buyer for such equipment or to modify these for other uses.

New Technology for Continuous Flow Process

Recent developments in computer applications have had their effect on continuous flow operations as well. The attempt in all this is to increase the flexibility of production and assembly lines.

CNC/DNC

Machines and processes which have been automated using some form of electronic system are said to use numerical control or NC. In the early NC machines, instructions for machine control were coded on punched paper tapes to be read by tape readers. In CNC (Computer Numerical Control) machines, relatively simple programmes can be stored in the memory of the computer and so it is not necessary to read the control tape for every item manufactured. This is an advantage since the control tapes and the associated tape readers are among the most unreliable components of an NC machine.

In DNC (Direct Numerical Control) machines, programmes for a number of NC machines are stored in a single computer of larger capacity than the type used in CNC. Also, the integration of a number of machines and processes by one computer enables a set of machines to work as a manufacturing system, with parts scheduling and process monitoring. Automation by numerical control can be thought of as soft automation as this allows fast changeovers from one component part to another.

Robotics

According to the Robot Institute of America, "A robot is a reprogrammable multi-functional manipulator designed to move material, parts, tools or specialised devices through variable programmed motions for the performance of a variety of tasks." Robots have come in a big way in the task of moving, transferring and manipulating materials in between operations as well as during some specialised operations. An industrial Robot has three principal components:

i) One or more arms, usually situated in a fixed base, that can move in several directions

ii) A manipulator, being the "hand" that holds the tool or the part to be worked

iii) A controller that gives detailed movement instructions.

Robotics is helping continuous flow processes to changeover from one output to another since the material handling equipment, which was earlier designed as part of a production or assembly line, can now be independently programmed.

CAD/CAM/CAE

This trilogy of terms stands for computer aided design (CAD), computer aided manufacturing (CAM) and computer aided engineering(CAE). In these systems, the computer aids in the design process by providing different images of the designed product from different views—the computer screen acting as the designer's drawing board. The CAM ties the NC machines with the material handling equipment so the manufacturing operations are working together. In CAE, the computer is used to aid in analysing engineering problems, particularly structured analysis where the structure has previously been designed using CAD. In its widest sense, these imply the automation using computer control of all activities necessary to take a product from concept to its completed manufacture.

Flexible Manufacturing

Current usage of the term flexible manufacturing relates to automated manufacture. Traditionally, automation in manufacturing has been possible only for high volume low variety products where the production process adopted had been of the continuous flow process form. Such process had suffered from inflexibility—not only in terms of output characteristics but also of output rate. In flexible manufacturing an attempt is made to introduce flexibility not only in terms of component design but also operation sequence, batch sizes and overall production capacity. Flexible manufacturing tries to combine the advantages of conventional automation with the strategic advantages attached to intermittent processing viz., increased variety, improved response to customer orders, updated product designs etc.

3.6 PROCESSING INDUSTRIES

The processing industries e.g., fertiliser, petrochemicals, petroleum, milk, drugs, etc. also use continuous processing. However, they deserve a special mention as they differ from organisations producing either discrete products or services. In general, the operations in these organisations are highly automated with very sophisticated controls, often electronic or computerised. The labour requirements are generally low and the role of the production workers is limited to monitoring and taking some corrective action if necessary. However, maintenance of equipment is very critical and the skills required in maintenance are of high order.

A Single Input

In processing industries, there is usually a single principal input material which is processed into one or more different products. In discrete manufacturing, on the other hand, there are many different input materials which are processed and assembled to form the product.

Analytic and Synthetic Processes

In an analytic process, a single input is processed into many separate outputs. A typical example would be a petroleum refinery, where the single input, viz. petroleum is processed into petrol, diesel, naphtha, furnace oil and a host of other intermediates. In a synthetic process, on the other hand, many different inputs are synthesised into one output. Processing industries generally use analytic processes whereas continuous flow processing in discrete manufacturing generally use synthetic processes.

Continuous Processing

In spite of the differences mentioned above, there is a basic similarity in the concept as well as the approach followed in both flow shops and the processing industries—only the variety in outputs is nil so far as processing industries are concerned. Because of this, automation could be carried out to its physical limits and the process is designed for a specific mix of outputs. The result is that initial set up of equipment and procedures is even more complex and critical than for continuous flow processing.

3.7 SELECTION OF THE PROCESS

In this section we would address ourselves to the issue of selecting the appropriate process form or mix of forms for an organisation to produce its output. The details involved in the actual designing and laying out of the transformation processes, the laying out of the workplaces, the designing of the planning and control procedures, the assurance of quality, etc. is the subject matter of the complete course and would be taken up later in other units

Combination of Process Forms

The four forms of processing that we have referred to earlier, are really four simplified extremes of what is likely to be observed in practice. We will find very few organisations using only one of these processing forms in its pure sense. In fact by alluding to concepts like group technology and flexible manufacturing we have referred to systems which attempt to combine the advantages of two or more of these pure forms.

Most organisations combine two or more of these process forms to produce different components and the final product. In many industries including automobiles, domestic electrical appliances etc. the components are made using the intermittent form of processing whereas the final assembly is based on continuous flow processing.

Production of Services

Like products, services could also be produced using different process forms. Although the intermittent processing form has been the typical form used for services, services as those provided by a lawyer are more like project processes. Again, by standardising the outputs and consequently increasing the volume of standard outputs, many services are now produced using the continuous flow process form. We have already given the example of fast food service in this context. Another example comes from the Soviet Union where a flowline has been used for routine eye surgery whereby patients are literally passed along a line from one surgeon to another, each of whom performs a small part of the total operation. We are, therefore, slowly coming to realise that services can be mass produced.

Product/Process Life-cycles

In Units 1 and 4 we have referred to the life-cycle which a typical output undergoes—from its introduction through growth, maturity and decline phases. There is a similar life-cycle for the process used to produce the output. Figure I can be interpreted to show that the product and the process life cycles are related.

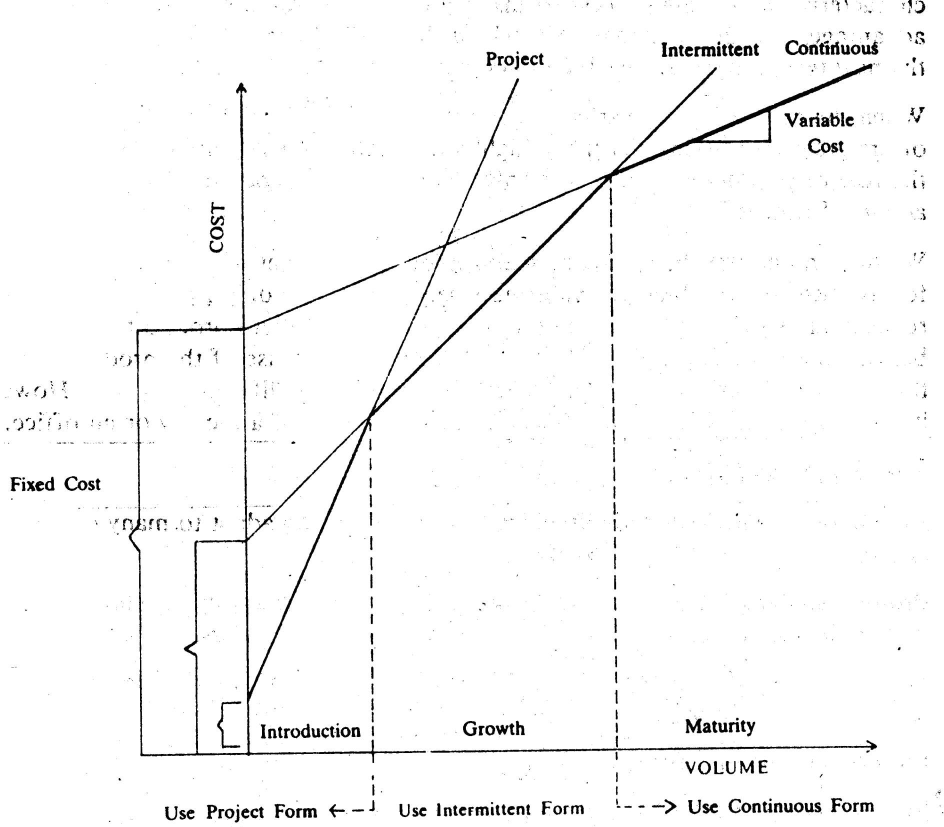
When an output is just introduced, it is made in small volumes in an inefficient, uncoordinated manner which might start using the project form. However, very soon it is produced in small batches using the intermittent processing form. As the output goes through the growth phase, more and more sub-processes are designed using the continuous flow processing form. Finally, in the maturity phase, the product competes mostly on price. The volumes are high and highly cost efficient methods are required to produce the product at a low cost. The continuous flow processing form is then the most suitable form of process.

Break-even Analysis For Process Forms

The progress along the process life-cycle is shown below in Figure III using break-even analysis for each of the process forms. At the introduction stage, the product is first produced with little or no commitment of equipment and facilities using mostly labour intensive methods. The process form used is the project form and most of the cost is variable cost including the cost of labour.

As the product passes on the growth phase, general purpose machines and equipment are organised into the intermittent form to produce the output in a flexible manner. Finally, when the continuous flow processing form is used towards the maturity phase of the product life-cycle, the fixed costs of operation are very high and the variable cost per unit of output is quite low. Figure III also shows the least cost process at any stage of the life-cycle (heavy line) and it can be easily seen that as volumes rise a different form of process might become the least cost alternative.

Figure III: Break-even analysis of process form selection with phases of life-cycle.



Maintaining the Focus

The point to note is that the process form adopted should evolve as the market ano the output evolve. If a company feels that its competitive strength lies in having a flexible production system which can respond very fast to specific customer needs, then as the outputs move into another phase of their life-cycle in which a different process form is preferable, it drops the output or licences it to someone else and switches to another output more appropriate to its competitive strengths.

Each factory or office should have a clearly defined focus in its operations and the process form adopted is one of the key elements that creates the focus. It is not possible to have a production system which can satisfy all sorts of demands made on it—e.g., fast response to changes in output design, low cost of production, high capacity utilisation of resources, and so on.

3.8 SUMMARY

In this unit we have looked at the various process forms that can be usea to effect transformation of inputs into outputs. Having established the strategic nature of process selection decisions, we explored the various considerations which affect the process selection. The major consideration in choosing an appropriate process form i the output characteristics in terms of its volume and variety. A related consideration is whether the output is produced-to-stock or produced-to-order.

When the output is produced in very low volumes and the output variety is large, th project form of transformation is often the most appropriate. Project processes have short life-cycles and need a high level of coordination so that in spite of strict precedence relationships between activities, the project is not delayed beyond its scheduled date of completion.

For low vloume high variety output, the intermittent flow processing form offers the advantage of flexibility at reasonable cost, whereas for high volume low variety outputs, the continuous flow processing form is often used. We have looked at the characteristics of these process forms in great detail and also discussed the advantages and disadvantages of each of these. We have also mentioned some of the new technologies for each of these process forms.

When the output has no variety, and if it is a commodity, the processing form offers great cost savings by using highly automated transformation processes where the role of productic workers is only to monitor the processes and take corrective action, if needed.

We have noted that most organisations adopt a combination of different process forms. Just like products, even services can be mass produced if the variety can be reduced giving rise to high volumes. Interestingly, different process forms might become the most appropriate ones depending on the phase of the product life-cycle the output is in and so we have some kind of a process life-cycle as well. However, it is important to have a clear focus in the operations of a factory or an office.

3.9 KEY WORDS

An adaptive process: A process which has to continually adapt to many external factors.

Produce-stock: A production policy which allows products to be produced and stocked in our warehouse and sold as and when demand occurs.

Produce-to-order: A production policy which allows outputs to be produced only on receipt of an order from the customer.

Project form of processing: Used to produce an output which is one of a kind.

Reaction times: Time required for an organisation or a system to react to a change either internal or external.

Matrix organisation: A form of organisation structure in which a dual system of grouping is adopted, e.g., a person is assigned to a project which he or she retains membership of the functional organisation.

Intermittent form of processing: When the output variety is large, the production facilities are organised specialisation-wise, thus making the material flow non-uniform, zig-zag and intermittent.

Flexibility refers to the ease with which a productive facility can be used to produce different outputs.

In-process inventory: The stock of semi-finished products usually required to cushion the effect of unequal production rates and to balance the high set up cost for some operations.

Group technology: Attempts to find groups of component parts, machines, equipment and people which can be exploited while organising the team formation process.

Line balancing: Implies that each work station in a production or an assembly line has an equal work content so that no work station has an idle time, nor does it have bottlenecks.

NC or **numerical control** refers to the use of some form of electronic system for automating machines and process.

Flexible manufacturing is the approach towards making automated manufacture flexible both in terms of output characteristics and output rate.

Analytic process: In an analytic process, a single input is processed into many separate outputs.

Synthetic process: In a synthetic process, many different inputs are synthesised into one output.

3.10 SELF-ASSESSMENT EXERCISES

1 The equipment used in intermittent flow shops is less specialised than that used in continuous flow shops. What about the labour?

2 Can flexibility or economy be obtained only at the cost of each other?

3 Why do you think is managing a high-volume continuous operation easier than managing a high-variety intermittent operation?

4 Please explain why the in-process inventory is likely to be higher for an intermittent operation than for a continuous flow operation?

5 Hospitals are commonly physically laid out as continuous flow systems. (True/False).

6 The continuous form of processing is the most economical when the system requires flexibility. (True/False).

7 Special purpose equipment are more likely to be affected by obsolescence than general purpose equipment. (True/False)

3.11 FURTHER READINGS

Adam, E.E. and R.J. Ebert. 1982. *Production and Operations Management* (2nd edition), Prentice-Hall: Englewood-Cliffs.

Bennett, D.:1986. *Production Systems Design*, Butterworth & Co. London.

Buffa, E.S. 1983. *Modern Production/Operations Management* (7th edition); Wiley Eastern: New Delhi.

Hall, R.W. 1987. *Attaining Manufacturing Excellence*, Dow-Jones Irwin: Homewood.

Hayes, R.H. and S.G. Wheelwright. 1979. The Dynamics of Process-Product Life Cycles, *Harvard Business Review:* Mar-Apr.

McClain, J.O. and L.J. Thomas. 1985. *Operations Management* (2nd edition): Prentice-Hall of India: New Delhi.

Meredith, J.R. and T.E. Gibbs. 1984. *The Management of Operations* (2nd edition), John Wiley & Sons: New York.

UNIT 4 FACILITIES LOCATION

Objectives

After going through this unit, you should be able to:

- understand the strategic importance and objectives of facilities location
- realise the enlarged scope of dealing with facility rather than just plant/factory location
- identify various factors relevant for general territory selection as well as those relevant for specific site/community selection
- appreciate that the location decisions are quite complex because of the existence of subjective intangible factors along with objective tangible factors
- be in a position to apply some relevant technique either subjective, qualitative or semi-quantitative in nature
- grasp some simple operational research oriented models
- realise the need for recognition of the assumptions and limitations of the quantitative models discussed
- provide a blend of some good rational qualitative judgment and the analytical model solutions
- be in a position to identify relevant factors for facility location

Structure

4.1 INTRODUCTION

Facility location decisions are strategic, long term and non-repetitive in nature. Without sound and careful location planning in the beginning itself, the new facility may pose continuous operating disadvantages, for the future operations. Location decisions are affected by many factors, both internal and external to the organisation's operations. Internal factors include the technology used, the capacity, the financial position, and the work force required. External factors include the economic political and social conditions in the various localities. Most of the fixed and some of the variable costs are determined by the location decision. The efficiency, effectiveness, productivity and profitability of the facility are also affected by the location decision. The facilities location problem is concerned primarily with the best (or optimal!) location depending on appropriate criteria of effectiveness. Location decisions are based on a host of factors, some subjective, qualitative and intangible while some others are objective, quantitative and tangible.

Concept of a facility

Traditionally, location theorists have dealt with industrial plant/factory location. However, the concept of **plant location** has now been generalised into that of **facility location,** since the facility could include a production operation or service system. The term 'Plant' has been traditionally used as synonymous to a factory, manufacturing or assembly unit. This could include fertiliser, steel, cement, rice milling plants, textile, jute, sugar mills, rubber factories, breweries, refineries, thermal or hydro-electric nuclear power stations etc.

However, with the enlarged scope of a facility, this term can now be used to refer to banks, hospitals, blood banks, fire stations, police stations, warehouse, godown, depot, recreation centre, central repair workshop etc. At a lower hierarchical level is the facility/plant layout problem which will be discussed in the next unit. In such a case machines, equipment, desks, workshop, canteen, emergency room etc. could mean a facility. Thus, in fact, we could generally state that a facility could connote almost any physical object relevant to location analysis. Let us now see when a location decision arises.

4.2 WHEN DOES A LOCATION DECISION ARISE?

The impetus to embark upon a facility location study can usually be attributed to various reasons:

i) It may arise when a new facility is to be established.

ii) In some cases, the facility or plant operations and subsequent expansion are restricted by a poor site, thereby necessitating the setting up of the facility at a new site.

iii) The growing volume of business makes it advisable to establish additional facilities in new territories.

iv) Decentralisation and dispersal of industries reflected in the Industrial Policy resolution so as to achieve an overall development of a developing country, would necessitate a location decision at a macro level.

v) It could happen that the original advantages of the plant have been outweighed due to new developments.

vi) New economic, social, legal or political factors could suggest a change of location of the exisiting plant.

Some or all the above factors could force a firm or an organisation to question whether the location of its plant should be changed or not.

Whenever the plant location decision arises, it deserves careful attention because of the long term consequences. Any mistake in selection of a proper location could prove to be costly. Poor location could be a constant source of higher cost, higher investment, difficult marketing and transportation, dissatisfied and frustrated employees and consumers, frequent interruptions of production, abnormal wastages, delays and substandard quality, denied advantages of geographical specialisation and so on. Once a facility is set up at a location, it is very difficult to shift later to a better location because of numerous economic, political and sociological reasons. Economic reasons could include total costs, profits, availability of raw materials, labour, power, transportation facilities, markets etc. Social reasons could include employee welfare, employment opportunities etc. Political reasons could be because of pursuance of a policy of decentralisation, regional and developmental planning especially in a developing country like ours. There could be security considerations on risk of military invasions, sabotage from anti-social elements etc. and some may be prone to natural calamities like floods, earthquake etc. Policy matters like anti-pollution etc. would have to be given their due consideration.

Alfred Weber's analysis was one of the first attempts to base location decisions on some sort of analysis, its imperfections notwithstanding. Besides discussing the importance of transport and labour cost differentials in deciding location, the main burden of Weber's analysis is transport cost of raw material which was least mobile. One the basis of availability, he categorised raw materials into: (a) **ubiquities**—to denote those available almost everywhere like sand, water etc. and (b) **localised materials**, having specific locations, which are further divided into pure material which contributes nearly the total weight of it to the finished goods, and gross material, which contributes only a small fractions of total weight to the finished goods. It is obvious that ubiquities hardly influence the decision of location. Weber then proceeds to formulate the material index which equals the weight of localised material used in the finished product divided by the weight of the finished product

$$\text{Material Index (MI)} = \frac{\text{Weight of localised material used in finished product}}{\text{Weight of the finished product}}$$

If the material index is greater than unity, location should be nearer to the source of raw material and if it is less than unity, then a location nearer to market is advised. The commonsense involved in such conclusion is unquestionable. But such an approach tacitly assumes the existence of a static point of lowest transportation cost for raw material.

Later analyses by various other authors, like, Weigman, Palander, Losch, Ohlin and others have been attempted on increasingly comprehensive bases such as the interrelationship between factors like, (a) economic differences—(prices, market), (b) cost differences—(productivity, transport cost and accessibility), (c) human differences—(attitudes of founders and wage-earners), (d) national characteristics, and (e) various barriers—(political, geographic and transportation). Let us now see how a location study is made.

4.3 STEPS IN THE FACILITY LOCATION STUDY

Location studies are usually made in two phases namely, (i) the general territory selection phase, and (ii) the exact site/community selection phase amongst those available in the general locale. The considerations vary at the two levels, though there is substantial overlap as shown in Table 1.

Table 1
Overlap of considerations of factors in the two stages of facility location

	Location Factors	Phase I General Territory Selection	Phase II Particular Selection of Site and Community
1	Market	●	
2	Raw Materials		
3	Power	●	
4	Transportation	●	●
5	Climate and Fuel	●	●
6	Labour and Wages	●	
7	Laws and Taxation	●	●
8	Community Services and Attitude	●	●
9	Water and Waste		●
10	Ecology and Pollution		●
11	Capital Availability		●
12	Vulnerability to enemy attack		●

A Typical team studying location possibilities for a large project might involve economists, accountants, geographers, town planners, lawyers, marketing experts, politicians, executives, industrial engineers, defence analysts, ecologists etc. It is indeed an inter-disciplinary team that should be set up for undertaking location studies.

Territory Selection

Now in step (i) for the general territory/region/area selection, the following are some of the important factors that influence the selection decision.

Markets: There has to be some customer/market for your product/service. The market growth potential and the location of competitors are important factors that could influence the location. Locating a plant or facility nearer to the market is preferred if promptness of service required, if the product is fragile, or is susceptible to spoilage. Moreover, if the product is relatively inexpensive and transportation costs add substantially to the cost, a location close to the markets is desirable. Assembly type industries also tend to locate near markets.

Raw Materials and Supplies: Sometimes accessibility to vendors/suppliers of raw materials, parts supplies, tools, equipment etc. may be very important. The issue here is promptness and regularity of delivery and inward freight cost minimisation. If the raw material is bulky or low in cost, or if it is greatly reduced in bulk viz. transformed into various products and by-products of if it is perishable and processing makes it less so, then location near raw materials sources is important. If raw materials come from a variety of locations, the plant/facility may be situated so as to minimise total transportation costs. The costs vary depending upon specific routes, mode of transportation and specific product classifications.

Transportation Facilities: Adequate transportation facilities are essential for the economic operation of a production system. For companies that produce or buy heavy bulky and low value per ton commodities, water transportation could be an important factor in locating plants. It can be seen that civilisations grew along rivers/waterways etc. Many facilities/plants are located along river banks.

Manpower Supply: The availability of skilled manpower, the prevailing wage pattern, living costs and the industrial relations situation influence the location.

Infrastructure: This factor refers to the availability and reliability of power, water, fuel and communication facilities in addition to transportation facilities.

Legislation and Taxation: Factors such as financial and other incentives for new industries in backward areas or no-industry-district centres, exemption from certain state and local taxes, octroi etc. are important.

Climate: Climatic factors could dictate the location of certain type of industries like textile industry which requires high humidity zones.

Site/Community Selection

Having selected the general territory/region, next we would have to go in for site/community selection. Let us discuss some factors relevant for this stage.

Community Facilities: These involve factors such as quality of life which in turn depends on availability of facilities like schools, places of worship, medical services, police and fire stations, cultural, social and recreation opportunities, housing, good streets and good communication and transportation facilities.

Community Attitudes: These can be difficult to evaluate. Most communities usually welcome setting up of a new industry especially since it would provide opportunities to the local people directly or indirectly. However, in case of polluting, or 'dirty' industries, they would try their utmost to locate them as far away as possible. Sometimes because of prevailing law and order situation, companies have been forced to relocate their units. The attitude of people as well as the state government has an impact on industrial location.

Waste Disposal: The facilities required for the disposal of process waste including solid, liquid and gaseous effluents need to be considered. The plant should be positioned so that prevailing winds carry any fumes away from populated areas and so that waste may be disposed off properly and at reasonable expense.

Ecology and Pollution: These days there is a great deal of awareness towards maintenance of natural ecological balance. There are quite a few agencies propagating the concepts to make the society at large more conscious of the dangers of certain avoidable actions.

Site Size: The plot of land must be large enough to hold the proposed plant and parking and access facilities and provide room for future expansion. These days a lot of industrial areas/parks are being earmarked in which certain standard sheds are being provided to entrepreneurs (especially small scale ones).

Topography: The topography, soil structure and drainage must be suitable. If considerable land improvement is required, low priced land might turn out to be expensive.

Transportation Facilities: The site should be accessible by road and rail preferably. The dependability and character of the available transport carriers, frequency of service and freight and terminal facilities is also worth considering.

Supporting Industries and Services: The availability of supporting services such as tool rooms, plant services etc. need to be considered.

Land Costs: These are generally of lesser importance as they are non-recurring and possibly make up a relatively small proportion of the total cost of locating a new plant. Generally speaking, the site will be in a city, suburb or country location. In general, the location for large-scale industries should be in rural areas, which helps in regional development also. It is seen that once a large industry is set up (or even if a decision to this effect has been taken), a lot of infrastructure develops around it as a result of the location decision. As for the location of medium scale industries, these could be preferably in the suburban/semi-urban areas where the advantages of urban and rural areas are available. For the Small-scale Industries, the location could be urban areas where the infrastructural facilities are already available. However, in real life, the situation is somewhat paradoxical as people, with money and means, are usually in the cities and would like to locate the units in the city itself.

Some of the industrial needs and characteristics that tend to favour each of these locales are now discussed. **Requirements** governing choice **of a city location** are:

1 Availability of adequate supply of labour force.
2 High proportion of skilled employees.
3 Rapid public transportation and contact with suppliers and customers.
4 Small plant site or multi floor operation.
5 Processes heavily dependent on city facilities and utilities.
6 Good communication facilities like telephone, telex, post offices.
7 Good banking and health care delivery systems.

Requirements governing the choice **of a suburban location are:**

1 Large plant site close to transportation or population centre.
2 Free from some common city building zoning (industrial areas) and other restrictions.
3 Freedom from higher parking and other city taxes etc.
4 Labour force required resides close to plant.
5 Community close to, but not in, large population centre.
6 Plant expansion easier than in the city.

Requirements governing the choice **of a country/rural location are:**

1 Large plant site required for either present demands or expansion.
2 Dangerous production processes.
3 Lesser effort required for anti-pollution measures.
4 Large volume of relatively clean water.
5 Lower property taxes, away from Urban Land Ceiling Act restrictions.
6 Protection against possible sabotage or for a secret process.
7 Balanced growth and development of a developing or underdeveloped area.
8 Unskilled labour force required.
9 Low wages required to meet competition.

4.4 SUBJECTIVE, QUALITIVE AND SEMI-QUANTITATIVE TECHNIQUES

Three subjective techniques used for facility location are Industry Precedence, Preferential Factor and Dominant Factor. Most of us are always looking for some precedents. So in the industry precedence subjective technique, the basic assumption is that if a location was best for similar firms in the past, it must be the best for us now. As such, there is no need for conducting a detailed location study and the location choice is thus subject to the principle of precedence—good or bad. However in the case of the preferential factor, the location decision is dictated by a personal factor. It depends on the individual whims or preferences e.g. if one belongs to a particular state, he may like to locate his unit only in that state. Such personal factors may override factors of cost or profit in taking a final decision. This could hardly be called a professional approach though such methods are probably more common in practice than generally recognised. However, in some cases of plant location there could be a certain dominant factor (in contrast to the preferential factor) which could influence the location decision. In a true dominant sense, mining or petroleum drilling operations must be located where the mineral resource is available. The decision in this case is simply whether to locate or not at the source.

For evaluating qualitative factors, some factor ranking and factor weight rating systems may be used. In the ranking procedure, a location is better or worse than another for the particular factor. By weighing factors and rating locations against these weights a semi-quantitative comparison of location is possible. Let us now discuss some specific methods.

Equal Weights Method

We could assign equal weights to all factors and evaluate each location along the factor scale. For example, Banson, a manufacturer of fabricated metal products selected three factors by which to rate four sites. Each site was assigned a rating of 0 to 10 points for each factor. The sum of the assigned factor points constituted the site rating by which it could be compared to other sites.

Table 2

Decision Matrix

Factor ↓ \ Potential Sites →	S_1	S_2	S_3	S_4
F_1	2	5	9	2
F_2	3	3	8	3
F_3	6	2	7	3
Site Rating	11*	10	24	8
Sample Calculation	11	2 + 3 + 6		

F Factor; F_1 Factor 1; S Site; S_1 Site 1.

Looking at Table 2, Site 3 has the highest site rating of 24. Hence, this site would be chosen.

Variable Weights Method

The above method could be utilised on account of giving equal weightage to all the factors. Hence, we could think of assigning variable weights to each of the factors and evaluating each location site along the factor scale. Hence, factor F_1 might be assigned 300 points, factor 2 might be assigned 100 points and factor 3 might be assigned 50 points. Thus the points scored, out of the maximum assigned to each of the factors, for each possible location site could be obtained and again the site rating could be derived as follows:

Table 3
Decision Matrix

Factor	Max. Pts.	Potential Sites			
		S_1	S_2	S_3	S_4
F_1	(300)	200	250	250	50
F_2	(100)	50	70	80	100
F_3	(50)	5	50	10	40
Site Rating		255*	370	340	190

*Sample Calculation 255 = 200 + 50 + 5

Looking at the Table 3, Site 2 has the highest site rating of 370. Hence, this site would be chosen.

Weight-cum-Rating Method

We could have yet another method of evaluating a potential location site. We could assign variable weights to each factor. The locations are then rated by a common scale for each factor. The location point assignment for the factor is then obtained by multiplying the location rating for each factor by the factor weight. For example, rating weights of one to five could be assigned to the three factors F_1 (Labour climate), F_2 (community facilities) and F_3 (power availability and reliability), as 5, 3, 2 respectively. Now for each of the factors, sites S_1, S_2, S_3, or S_4 could receive 0 to 10 points as follows. Now each site rating could be obtained.

Table 4
Decision Matrix

Factor	Factor Rating Weights	Potential sites			
		S_1	S_2	S_3	S_4
F_1	5	2	5	9	2
F_2	3	3	3	8	3
F_3	2	6	2	7	3
Site Rating :		31*	38	83	25

*Sample Calculation $31 = (5) \times 2 + (3) \times 3 + (2) \times 6$

As shown in Table 4, the sample calculation should hopefully suffice to obtain the site ratings. Hence, site S_3 with the highest rating of 83 is chosen.

Factor-Point Rating Method

Now for a last one, establish a subjective scale common to all factors. Assign points against the subjective scale for each factor and assign the factor points of the subjective rating for each factor. For example, five subjective ratings—Poor, Fair, Adequate, Good and Excellent were selected to be used in evaluating each site for each factor. For each of the factors, 'adequate' was assigned a value zero and then negative and positive relative worth weights were then assigned the subjective ratings below and above adequate for each factor in Table 5.

Table 5
Factor Point Ratings Sample

	Poor	Fair	Adequate	Good	Excellent
Factor F_1 Water Supply	−15	12	0	6	10
F_2 Appearance of Site	−3	−1	0	1	2

The range between minimum and maximum weights assigned to a factor in effect weighs that factor against all other factors in a manner equivalent to the method (iii) described just previous to this one. Each location site S_1 to S_4 were then rated by selecting the applicable subjective rating for each factor for each location and the equivalent points of that subjective factor rating assigned to the factor. Thus we can now obtain Table 6.

Table 6
Decision Matrix

Factors	Potential Sites			
	S_1	S_2	S_3	S_4
F_1	(Adequate) 0	(Fair) 12	(Good) 6	(Adequate) 0
F_2	(Adequate) 0	(Poor) 3	(Excellent) 3	(Fair) 1
F_3	(Adequate) 0	(Adequate) 0	(Adequate) 0	(Adequate) 0
Site Rating	0	− 15*	9	− 1

*Sample Calculation $-15 = (-12) + (-3) + (0)$

Accordingly Site 3 with the highest rating of 9 would be chosen.

In most cases, hardly any attempt is made to establish a direct relationship between the site rating point value and the cost values. Usually, this is left to the management. The location analyst presents to management both the cost and the intangible data results. In such cases, management could take a decision based on a simple composite measure method illustrated below with the aid of a numerical example.

Composite Measure Method

Let us enlist the steps of the composite measure method

Step-1 Develop a list of all relevant factors.

Step-2 Assign a scale to each factor and designate some minimum.

Step-3 Weigh the factors relative to each other in light of importance towards achievement of system goals.

Step-4 Score each potential location according to the designated scale and multiply the scores by the weights.

Step-5 Total the points for each location and either (a) use them in conjunction with a separate economic analysis, or (b) include an economic factor in the list of factors and choose the location on the basis of maximum points.

Now let us illustrate the composite measure method with a numerical example. There are three potential sites and five relevant factors like transportation costs per week, labour costs per week, finishing material supply, maintenance facilities and community attitude. The costs are in rupees whereas for the last three factors, points are assigned on 0-100 scale. The data collected is shown in Table 7 below.

Table 7
Payoff Matrix

Factors		Potential Location Sites		
		S_1	S_2	S_3
Transportation cost/week (Rs)	F_1	800	640	580
Labour cost/week (Rs.)	F_2	1180	1020	1160
Finishing Material Supply	F_3	30	80	70
Maintenance Facilities	F_4	60	20	30
Community Attitude	F_5	50	80	70

The location analyst has pre-established weights for various factors. This includes a standard of 1.0 for each Rs. 10 a week of economic advantage. Other weights applicable are 2.0 on finishing material supply, 0.5 on maintenance facilities and 2.5 on community attitudes. Also the organisation prescribes a minimum acceptable score of 30 for maintenance facilities.

First of all let us look at the economic factors F_1 and F_2 for which monetary values were possible. If we total the costs for each site, we get the costs for sites S_1, S_2 and S_3 as Rs. 1980, Rs. 1660 and Rs. 1740, respectively. Thus site S_1 would be the worst cost wise. Site S_2 would have an economic advantage over site S_1 to the extent of Rs. (1980 − 1660) = Rs. 320. Similarly, site S_3 would have an economic advantage over site S_1 to the extent of Rs. (1980 − 1740) = Rs. 240. Now the monetary value in Rs. can be converted to a point scale as you would realise that a standard of 1.0 is to be assigned for each Rs. 10 per week of economic advantage. Thus we could get the following Table 8.

Table 8
Decision Matrix

Factors	Weightage	Potential Location Sites S1	S2	S3
Combine $(F_1 + F_2)$ Economic Advantage				
F_3	1.0	0	32	24
F_4	2.0	30	80	70
F_5	0.5	60	20	30
	2.5	50	80	70
Composite Site Rating		*215	402	354

* Sample calculation $215 = (1.0) \times 0 + (2.0) \times 30 + (0.5) \times 60 + (2.5) \times 50$

Activity A
Based on the previous table, the location analyst site S_2 on the basis that site S_2 has a maximum location site rating of 402. Do you agree? State reasons for either agreeing or disagreeing.
....
....
....
....
....
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....

Now on referring to certain prerequisites for certain factors, because of the nature of the situation, a constraint in the form of a site scoring at least 30 on account of maintenance had been given. You would be able to observe that this basic requirement is not met by site S_2. In fact any further calculations for S_2 need not have been carried out as soon as one detected this flaw. However, we deliberately persisted on going through all the calculations. There could have been the possibility of revision of the maintenance clause constraint viz., perhaps it might have been felt that a bare minimum score of 15 would suffice. In such cases, therefore, it is better to go through all the calculations and when finally taking a decision, do keep the constraints in mind.

4.5 LOCATIONAL BREAK-EVEN ANALYSIS

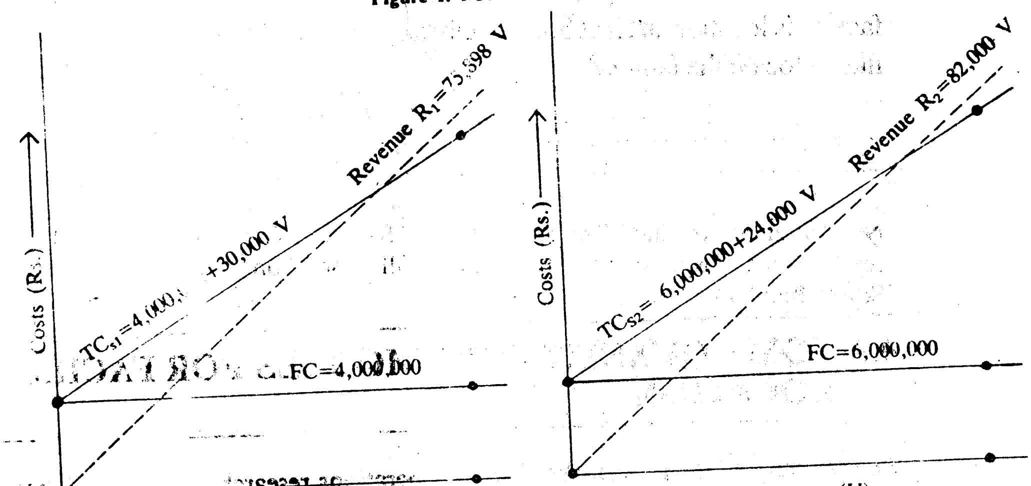
Sometimes, it is useful to draw location break-even charts which could aid in deciding which location would be optimal. The location of a Tractor factory in a South Delhi site will result in certain annual fixed costs, variable costs and revenue. The figures would be different for a South Bombay site. The fixed costs, variable costs and price per unit for both sites are given below in Table 9.

Table 9
Cost Data

Location Site	Fixed Costs	Variable Costs	Price Per Unit
South Delhi (S_1)	40,00,000	30,000	75,898
South Bombay (S_2)	60,00,000	24,000	82,000

Let us assume that the expected sales volume as estimated by a market research team is 95.

Figure 1: Locational Break-even Charts



The data of Table 8 is depicted pictorially in Figure 1 showing the location break-even charts. Now the break-even point is defined to be the point or volume where the total costs equal total revenue. Thus for each site S_1 and S_2, the break-even point can be determined by using a simple formula (which could be easily derived) as follows:

$$\text{Break-even Volume (BE)} = \frac{\text{Fixed Costs}}{\text{(Revenue per Unit—Variable Cost per Unit)}}$$

At the South Delhi Location S_1

$$BE = \frac{40,00,000}{75,898—30,000} = 87.1497 = 88 \text{ tractors.}$$

and at the South Bombay location S_2,

$$BE = \frac{60,00,000}{82,000—24,000} = 103.448 = 104 \text{ tractors.}$$

Let us see what would be the profit or loss for the two sites at the expected volume of 95 Units. The calculations are shown in Table 10.

Table 10
Cost Comparisons

South Delhi (S_1)		South Bombay (S_2)	
Costs		Costs	
Fixed	40,00,000	Fixed	60,00,000
Variable	28,50,000	Variable	22,80,000
	68,50,000		82,80,000
Revenue		Revenue	
75,898 x 95 =	72,10,310	82,000 x 95 =	77,90,000
Profit = (72,10,310—68,50,000)	= 1,80,155	Loss = (77,90,000—82,80,000)	= 4,90,000

Activity B

What would be the expected revenues for an estimated volume of 95 Units if the factory is location at (i) at South Delhi and (ii) at South Bombay? Where you would like to locate the factory?

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Now what do we find? The South Delhi (S_1) site is preferable, eventhough the revenues are lower, since the Company will lose money by locating the plant in South Bombay (S_2).

4.6 SOME QUANTITATIVE MODELS FOR FACILITY LOCATION

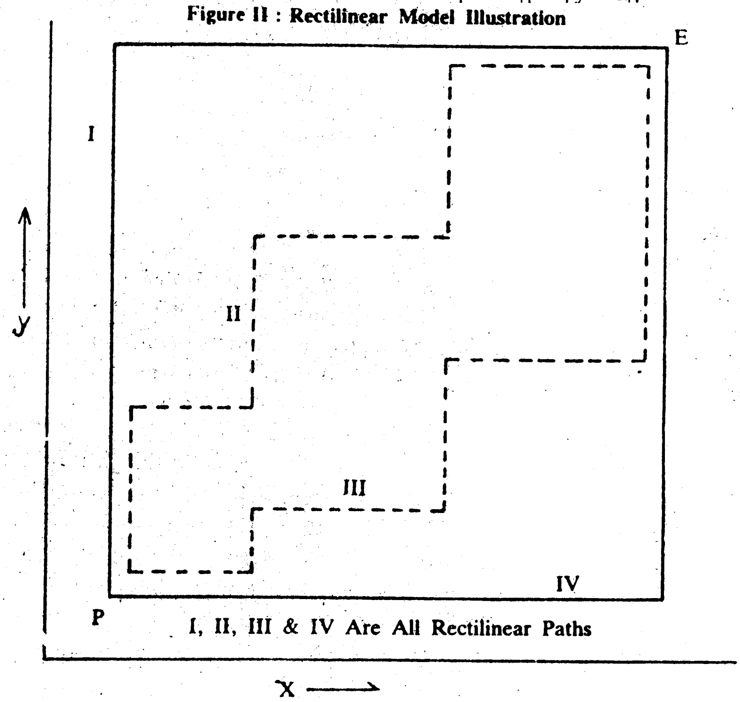
Various types of quantitative models (or operations research models) have been used to help determine the best facilities location. Let us describe a few models that are simple to understand and powerful enough to give some good answers that could aid you in taking a location decision.

Median Model

Let us discuss the simple median model which is based on the assumption that the mode of interaction or the path of movement/transportation of load is done on a rectangular/rectilinear pattern. The movement is similar to the movement of 'rooks' on a chess board. Thus all movements are made horizontally along and east-west and/or vertically in a north-south direction. Diagonal moves are not considered. You could refer to Figure II for a diagrammatic portrayal of the rectilinear path. The paths I, II, III and IV are all alternative rectilinear paths between two reference points say a new facility, P, having coordinate locations (x, y) and an ancillary existing facility, A having coordinate locations (a_i, b_i). Though there are alternative rectilinear paths, the rectilinear distance between the points A and P is however unique and it is mathematically stated as

$$Dr = \text{Rectilinear Distance} = |x - a_i| + |y - b_i|$$

Figure II : Rectilinear Model Illustration



I, II, III & IV Are All Rectilinear Paths

Now there would be some interaction by way of say the annual number of loads to be moved between two reference points. We could safely assume that the transportation cost for a load is proportional to the distance for which it is moved. This assumption could be questioned on the plea that there is a 'telescopic' scheme of rates charged in actual practice by Indian Railways. The total transportation cost is obtained by adding the number of loads to the times the rectilinear distance is moved.

$$\text{(TC) Total Transportation Cost} = \sum_{i=1}^{m} L_i \times D_i$$

Where L_i is the number of loads to be moved between the new facility to be located, and the ancillary existing i^{th} facility (say, raw material sources or market distribution outlet points), D_i is the rectilinear distance between a new facility and i^{th} existing facility and 'm' is the number of ancillary existing facilities.

Thus as a location analyst, we essentially want to determine the 'least transportation cost' location solution. The simple median model can help answer this question by using these three steps.

i) Identify the median value of the total number of loads moved.

ii) Find the X-coordinate value of the existing facility that sends (or receives) the median load and

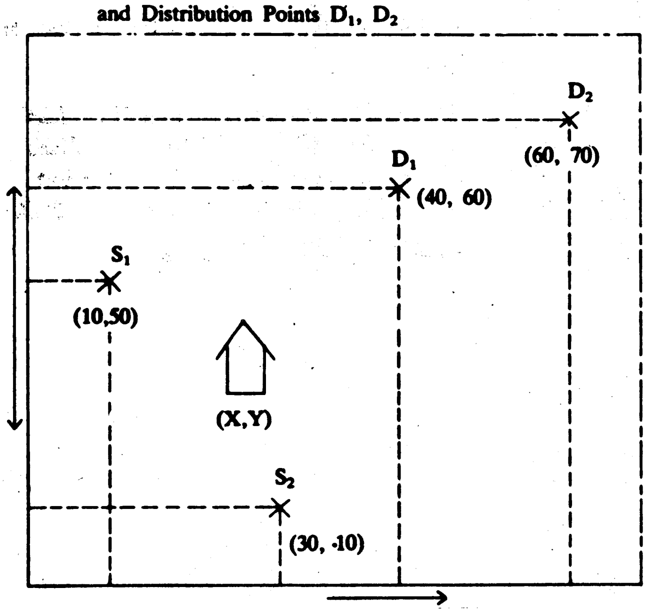
iii) Find the Y-coordinate value of the existing facility that sends (or receives) the median load.

The x and y values found in steps (ii) and (iii) define the desired optimal (best) location of the new facility.

Let us illustrate the above steps with a small example. Let us assume that a new processing plant is to be located. It would be receiving certain raw materials from two supply sources, S_1 and S_2. It would be sending its finished products to two distribution points, D_1 and D_2. The coordinate locations of the sources and distribution points are shown in Figure III below.

Figure III : Sample Problem Data

Current Location of Raw Material Source S_1, S_2 and Distribution Points D_1, D_2



Total Annual No. of Load L_i Moved To/From New Facility-N
From S_1 To New Facility 60
From S_2 To New Facility 70
From New Facility To D_1 40
From New Facility To D_2 50

Now in step (i), we have to identify the median value of the total number of loads moved. The total load moved is 220 (viz. $60+70+40+50=220$). The median number of loads is the value that has half an equal number of loads above and below it. When the total number of loads is odd, the median load is the middle load; in case of an even number, the median loads are the two middle loads. Thus for 220 loads, the median loads are 111 and 110 since there are 109 above and below this pair of values.

In step (ii) Let us now determine the X-coordinate of the median load. We could place in an ascending order the x-co-ordinates of the existing facilities viz. it is just going horizontally from left to right in Figure III. Thus the order of the existing facilities would be as S_1, S_2, D_1 and D_2 having annual loads of movement of 60, 70, 40 and 50, respectively. Loads 1 to 60 are shipped by source S_1 at $X_1=10$. Loads 61 to 130 are shipped by source S_2 at $X_2=30$. Since the median loads (110) and (111) fall in the interval 61 to 130, therefore, $x=30$ is the best x-co-ordinate location for the new facility.

Similarly, in step (iii), we can determine the y-co-ordinate of the median load. In this case we move vertically upwards. From Figure III, it can readily be seen that this ascending order would be represented by the existing facilities S_2, S_1, D_1 and D_2 with annual movement of loads to the tune of 70, 60, 40 and 50, respectively. Loads 1 to 70 are shipped by source S_2 at $Y_2=10$. Loads 71 to 130 are shipped by source S_1 at $Y_1=50$. Since the median loads (110 and 111) fall in the interval 71 to 130, therefore $Y=50$ is the best Y-coordinate location for the new facility.

Th the optimal best location for the new manufacturing facility is $(x=30,\ y=50)$. Location at this point minimises annual transportation costs for the above production distribution system.

Now the total transportation cost as explained earlier on is $TC=\sum_{i=1}^{m} Li.\ Di$ and as Di is the rectilinear distance

$$TC=\sum_{i=1}^{m}\left[Li\ |x-ai|+|y-bi|\right]$$

Let us assume that each distance unit cost is Re. 1 per load.

At $x=30$, $y=50$ viz. the optimal location of the new facility, the total cost TC can be computed as follows:

a) Cost for S_1 to New Facility $= 60\ [|30-10|+|50-50|] = 60\ (20+10) = 1200$
b) Cost for S_2 to New Facility $= 70\ [|30-30|+|50-10|] = 70\ (0+40) = 2800$
c) Cost for New Facility to D_1 $= 40\ [|30-40|+|50-60|] = 40\ (10+10) = 800$
d) Cost from New Facility to D_2 $= 50\ [|30-60|+|50-70|] = 50\ (30+20) = 2500$

$TC=(a)+(b)+(c)+(d)=1,200+2,800+800+2,500$
viz $TC=7,300$

Activity C

Supposing the new facility at a place at x =50, y =30. What would be the total transportation costs in this case? is it a better location than the new location at a (x = 30, y = 50)?

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The median model is very simple to operate. It could suffer from some major disadvantages such as:

i) It assumes that only one single new facility is to be located

ii) every point in the (x, y) plane has been assumed to be an eligible point for the location of the new facility.

iii) the median model is valid when the movement is based on a rectilinear mode only.

Let us now look at another model, which though a single facility model, doesn't assume the rectilinear mode of interaction. This is popularly known as the Gravity Model.

The Gravity Model

The technique determines the low cost 'Centre of Gravity' location of a new facility with respect to the fixed ancillary existing facilities like source suppliers (S_1, S_2 etc.) and distribution points (D_1, D_2 etc.) for which each type of product consumed or sold is known. Let us use the same data as that of the median model and thus let us refer to Figure III once more. The only difference is the mode of interaction between the single new facility and the existing facilities. In this case we assume that all goods move in a straight line joining the ancillary facility and the new facility. This is the so-called 'Euclidean' mode of interaction and is in fact the shortest distance between any two reference points.

Thus D_e = Euclidean Distance $= [(x-a_i)^2 + (y-b_i)^2]^{\frac{1}{2}}$

Thus the total transportation costs in this case are

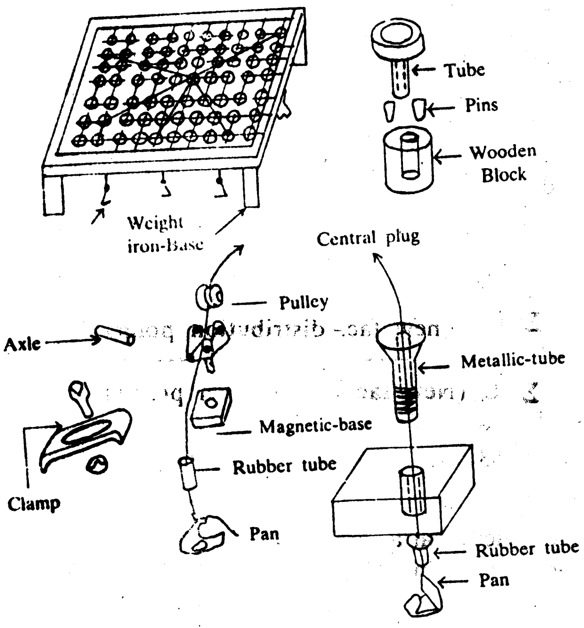
TC_e (Total transportation cost) (Euclidean case) = $\sum_{i=1}^{m}$ (LiDi)

$$\text{viz } TC_e = \sum_{i=1}^{m} L_i \left[/x-a_i/^2 + /y-b_i/^2\right]$$

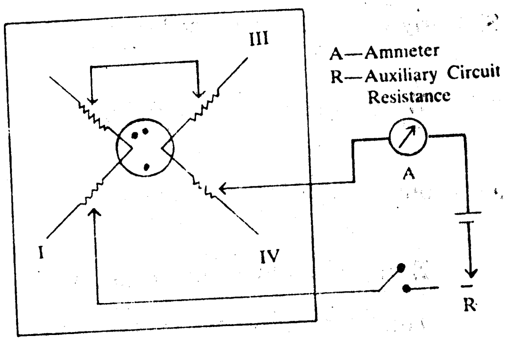
Our aim, once again, is to determine the location of the new facility at (x,y) such that TC_e, viz. the total transportation costs are as minimum. We will not get into a discussion on certain analytical problems and difficulties in obtaining optimal solutions at this stage/level, but rather present an analogue model and a gravity model which are simple to understand and could be readily applied.

The concept underlying the technique is best visualised as a series of strings to which are attached weights corresponding to the loads/weights of raw materials consumed/despatched at each source and of finished goods sold/received at each distribution point/market. The strings are threaded through holes in a flat plain metallic sheet; the holes correspond to the ancillary facility locations. The other ends of the string are tied together to a small concentric ring. The ring will finally reach an equilibrium based on the principle of equilibrium of coplanar forces. This equilibrium will be the centre of mass or the ton-mile centre. It is for this reason that this model is also called the Gravity Model. This mechanical analogue model constructed on a Varignon frame does suffer on account of friction. Banwet[2] and Vrat have devised a superior electro-mechanical analogue model, the details of which are given in Figure IV. The electrical analogue depends on making an appropriate electrical series circuit. The resistivity of the wire in resistance per unit length is synonymous to the weights/loads. Due care and precautions have to be taken for preventing short circuits by appropriate insulation devices. It will be noticed that when the central plug/ring is moved to different locations, the total resistance in the circuit changes. Determining a point with minimum total resistance is analogous to the gravity solution viz. the least cost location solution.

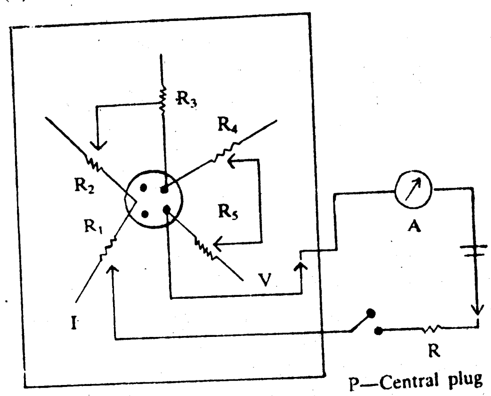
Figure IV : Analogue Model-Details



(a)



(b) Even Case Electric Circuit



(c) Odd Case Electric Circuit
R_1, R_2, R_3, R_4, R_5 Analogous to Ancilliary facility Locations I, II, III, IV, & V, respectively.

$$x = \frac{\sum_{i=1}^{m} L_i(a_i)}{\sum_{i=1}^{m} L_i} \qquad y = \frac{\sum_{i=1}^{m} L_i(b_i)}{\sum_{i=1}^{m} L_i}$$

Thus for our example under discussion now from supply sources S_1, S_2 to the new facility

$$\sum_{i=1}^{2} L_i = 60 + 70 = 130$$

$$\sum_{i=1}^{2} (L_i a_i) = (60x10) + (70x30) = 600 + 2100 = 2700$$

and from new facility to distribution points D_1 and D_2

$$\sum_{i=1}^{2} (L_i) = 40 + 50 = 90$$

$$\sum_{i=1}^{2} (L_i\, a_i) = (40x40) + (50x60) = 1{,}600 + 3{,}000 = 4{,}600$$

$$X = \frac{\sum_{i=1}^{2} L_i a_i \text{ (source-new facility)} + \sum_{i=1}^{2} L_i a_i \text{ (New facility - distribution points)}}{\sum_{i=1}^{2} L_i \text{ (sources-new facility)} + \sum_{i=1}^{2} L_i \text{ (new facility - distribution points)}}$$

$$X = \frac{2700 + 4600}{130 + 90} = \frac{7300}{220} = 33.19$$

Similarly y can be determined on similar lines from supply sources to the new facility

$$\sum_{i=1}^{2} (L_i b_i) = (60 \times 50) + (70 \times 10) = 3000 + 700 = 3700$$

and from the new facility to the distribution points

$$\sum_{i=1} (L_i b_i) = (40 \times 60) + (50 \times 70) = 2400 + 3500 = 5900$$

Total load $\sum_{i=1}^{4} L_i = 220$ as before

$$\text{Hence } y = \frac{\sum_{i=1}^{2} L_i b_i \text{ (sources-new fac.)} + \sum_{1}^{2} L_i b_i \text{ (new fac.--distribution points)}}{\sum_{i=1}^{2} L_i \text{ (sources-new fac.)} + \sum_{i=1}^{2} L_i \text{ (New fac--distribution points)}}$$

$$\text{or } y = \frac{3700 + 5900}{130 + 90} = \frac{9600}{220} = 43.63$$

Thus the gravity model solution is to locate the new facility at a point (33.19, 43.63) for which least total transportation costs would be incurred in the case of Euclidean (strictly square of Euclidean) mode of interaction

Let us compare the results of the median and gravity models. The median model for the rectilinear mode of interaction assumption gives the optimal location of the facility at (30,50) whereas the gravity model for the Euclidean (strictly squared Euclidean) mode of interaction gives the optimal location of (33.10,43.63). It is therefore necessary for the modeller to know the exact nature of the mode of interaction between the new and ancillary facilities. It is quite possible that the location solution could be highly sensitive to the mode of interaction.

You would have noticed that we have only discussed the location problems dealing with just a single new facility and also what is termed as a **minisium** objective of minimising the sum of weighted appropriate distances. There could be cases when the location as determined above turn out to be non-feasible, because of existence of certain restrictions or limitations. Methods are available for drawing iso-cost contour lines which aid the decision maker to take subsequent appropriate decisions. Sometimes a **minimax** objective might be more suited in which case the location analyst attempts to minimise the maximum weighted appropriate distances. Such a criterion would be applicable in emergency like facility location problems of fire stations, hospitals etc. **Minisium** objective situations are appropriate for locating factories, warehouses etc.

There are quite a few operational research techniques that aid the location analyst. Some of these are linear programming, transportation along with, heuristic programming, simulation, direct search procedures, graph theory, goal programming etc. Banwet has given a comprehensive review and progress in facilities location which could be referred to by those interested in further reading on the subject.

You would have observed that facilities location decision is based on a set of factors some of which are tangible/objective whereas some are intangible/subjective in nature. Brown and Gibson have proposed a composite location measure to aid the decision makers.

Composite Location Measure Model-2

Let us now discuss Brown Gibsons model which provides a composite location measure of the objective and subjective factors. We illustrate the procedure with the help of an example,

Step-1. First of all identify the factors that deserve to be included in the study and determine which of these must be absolutely satisfied, e.g., there is no point in choosing a site having a scarcity of water whereas the plant requires an abundant water supply. Say the objective factors, are labour, marketing, utilities and taxes. Now for the subjective factors, these could include housing, recreation and competition

Step-2. Let us derive an objective factor (OF) for i^{th} location site by multiplying that site's rupee cost (C_i) by the sum of the reciprocals of all the costs Σ $(1/C_i)$, and take the inverse of the product.

Viz $$OF_i = [C_i \times \Sigma(1/C_i)]^{-1}$$

Thus if we have the following data for three possible sites, OF can be obtained as below:

Site (i)	Annual costs in thousands of Rs.				Total C_i
	Labour	Marketing	Utilities	Taxes	
1	248	181	74	16	519
2	211	202	82	8	503
3	230	165	90	21	506

$\Sigma(1/C_i) = 1/519 + 1/503 + 1/506 = 0.005891$
$OF_1 = (519 \times 0.005891)^{-1} = 0.3271$
$OF_2 = (503 \times 0.005891)^{-1} = 0.3374$
$OF_3 = (506 \times 0.005891)^{-1} = 0.3355$

Step-3. Let us now deal with the subjective intangible factors with the help of a forced pair-wise comparison rating method. This procedure is first applied to rank the importance of the factors (I_k) for housing, recreation and competition; and is then applied to each site to rate how well that site satisfies the factors (S_{ik}). These two ratings are combined to obtain a subjective factor (SF_i) ranking for each site as

$$SF_i = \Sigma\ (I_k \cdot S_{ik})$$

The factor comparison is made in pairs. If one factor is preferred over the other, the one preferred is given 1 point whereas the other factor is given 0 points. Thus the table below is quite self-explanatory. If one is indifferent between the two factors, 1 point each can be assigned as seen in decision 3 while comparing factors B and C.

Factor	Comparisons Decision			Sum of preferences	Factors Rating (I_K)
	1	2	3		
A: Housing	1	1		2	2/4=0.5
B: Recreation	0		1	1	1/4=0.25
C: Competition		0	1	1	1/4=0.25
			Total	4	1.0

Next each of its factors A, B and C is then evaluated for site preferences in a similar manner

Factor A: Housing

Site	Decision			S_{AK}
	1	2	3	
1	1	0		0.33
2	0		0	0
3		1	1	0.67

Factor B: Recreation

Site	Decision			S_{BK}
	1	2	3	
1	0	0		0
2	1		1	0.67
3		1	0	0.33

Factor C: Competition

Site	Decision			S_{CK}
	1	2	3	
1	1	0		0.25
2	1		0	0.25
3		1	1	0.50

Summary of subjective factors

Factor	Site Rating			Importance
	1	2	3	
A	0.33	0	0.67	0.5
B	0	0.67	0.33	0.25
C	0.25	0.25	0.50	0.25

We can now calculate the subjective factor value (SF_i) for each site as follows:

$$SF_1 = (0.5)(0.33) + (0.25)(0) + (0.25)(0.25) = 0.2275$$
$$SF_2 = (0.5)(0) + (0.25)(0.67) + (0.25)(0.25) = 0.2300$$
$$SF_3 = (0.5)(0.67) + (0.25)(0.33) + (0.25)(0.50) = 0.5425$$

Step-4: Now depending on the parties concerned would depend a weightage (X) given to the objective versus subjective factors. Let us say we give a two thirds weightage to objective and only one third weightage to the subjective factors.

Viz, $X = 0.667$.

Step-5: Assuming that all sites that failed to meet the minimum levels set for the critical factors in step-1 have been eliminated for the remaining sites, a composite location measure (LM_i) can be obtained as follows:

$$(LM_i) = X(OF_i) + (1-X)\,SF_i$$

Using the data generated in steps 2, 3 and 4, we have

$$LM_1 = 0.67\,(0.3271) + 0.33\,(0.2275) = 0.29423$$
$$LM_2 = 0.67\,(0.3375) + 0.33\,(0.2300) = 0.30203$$
$$LM_3 = 0.67\,(0.3355) + 0.33\,(0.5425) = 0.40381$$

The site 3 is preferred. A sensitivity analysis could be done by varying the values of X. It will be seen that if X is very close to 1, site 2 would be preferred.

Bridgeman's Dimensional Analysis

As has already been observed, while selecting plant locations, we want to optimise different objectives which are interrelated but cannot be represented in the same dimensions. The location decision can be taken by making use of Bridgeman's dimensional analysis. Let us construct the utility payoff matrix once again as shown in Table below:

Factors	Potential Locations Sites				Weightage of factors
	S_1	S_2	S_3	S_4	
F_1	X_{11}	X_{12}	X_{13}	X_{14}	W_1
F_2	X_{21}	X_{22}	X_{23}	X_{24}	W_3
F_3	X_{31}	X_{32}	X_{33}	X_{34}	W_3

where X_{ij} = utility of having the plant in location j with respect to the ith factor. The utility values could be put in Rs. for the quantifiable cost oriented factors whilst the non-quantifiable non-cost factors are worked out by using a rating scale.

In this method we compare pair-wise locations in ratio with each other. A ratio R, a dimensionless quantity is then obtained as follows:
say we compare sites S_1 and S_2

$$\text{Hence } R_{12} = \frac{\text{Preference for location 1}}{\text{Preference for location 2}}$$

$$\text{viz}^{W_1}\ R_{12} = \left(\frac{X_{11}}{X_{12}}\right)^{W_1} \times \left(\frac{X_{21}}{X_{22}}\right)^{W_2} \times \left(\frac{X_{31}}{X_{32}}\right)^{W_2}$$

If $R_{12} > 1$, then the outcome of location site S_2 is better than the out-come of location 1. In this manner we can get other pair wise comparisons and would be thus in a position to choose the best site.
Let us take an example.

All Illustrative Example

Factors	S_1	S_2	Weight
Building cost and equipment costs	2500,000	1500,000	4
Taxes (per yr.)	250,00	100,000	4
Power cost (per yr.)	100,000	150,000	4
Community Attitude	2	4	1
Product Quality	4	6	5
Flexibility to adapt to situations	5	30	2

$$\text{Hence } R_{12} = \left(\frac{2500,000}{1500,000}\right)^4 \times \left(\frac{250,000}{100,000}\right)^4 \times \left(\frac{100,00}{150,000}\right)^4 \times \left(\frac{2}{4}\right)^1 \times \left(\frac{4}{6}\right)^5 \times \left(\frac{5}{30}\right)^2$$

viz., $R_{12} = 0.02$. As $R_{12} < 1$, hence location site 1 is better than location site 2 and is therefore selected.

4.7 SOME CASE EXAMPLES

By now we have had quite an exposure to qualitative, semi-qualitative, quantitative and analytical techniques which could aid in taking a proper location de ision. A location decision is quite a difficult and complex problem especially in the context of a developing country like ours which has a large variety of problems.

The distribution of industrial activity has been extremely uneven, because of unreasonable and neglected policies of the rulers/administrators of the country over the years. Almost about 50% of factory workers are found in Bombay and Calcutta. In 1951, 42% of factories were in the above two cities where 67% share of total industrial capital was invested and 63% share of industrial workers was engaged. Such tendencies of centralisation are because of factors of agglomeration. Agglomeration refers to the advantages gained due to production being made less expensive due to the concentration of industries. In the industrial field, one can easily note the clustering/grouping together/localisation of the jute industry in West Bengal and Textile Industry in Bombay and Ahmedabad. However, if due to any reason, the industrial unit is either unsuccessful or some difficult labour problems crop up, then there are a lot of subsequent hardships. Also with the point of a view of war and safety, the concentration of industry might not be a wise decision. The concentration of industry leads to the accumulation of unreasonable amount of workers which in turn creates crowded conditions, pollution, housing, schooling

After independence, the government is trying to bring about a regional balance in industrial location as reflected in the Industrial Policy resolutions that favour dispersal/decentralisation (because of the advantages of deglomeration factors). Balanced growth of all the areas or judicious dispersion of facilities in all the regions enables the nation to utilise both human and physical resources more effectively and efficiently. Agricultural, mineral and other resources can properly be tapped. Moreover, employment opportunities would be more equitably distributed. The needs of a particular area or community would also be served. It would foster national unity and check regional dissatisfaction. The North-Eastern Region has been neglected for quite some time. It is now being given its due consideration. Several problems of a socio-economic nature such as, acute shortage of housing and essential food materials, spread of epidemics, diseases, gambling etc. arise due to the creation of slums. The slums can hopefully be reduced by proper dispersion of industries. The people come to cities in search of employment. This migration could be checked provided the right opportunities are provided at the right time.

Let us see where some industries other than the jute and textile industries which prefer a climate having high humidity are located.

Steel Plants: We find that most of the steel plants lie along the Bihar, Bengal, Orissa belt. In the manufacture of steel, it is always economical to transport the finished product rather than the raw material inputs like coal, lime-stone and iron ore because during production considerable weight reduction is involved. You might be knowing that there also exists a port based steel plant at Vishakhapatnam, which in addition to taking advantage of proximity of iron-ore and coal also avails of the port facilities which aids in importing plant and machinery during the construction phase of the steel plant and in exporting the finished products when the plant goes into production.

Cement Plants: Again in the case of cement manufacturing plants, the raw materials lose weight significantly in the process of transformation, and so the cement plants are located near the lime stone and coal deposits.

Fertiliser Industry: The main feed stocks for the fertiliser industry are gas, oil or naphtha and coal. Here gain the fertiliser plants are located near the source of raw materials. The locations of fertiliser plants at Namroop and Thal Vaishet based on gas, and those at Ramagundam, Talcher and Sindri based on coal are examples. In the case of naphtha or oil based plants most of the feed stock required is imported and hence, the plants are located near the ports.

Mangalore Fertilizers at Mangalore, Madras Fertilizers at Madras, FACT at Cochin and Hindustan Fertilisers at Haldia are the relevant location examples.

Machine-tool Industries: Unlike the previous cases discussed, in the machine-tool industry case, the proximity to the source of raw material is not very significant. A number of other factors such as market factors and infrastructure will come into the picture. The machine tool industry is scattered over different parts of the country such as Bangalore, Bombay, Calcutta, Ludhiana etc.

Nuclear Power Stations: The selection and evaluation of sites of nuclear power plant throughout the world have become increasingly difficult in recent years as pressure from various societal segments, has resulted in strict consideration of the institutional environmental, safety, socio-economic and engineering factors affecting the siting, construction and operation of such facilities. A comprehensive site selection process presents a formidable task to the decision makers. The site selectior methodology combines selective screening to narrow down the search area and a classification and rating scheme to rank siting possibilities in order of preference for detailed consideration.

The basic procedural steps used in the selective screening policy are summarised below:

a) Countrywide screening—land availability, water availability seismotectonic areas,
b) Candidate regions screening—hydrology, geology, land use, meteorology, accessibility, transmission lines, demography topography.
c) Candidate siting areas screening—ecology and other factors as in (b) above.

This concludes the 'regional' approach heading to an aggregate of possible sites to be evaluated in detail for their suitability to host a nuclear power plant facility. Basic siting considerations are listed below:

a) Institutional—required service data or on line availability, system reliability requirements, size and number of units/sites, search area boundaries.
b) Engineering—safety—geology (seismic), hydrology (flooding and effluent disposal), demography, meteorology.
Functional: cooling water availability, geology (foundation, soil characteristics), accessibility (people, materials and components, transmission grid).
c) Environmental—**Ecological sensitivity** (site, transmission corridors, site environs): terrestrial, aquatic. **Land Uses:** (compatibility) dedicated lands, areas of historic and archaelogical significance, water quantities and qualities, climatology, demography, aesthetics.
d) Economic—Land costs, cooling system alternatives, site preparation costs: geology and topography, transmission line corridors, site: dictated special engineering safeguards.
e) Socio-economic: Land owner dislocations, competitive use of resources (water and land), community attitudes and public acceptance, economic influence on existing life styles.

It is essential to conduct detailed studies for the potential impact of nuclear power plant operation upon the natural characteristics of the ecology and environment. Many electric generating facilities have been located along the banks of rivers etc. so as to strategically utilise readily available cooling water for plant condenser needs. It is important to plan for effluent disposal so as to minimise pollution whether it be in the air, water or soil.

4.8 SUMMARY

In this unit we have dealt with an important strategic long term and non-repetitive problem namely the facilities location problem. The traditional factory/plant location concept has enlarged to include non-manufacturing enterprises, service industries etc. You would have realised that facilities location depends on a large number of factors, some concerned with the general territory selection whereas some factors that are relevant for site/community selection. A large number of methods are proposed that include subjective, qualitative, semi-quantitative and quantitative models for facility location. Locational break-even analysis is also an aid. Weights and ratings of factors are discussed; a median model for the single facility rectilinear mode and a gravity model for the Euclidean norm have been outlined. Some composite location measure models like the Brown and Gibson's model and the Bridgeman's dimensional analysis have been explained. A brief mention of a electro mechanical analogue model for solving Weber location problems has also been made. At the end, some case examples of different types of activities like steel, cement plants etc. have been discussed.

4.9 KEY WORDS

Agglomeration: Refers to advantages gained in production due to centralisation/ concentration of industries.

Deglomeration is the antithesis of Agglomeration. It leads to a reduction in the cost of production due to decentralisation.

Euclidean norm: The shortest path obtained by joining the reference points by a straight line.

Facility: A facility could connote any physical object, be it a factory, hospital or bank, relevant to location analysis.

Location of a facility: Geographic site at which a productive facility is suited.
between the two reference points.

Minisium objective: An objective whereby the location analyst wishes to minimise the sum of weighted appropriate distances between all relevant reference points.

Rectilinear norm: A path obtained by either moving horizontally or vertically between the two reference points.

4.10 SELF-ASSESSMENT EXERCISES

1 A manufacturer of farm equipment is considering three locations (P,Q and R) for a new plant. Cost studies show that fixed costs per year at the sites are Rs. 4,80,000, Rs. 5,40,000 and Rs. 5,04,000, respectively whereas variable costs are Rs. 100 per unit, Rs. 90 per unit and Rs. 95 per unit, respectively. If the plant is designed to have an effective system capacity of 2,500 units per year and is expected to operate at 80 per cent efficiency, what is the most economic location? If the operational efficiency that can be obtained is only 60%, what effect would this have on the site you had determined earlier on?

2 An equipment supplier has collected the following data on possible plant locations. Costs are in Rs. per year.

	Site P	Site Q	Site R
Rent and utilities	Rs. 20,000	Rs. 24,000	Rs. 30,000
Taxes	4,000	3,000	2,000
Labour	1,80,000	1,60,000	1,80,000
Materials	2,60,000	2,64,000	2,54,000
Community service	Good	Poor	Average
Community attitude	Indifferent	Indifferent	Favourable

If you were responsible for making the decision on the basis of the information given above, which site would you select and why?

3 Discuss the factors that influence the location of a plant with particular reference to Mathura Petroleum Refinery. Do you justify such a decision?

4 It is generally felt that "rural areas are good for locating large plant, semi-urban areas for locating medium-sized plants, and urban areas for small-scale plants". Comment.

5 A particular city is trying to find the best location for a master solid waste disposal station. At present four substations are located at the following coordinate locations: station 1 (4, 12), station 2 (6.5, 4) station 3 (11, 9) and station 4 (1, 13).

The number of loads hauled monthly to the master station will be 300, 200, 350 and 400 from stations 1, 2, 3 and 4, respectively. Use the simple median model to find the best location.

6 For the data given in exercise 5, what would be the best location in case the gravity model is used? Which do you think is the appropriate model to apply in the above situation—median or gravity model?

7 What are the steps of a facility location study? In case you want to locate a soft drink bottling plant, what factors would you consider relevant for taking a location decisions? How would you go about conducting the location study?

4.11 FURTHER READINGS

Adam Jr. E.E. and R.J. Ebert. 1978. *Production and Operations Management*, Prentice-Hall Inc:. Englewood-Cliffs.

Ballou, R.H. 1973. *Business Logistics Management*, Prentice-Hall Inc.: Englewood Cliffs.

Banwet, D.K. 1981. *Some Studies in Facilities Location Planning*, Unpub. Ph.D. Diss. IIT: Delhi.

Buffa, E.S. 1976. *Operations Management: The Management of Productive Systems*, John Wiley: New York.

Coyle, J.J. and E.J. Bardi. 1976. *The Management of Business Logistics.* West Publishing Co.: New York.

Francis, R.L. and J.A. White. 1974. *Facility Layout and Location. An Analytical Approach,* Prentice-Hall Inc.: Englewood-Cliffs.

Greenhut, M.L. 1956. *Plant location in theory and Practice,* Univ. of North Carolina Press: Durham.

Menipaz, E. 1984. *Essentials of Production and Operations Management,* Prentice-Hall Inc.: Englewood-Cliffs.

Mohanty, R.P. 1984. *Works Management,* AIMA-Vikas Management Service, Vikas Pub.: Delhi.

Monks, J.G. 1977. *Operations Management: Theory and Problems,* McGraw-Hill: New York.

Reed, R. 1965. *Plant Location, Layout and Maintenance,* Richard D. Irwin Inc.: Homewood.

Tompkins, J.A. and J.A. White. 1984. *Facilities Planning,* John Wiley: New York

Turner, W.C., Mize, J.H. and K.E. Case, 1978. *Introduction to Industrial and Systems Engineering,* Prentice-Hall: Englewood-Cliffs.

UNIT 5 FACILITIES LAYOUT AND MATERIALS HANDLING

Objectives

After going through this unit, you should be able to

- appreciate different types of layout problems
- become familiar with the basic types of plant layouts and the factors to be considered for layout design
- comprehend the procedure for designing the layouts in a systematic manner
- understand different kinds of tools that can be used for the analysis of material flow and activities in a plant
- realise how the space is estimated and allocated for different work centres and the facilities
- know the use of computerised techniques for designing the layouts
- learn how to evaluate, specify, present and implement a layout
- identify the factors that should be considered in the selection of material handling system
- become familiar with different types of material handling equipments used in plant design
- appreciate the integrated approach to layout planning and material handling system design and the role of automation in plant design.

Structure

5.1 INTRODUCTION

Importance and Function

Facilities layout refers to an optimum arrangement of different facilities including man, machine, equipment, material etc. Since a layout once implemented cannot be easily changed and costs of such a change are substantial, the facilities layout is a strategic decision. A poor layout will result in continuous losses in terms of higher efforts for material handling, more scrap and rework, poor space utilisation etc. Hence, need to analyse and design a sound plant layout can hardly be over emphasised. It is a crucial function that has to be performed both at the time of initial design of any facility, and during its growth, development and diversification.

The problem of plant layout should be seen in relation to overall plant design which includes many other functions such as product design, sales planning, selection of th production process, plant size, plant location, buildings, diversification etc. The layout problem occurs because of many developments including:

- change in product design
- introduction of new product
- obsolescence of facilities
- changes in demand
- market changes
- competitive cost reduction
- frequent accidents
- adoption of new safety standards
- decision to build a new plant

Plant layout problem is defined by Moore (1962) as follows:

"Plant layout is a plan of, or the act of planning, an optimum arrangement of facilities, including personnel, operating equipment, storage space, materials-handling equipment, and all other supporting services, along with the design of the best structure to contain these facilities."

Objectives and Advantages

Some of the important **objectives of a good plant layout** are as follows:

i) Overall simplification of production process in terms of equipment utilisation, minimisation of delays, reducing manufacturing time, and better provisions for maintenance.

ii) Overall integration of man, materials, machinery, supporting activities and any other considerations in a way that result in the best compromise.

iii) Minimisation of material handling cost by suitably placing the facilities in the best flow sequence.

iv) Saving in floor space, effective space utilisation and less congestion/confusion.

v) Increased output and reduced inventories-in-process.

vi) Better supervision and control.

vii) Worker convenience, improved morale and worker satisfaction.

viii) Better working environment, safety of employees and reduced hazards.

ix) Minimisation of waste and higher productivity

x) Avoid unnecessary capital investment

xi) Higher flexibility and adaptability to changing conditions.

Types of Layout Problems

The facilities layout problems can be classified according to the type of facility under consideration e.g.

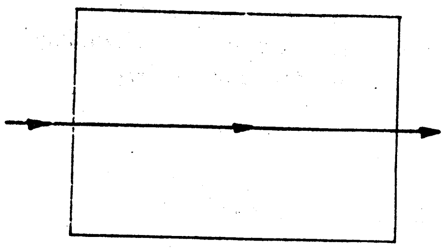
i) Manufacturing Plants
ii) Commercial facilities, e.g., shops, offices, Bank etc.
iii) Service facilities, e.g., Hospitals, Post Offices etc.
iv) Residential facilities, e.g., houses, apartments etc.
v) Cities, townships
vi) Reereational facilities, e.g. parks, theatres etc.

According to the nature of layout problem, it can be categorised into four types as follows:

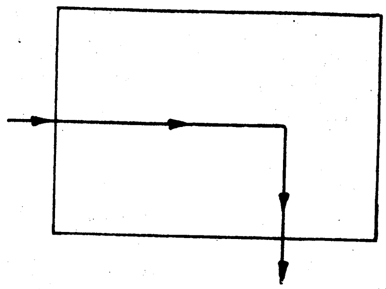
- Planning a completely new facility
- Expanding or relocating an existing facility
- Rearrangement of existing layout
- Minor modifications in present layout

Flow Patterns

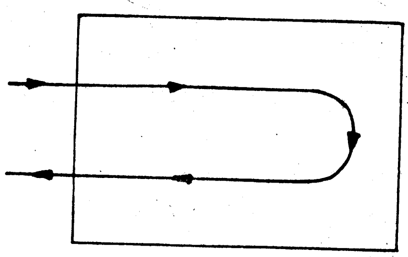
According to the principle of flow, the layout plan arranges the work area for each operation or process so as to have an overall smooth flow through the production/service facility. The basic types of flow patterns that are employed in designing the layouts are I-flow, L-flow, U-flow, O-flow, S-flow as shown in Figure 1. These are briefly explained below:



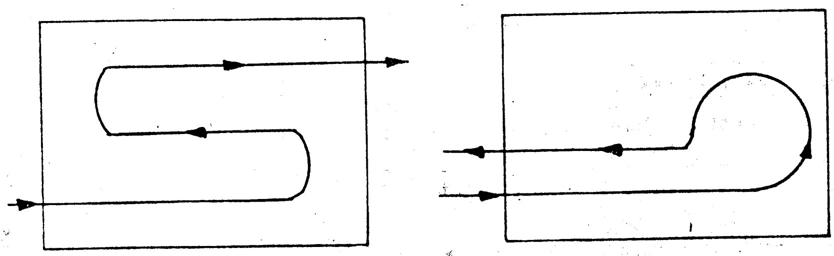
(a) I-Flow



(b) L-Flow



(c) U-Flow



(d) S-Flow (e) O-Flow

Figure I Flow Pattern

I-Flow: separate receiving and shipping area.

L-Flow: when straight line flow chart to be accommodated.

U-Flow: very popular as a combination of receiving and shipping.

O-Flow: when it is desired to terminate the flow near where it is originated.

Serpentine or S-Flow: when the production line is long and zigzagging on the production floor is required.

Activity A

Can you identify th flow pattern in the layout of facilities you work in?

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5.2 BASIC TYPES OF PLANT LAYOUTS

Depending upon the focus of layout design there are five basic or classical types of layouts. Most of the practical layouts are a suitable combination of these basic types to match the requirements of activities and flow. The basic types of the layouts are:

Product or Line Layout

This type of layout is developed for product focused systems. In this type of layout only one product, or one type of product, is produced in a given area. In case of product being assembled, this type of layout is popularly known as an 'assembly line'.

The work centres are organised in the sequence of appearance. The raw material enters at one end of the line and goes from one operation to another rapidly with minimum of work-in-process storage and material handling. A typical product layout is shown in Figure II (a).

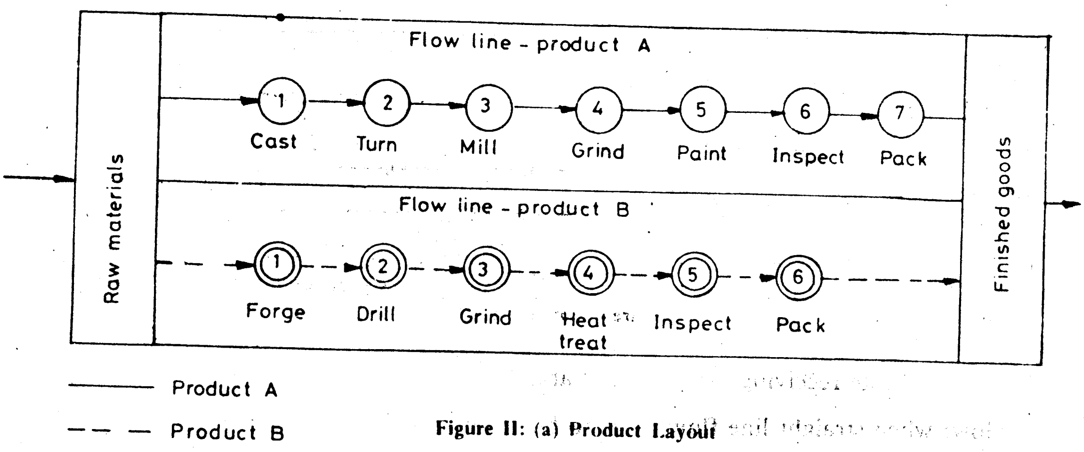

Figure II: (a) Product Layout

The decision to organise the facilities on a product or line basis is dependent upon a number of factors and has many consequences which should be carefully weighed. Following conditions favour the decision to go for a product focused layout.

i) High volume of production for adequate equipment utilisation.
ii) Standardisation of product and part interchangeability.
iii) Reasonably stable product demand.
iv) Uninterrupted supply of material.

The major problem in designing the product-focused systems is to decide the cycle time and the sub-division of work which is properly balanced (popularly known as line balancing).

Some of the major advantages of this type of layout are:
i) Reduction in material handling
ii) Less work-in-process
iii) Better utilisation and specialisation of labour
iv) Reduced congestion and smooth flow
v) Effective supervision and control.

Process or Functional Layout

This type of layout is developed for process focused systems. The processing units are organised by functions into departments on the assumption that certain skills and facilities are available in each department. Similar equipments and operations are grouped together, e.g., milling, foundry, drilling, plating, heat treatment etc. A typical process layout is shown in Figure II (b)

The use of process-focused systems is very wide both in manufacturing and other service facilities such as hospitals, large offices, municipal services etc.

The functional layout is more suited for low-volumes of production (batch production) and particularly when the product is not standardised. It is economical when flexibility is the basic system requirement. The flexibility may be in terms of the

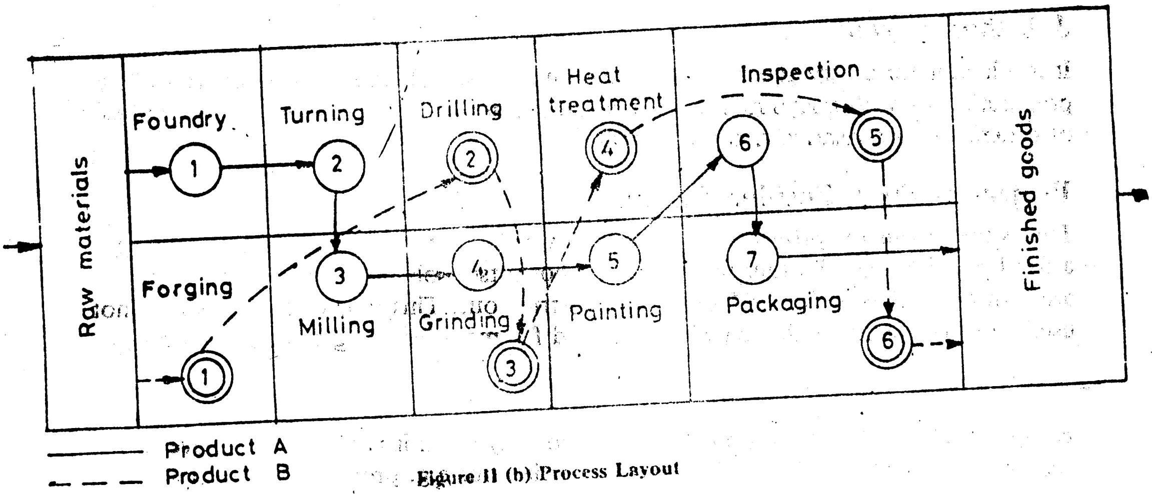

Figure II (b) Process Layout

routes through the system, volume of each order, and the processing requirements of the items.

The major advantages of a process layout are:

i) Better machine utilisation
ii) Higher flexibility
iii) Greater incentive to individual worker
iv) More continuity of production in unforeseen conditions like breakdown, shortages, absenteeism etc.

Cellular or Group Layout

It is a special type of functional layout in which the facilities are clubbed together into cells. This is suitable for systems designed to use the concepts, principles and approaches of 'group technology'. Such a layout offers the advantages of mass production with high degree of flexibility. We can employ high degree of automation even if the number of products are more with flexible requirements. In such a system the facilities are grouped into cells which are able to perform similar type of functions for a group of products. A typical cellular layout is shown in Figure II (c).

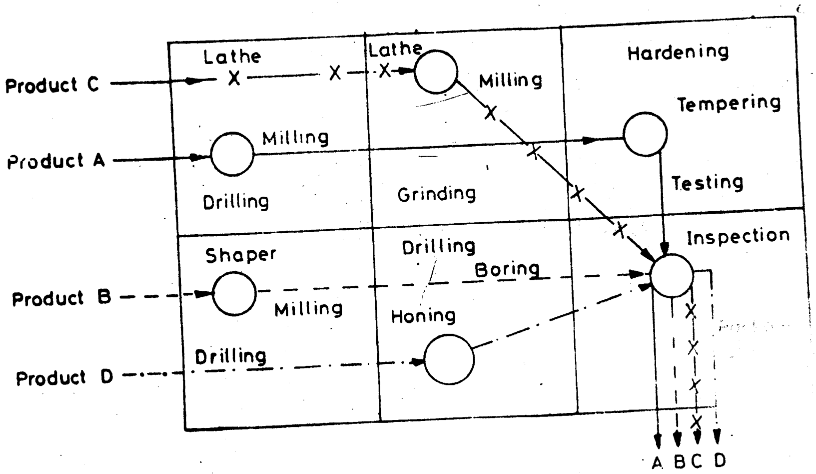

Figure II (c) Cellular Layout

Job-shop Layout

It is a layout for a very general flexible system that is processing job production. The preparation of such a layout is dependent on the analysis of the possible populations of orders and is a relati·ely, complex affair.

Project or Fixed Position Layout

This is the layout for project type systems in which the major component is kept at a fixed position and all other materials, components, tools, machines, workers etc. are brought and assembly or fabrication is carried out. This type of layout is now not used very commonly as the machines required for manufacturing work are big and complicated. The fixed position layout is used only when it is difficult to move the major component and fabrication is to be carried out, e.g. production of ships.

Some of the major advantages of fixed position layout are as follows:

i) The handling requirements for major unit are minimised.
ii) Flexible with reference to the changes in product design.
iii) High adaptability to the variety of product and intermittent demand.
iv) The responsibility for quality can be pin-pointed.
v) The capital investment is minimum.

A typical fixed position layout is shown in Figure II (d).

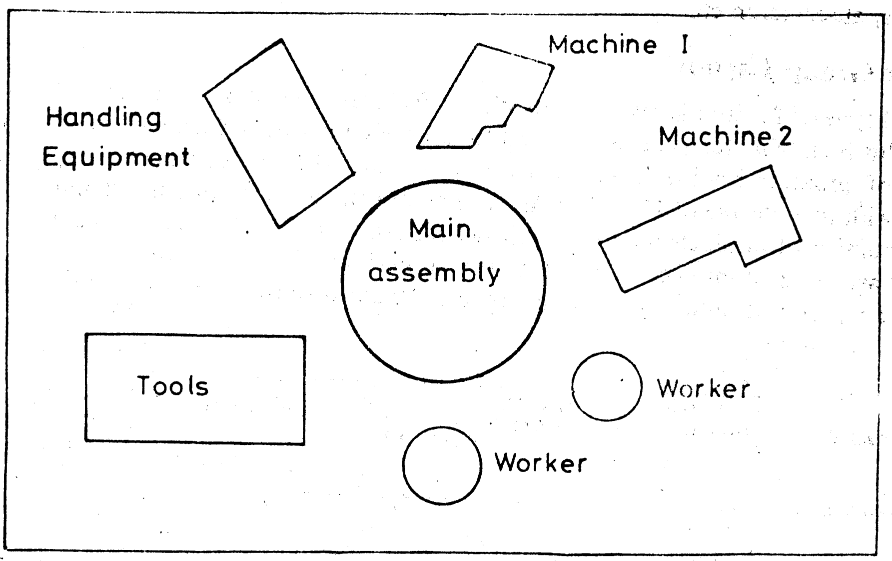

Figure II (d) Fixed Position Layout

Activity B

Can you identify the basic type of plant layout in the facility you work in? Is it optimal? Would some other type of layout than the one currently prevailing in your facility be better?

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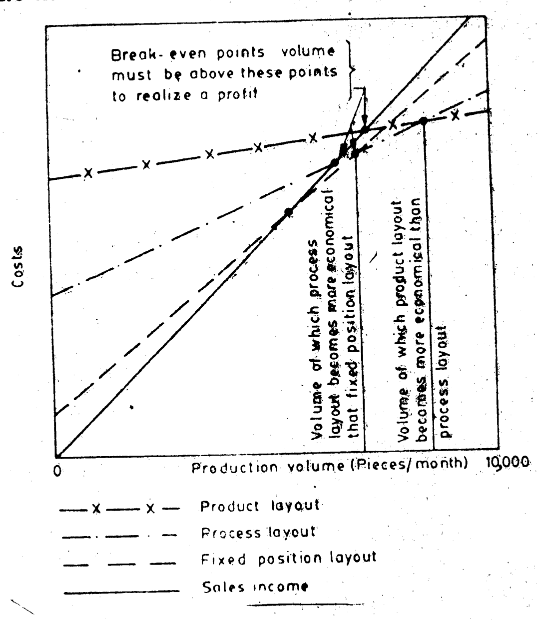
The fixed position layout is used ideally for a project situation i.e. for one product of a different type. As the quantity increases the production operations can be broken down into different work centres and material can be allowed to move rather than the machines and a process layout is preferred. With further increase in volume i.e. with mass production the advantages of production line can be better derived and a product layout is desirable. The break-even analysis comprising the production volume of the three basic layouts i.e., product, process and fixed position layout is shown in Figure III.

Figure III: Break-even Point Analysis of Basic Types of Layouts



5.3 PLANT LAYOUT FACTORS

The design of any layout is governed by a number of factors and the best layout is the one that optimises all the factors. As discussed by Muther (1955) the factors influencing any layout are categorised into the following eight groups:

i) The material factor: Includes design, variety, quantity, the necessary operations, and their sequence.
ii) The man factor: Includes direct workers, supervision and service help, safety and manpower utilisation.
iii) The machinery factor: Includes the process, producing equipment and tools and their utilisation.
iv) The movement factor: Includes inter and intradepartmental transport and handling at the various operations, storages and inspections, the materials handling equipments.
v) The waiting factor: Includes permanent and temporary storages and delays and their locations.
vi) The service factors: Include service relating to employee facilities such as parking lot, locker rooms, toilets, waiting rooms etc. service relating to materials in terms of quality, production control, scheduling, despatching, waste control; and service relating to machinery such as maintenance.
vii) The building factor: Includes outside and inside building features and utility distribution and equipment.
viii) The change factor: Includes versatility, flexibility and expansion.

Each of the above mentioned factors comprise a number of features and the layout engineer must review these in the light of his problem. Usually the layout design process is a compromise of these various considerations to meet the overall objectives in the best possible manner.

5.4 LAYOUT DESIGN PROCEDURE

The overall layout design procedure can be considered to be composed of four phases viz.,

Phase I Location
Phase II General Overall layout
Phase III Detailed layout
Phase IV Installation

Some important guidelines that help in the layout design are:

i) Plan from whole to details
ii) First plan the ideal and then move to the practical aspects
iii) Material requirements should be central to the planning of process and machinery.
iv) Modify the process and machinery by different factors to plan the layout.

Though there is always an overlap in the different phases of layout design the major steps that have to be followed in the layout design are outlined as follows:

i) Statement of the problem in terms of its objective, scope and factors to be considered.
ii) Collection of basic data on sales forecasts, production volumes, production schedules, part lists, operations to be performed, work measurement, existing layouts, building drawings etc.
7) iii) Analysis of data and its presentation in the form of various charts.

iv) Designing the production process
v) Planning the material flow pattern and developing the overall material handling plan.
vi) Calculation of equipment requirements and work centres
vii) Planning of individual work centres
viii) Selection of material handling equipment
ix) Determining storage requirements
x) Designing activity relationships
xi) Planning of auxiliary and service facilities
xii) Calculation of space requirements and allocation of activity areas
xiii) Development of Plot Plan
xiv) Development of Block Plan
xv) Development of detailed layouts in terms of steps (vii) to (xi)
xvi) Evaluation, modification and checking of layouts
xvii) Installation of layouts
xviii) Follow up.

The S.L.P. (Systematic Layout Planning) procedure as presented by Francis and White (1974) is shown in Figure IV. We see that once the appropriate information is gathered, a flow analysis can be combined with an activity analysis to develop the relationship diagram. Space considerations when combined with the relationship diagram lead to the construction of the space relationship diagram. Based on the space relationship diagram, modifying considerations and practical limitations, a number of alternative layouts are designed and evaluated.

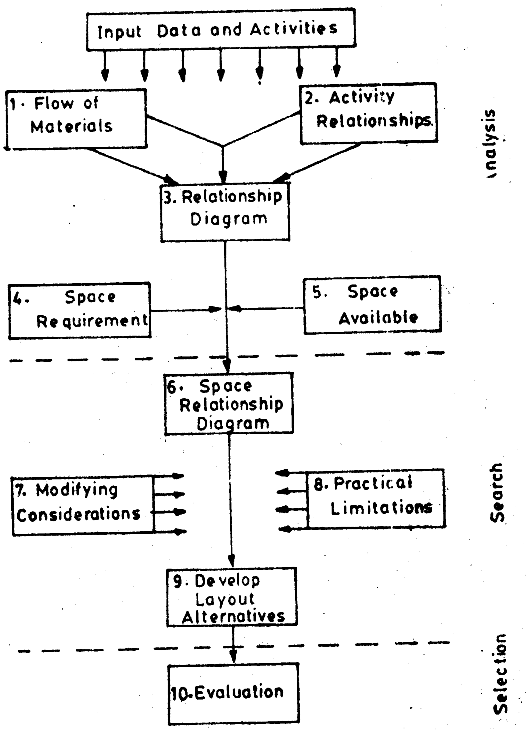


Figure IV: Systematic Layout Planning Procedure

5.5 FLOW AND ACTIVITY ANALYSIS

Data Collection

The development of any layout is dependent on the quality and quantity of facts that we have about the various factors influencing it. The data collection phase is not a one time effort but an ongoing function. The data for overall plan is to be collected at initial stages whereas the data for detailed layouts may be obtained at a later stage. The facts have to be obtained regarding various materials and processes, the flow routing and sequencing, space requirements, and different activities and relationships. The information required about the materials and processes is listed in Table 1. We will now discuss some of the tools and techniques that help in the layout analysis.

Table 1
Information Required about Materials and Processes

	Data Required	Source of Data
Product Specifications	Product size, weight and shape Quality requirements Special properties	Product engineering, quality control, inspection
Production Volume	Number of different items (product mix) Quantity of each item per unit time Variation in output Variation in demand	Sales department, market research, production planning
Component Parts	Performance times for all operations Variation in performance times Sequence of fabrication Operations Sequence of assembly Operations Types of machinery required	Production Planning, time study department

Source: Moore, J.M. 1970. *Plant Layout and Design*. The Macmillan Company: New York.

Process Charts

There are many types of process charts that can be developed. The most commonly used ones are operation process charts and Flow Process Charts.

i) **Operation Process Chart:** This is a graphic representation that describes the different operations (O) and inspection (□) in a sequential manner including information regarding time, location etc.

ii) **Flow Process Chart:** The arrangement of facilities in a production process govern the flow of product and vice-versa. Thus the analysis of flow should be carried out closely when formulating a plant layout proposal. The flow process chart summarises the flow and activity of a component/man through a process or procedure in terms of sequence of operation, transportation, inspection, delay and storage. It includes the information about time required and distance moved. A sample flow process chart is shown in Figure V.

Flow Diagram

It is a sketch of the layout which shows the location of all activities appearing on a flow process chart. The path of movement of material or man is traced on the flow diagram. The different activities are given by process chart symbols with a number. This gives an idea about the overall flow through the plant in a pictorial manner. Any back tracking or crisis crossing of the flow can be pin-pointed and the layout engineer can redesign the layout for a smoother flow by minimising these wasteful flows. If necessary a three dimensional flow diagram can be developed, particularly in case of multi-storeyed buildings. This helps in developing the activity relationship diagram which when superimposed by space relationships results in block plan.

Travel Chart

It is also known as **From To Chart.** This chart is helpful in analysing the overall material flow. It indicates the distance and number of moves between different pairs of departments taken as origin and destination. A typical travel chart is shown in Figure VI. The travel chart is helpful in the process type layout design; but in product layout, it is not important. It indicates the relationship between different departments in terms of material interaction. Attempts should be made in layout design to put those departments close to each other which have high level of material interaction so as to minimise the materials handling requirements provided other objectives are also satisfied. In most of the practical situations, it may be difficult to achieve the theoretical optimum, but the closest possible solution to the optimum should be approached.

The travel chart summarises the data on material handling in compact matrix form, which is amenable to computer applications also. Further, the information regarding the bulk of material handled, mode of material handling, material handling equipment etc. may also be listed to make it more informative.

Analysis				
Why ?				
What?	Where	When?	Who?	How?

Question each detail

FLOW PROCESS CHART

No. 1

Page/of 1

Summary

	Present		Proposed		Difference	
	No	Time	No	Time	No	Time
○ Operations	3	90				
⇨ Transportations	2					
□ Inspections	1	10				
D Delays	2	35				
▽ Storages	3					
Distance traveled	15 m					

Job Cast, Turn, Drill

☐ Man or ☒ Material

Chart begins Raw material store

Chart ends Inspection

Charted by Sushil

Date 20-3-87

	Details of (present) method proposed	Operation	Transport	Inspection	Delay	Storage	Distance in m	Quantity	Time (min.)	Possibilities: Eliminate	Combine	Change: Sequence	Place	Person	Improve	Notes
1.	Raw material store	○	⇨	□	D	**▽**										
2.	Casting	**○**	⇨	□	D	▽			60						x	
3.	Casting store	○	⇨	□	D	**▽**										
4.	Handling to turning shop	○	**⇨**	□	D	▽	10						X			
5.	Delay at Lathe M/C	○	⇨	□	**D**	▽		10	20							
6.	Turning	**○**	⇨	□	D	▽			15							
7.	Work in process store	○	⇨	□	D	**▽**										
8.	Handling to drilling shop	○	**⇨**	□	D	▽	5									
9.	Delay at Drilling M/C	○	⇨	□	**D**	▽		8	15	X						
10.	Drilling	**○**	⇨	□	D	▽			15						x	
11.	Inspection	○	⇨	**□**	D	▽			10							
12.		○	⇨	□	D	▽										
13.		○	⇨	□	D	▽										
14.		○	⇨	□	D	▽										

Figure V: Low Process Chart Summarises The Flow and All Activity of A Component Through Its Manufacturing Process

	Casting	Forging	Drilling	Mach-ing	Metro-logy	Elects	Welding	Insp-ection	Total
Casting			7	10	4	4	3	10	38
Forging			3	5			2	6	16
Drilling				2				12	14
From 'i' Machining			4		5		2	6	17
Metrology			Mij					14	14
Electic								4	4
Welding								7	7
Inspection					5				5
Total	0	0	14	17	14	4	7	59	

Mij - No of moves from ith to jth department

Figure VI: Travel Chart

The entries in the travel chart are on both sides of the diagonal. The travel requirements from department 'A' to 'B' may be different than from department 'B' to 'A'.

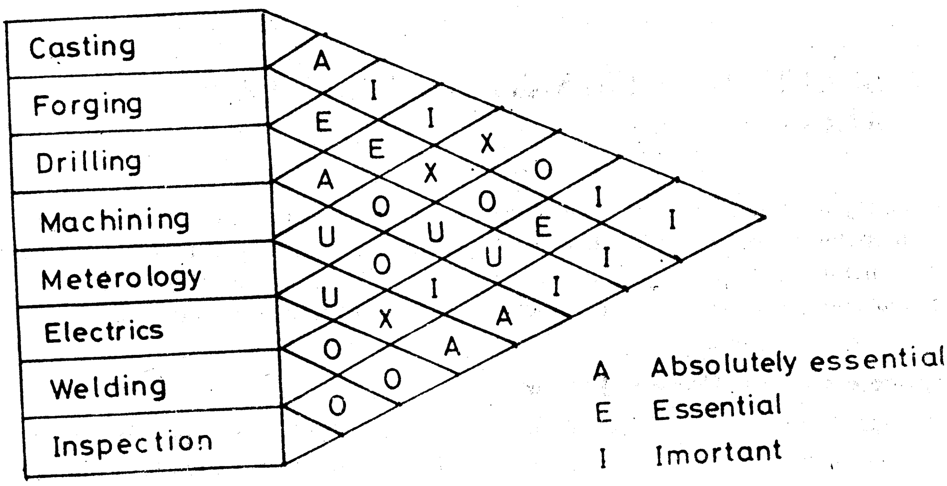
The sum of each row should be equal to the sum of each column indicating that the number of jobs entering to department and leaving the same department are equal. This puts a check on the continuity of the system. However, this is not true the first and last departments in the sequence. The addition of the first and last row should balance with the addition of first and last column.

Some of the important advantages and uses of travel chart are:

i) It helps in analysing the material movement
ii) It aids in determining activity locations
iii) It alternates flow patterns and layouts can be compared
iv) It shows relationship of different activities in terms of volume of movement.
v) It depicts quantitative relationships which can be used for computerised analysis and OR applications.

REL Chart

This is known as 'Relationship Chart' which indicates the relationship between pairs of departments in terms of closeness depending upon the activities of the department as A-Absolutely essential, E-Essential, I-Important, O-Ordinary, U-Unimportant and X-Undesirable. A typical REL chart is shown in Figure VII.



O Ordinary

U Unimportant

X Not dessiable

Figure VII: REL Chart

Activity C

Develop Process charts for some activities of your organization.

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Application of Quantitative Techniques

The techniques of Operations Research can be applied to quantitatively analyse the layout problems, particularly in terms of material flow. Some of the important techniques that have been applied by different researchers in the field of layout planning are as follows:

i) Linear Programming
ii) Transportation Algorithm
iii) Transhipment Problem
iv) Assignment Problem
v) Travelling Salesman Problem
vi) Dynamic Programming
vii) Queueing Theory
viii) Simulation.

Linear Programming is used when there is a linear objective function which is to be maximised/minimised subject to certain linear constraints. In the layout design the objective is to minimise the materials handling. Transportation and assignment problems are special cases of Linear Programming. Further, to meet the multiple objectives of layout planning attempts have also been made to apply **Goal Programming** as a technique of Multi-criteria Decision-making. These operations research techniques are discussed in MS. 7.

5.6 SPACE DETERMINATION AND AREA ALLOCATION

In the layout planning process the space is allocated to different activities. The requirement of space by a facility bears a close relationship to equipment, material, personnel and activities. Two major methods that are being used for space calculations are space based on present layout and production centre method.

Space Bas. . on Present Layout

This approach is suitable when the proposed layout is to be developed for an existing product. While determining the space, consideration should be given to space requir_d for

- operating equipment
- storage
- service facilities
- operators

Allowance must be made for space between machines for operator movement, work in-process, access of materials handlers, maintenance personnel etc.

Production Centre Method

The space for each production centre is determined including the space for machines, tool cabinets, worked and unworked parts, access to the aisle and maintenance. In this method actual arrangement of equipment is considered for space calculation. The departmental space is calculated by multiplying it with the number of production centres in that department.

Work Place Layout

The details of the arrangements at a work centre is to be provided in terms of the machines and auxiliary equipment, operator, tools, materials and auxiliary services. The procedure for work place design is as follows:

i) Determination of direction of overall flow
ii) Determination of the desired direction of flow at work place
iii) Determination of the items contained in a work place
iv) Sketching the arrangement of these items
v) Specifying the sources of material and direction of flow
vi) Indicating the destination of material
vii) Method of waste disposal specified
viii) Sketching the material handling equipment
ix) Checking the arrangements against the principles of motion economy
x) Marking of distances between items
xi) Recording the layout on scale
xii) Indicate method of operation on chart.

Area Allocation

The activity relationships and space requirements are integrated to allocate the areas which forms the basis for detailed layout planning. There are a number of factors that should be considered for area allocation some important ones are:

i) Area should be allocated for expansion purposes. The allocation of expansion area depends upon the type of flow pattern i.e. straight line, U-flow, O-flow etc.
ii) Area allocation to maintain flexibility in layout.
iii) Maximum use of third dimension
iv) Area allocation for point of use storage and centralised storage
v) Area allocation for aisles
vi) Consideration of column spacing.

5.7 COMPUTERISED LAYOUT PLANNING

A recent trend has been the development of computer programme to assist the layout planner in generating alternative layout designs. Computerised layout planning can improve the search of the layout design process by quickly generating a large number of alternative layouts.

Computer programmes are generally either construction programmes or improvement programmes:

i) Construction programmes	(CORELAP Computerised Relationship Layout Planning)
(Successive selection and placement of activities)	ALDEP (Automated Layout Design Programme)
ii) Improvements programmes	CRAFT. (Computerised Relative Allocation of Facilities Techniques)
(A complete existing layout is required initially and locations of departments are inter-changed to improve the layout design)	

Both ALDEP and CORELAP are concerned with the construction of a layout based on the closeness ratings given by the REL chart.

CRAFT is concerned with the minimisation of a linear function of the movement between departments. Typically CRAFT employs an improvement procedure to obtain a layout design based on the objective of minimising material handling costs.

CORELAP

It begins by calculating which of the activities in the layout is the busiest or most related. The sums of each activity's closeness relationships with all other activities are compared and the activity with the highest total closeness relationship (TCR) count is selected and located first in the layout matrix. This activity is named **Winner.** Next, an activity which must be close to the winner is selected and placed as adjacent as possible to winner. This activity is denoted as A (closeness absolutely necessary) and is named **Victor.** A search of winner's remaining relationships for more A-related victors is then made. These are placed, again, as close to each other as possible. If no more A's can be found, the victors become potential winners and their relationships are searched for A's. If an A is found, the victor becomes the new winner, and the procedure is repeated. When no A's are found, the same procedure is repeated for E's (closeness Especially important), I's (closeness important), and O's (Ordinary closeness o.k.) until all activities have been placed in the layout. CORELAP also puts a value on the U (closeness Unimportant) and X (closeness not desirable) relationship.

ALDEP

It uses a preference table of relationship values in matrix form to calculate the scores of a series of randomly generated layouts. If for example, activities 11 and 19 are adjacent, the value of the relationship between the two would be added to that layout's score. A modified random selection technique is used to generate alternate layouts. The first activity is selected and located at random. Next, the relationship data are searched to find an activity with a high relationship to the first activity. This activity is placed adjacent to the first. If none is found, a second activity is selected at random and placed next to the first. This procedure is continued until all activities are placed. The entire procedure is repeated to generate another layout. The analyst specifies the number of layouts wanted which must satisfy a minimum score.

CRAFT

It is the only one which uses flow of materials data as the sole basis for development of closeness relationships. Material flow, in terms of some unit of measurement (pounds per day, in terms of skid-loads per week), between each pair of activity areas, forms the matrix to the programme.

A second set of input data allows the user to enter cost of moving in terms of cost per unit moved per unit distance. In many cases this cost input is unavailable or inadequate, in which case it can be neutralised by entering 1.0 for all costs in the matrix.

Space requirements are the third set of input data for CRAFT. These take the form of an initial or an existing layout. For new area layouts, best guess or even completely random layouts can be used. In any case, activity identification numbers, in a quantity approximate to their space requirements, are entered in an overall area of configuation. The location of any activity can be fixed in the overall area through control cards CRAFT limits the number of activities involved in the layout to 40

5.8 EVALUATION, SPECIFICATION, PRESENTATION AND IMPLEMENTATION

Plot Plan

It is a diagrammatic representation of the building outline, showing its location on the property, the location of external transportation facilities and other items such as tanks, storage areas, parking lots etc. It can be used as a key or master drawing for locating separate detailed drawings of the layout. The plot plan is presented in the form of a drawing or as a scaled model.

Block Plan

A block plan is a diagrammatic representation showing internal partitions of departments (Figure II), columns and area allocation but not machinery, equipment and facilities. This is usually presented in the form of drawings and is used as a reference or master for detailed layouts of different departments. This shows the area allocations for aisles, column spacing etc.

Detailed Layout

It is a diagrammatic representation of the arrangement of equipment operator and materials along with the arrangement of supporting activities. The detailed layout can be constructed by utilising any one of the following methods

- drafting or sketching
- templates
- models

A template is a scaled representation of a physical object in a layout may be of a machine, workman, material-handling equipment, work-in-process storage etc.

Models are three dimensional representations of the physical objects which give depth to the layout and make it more presentable.

These templates and models may be prepared from cardboard, paper, sheet metal, plastic or wood and may be black and white or coloured. These may be attached to the backing material by using various fastening devices such as glue, staples, rubber cement, thumbtacks, magnetism etc.

Checking the Layout

The layout finally developed should be checked for

- overall integration
- minimum distance moved
- smooth flow of the product
- space utilisation
- employee satisfaction and safety
- flexibility

ii) An :ral report

iii) A W :itten report

When the final layout is approved it is installed in a number of phase, and it is needed to prepare

- detailed drawings
- precise specifications of production and materials handling equipment
- detailed listing of all equipment and utility requirements
- actual plans and schedule of construction and installation.

The techniques of project management such as CPM/PERT may be used for planning and monitoring the progress of the layout installation.

5.9 MATERIALS HANDLING SYSTEMS

We have discussed in previous sections the analysis of material flow and the design of layout based on it. We have referred to the selection of material handling equipment and area allocation for it. Materials handling is the art and science involving the movement, packaging and storing of substances in any form. In this section we will discuss about the objectives of the material handling system design, basic types of material handling systems and the procedure for the design and selection of material handling system while developing a plant layout.

Objectives and Functions

In order to perform the activities of materials handling the basic goal is to minimis the production costs. This general objective can be further subdivided into specific objectives as follows:

i) To reduce the costs by decreasing inventories, minimising the distance to be handled and increasing productivity.

ii) To increase the production capacity by smoothing the work flow.

iii) To minimise the waste during handling

iv) To improve distribution through better location of facilities and improved routing.

v) To increase the equipment and space utilisation.

vi) To improve the working conditions.

vii) To improve the customer service.

The analysis of materials handling requirements can be carried out by using travel charts and other quantitative techniques as outlined in section 7.5.

The basic materials handling function has to answer a number of questions as follows:

i) Why do this at all? Justifying the necessity of material handling.

ii) What material is to be handled? Giving the type (unit, bulk etc.), characteristics (shape, dimension etc.) and quantity.

iii) Where and when? Specifying the move in terms of source and destination, logistics, characteristics (distance, frequency, speed, sequence etc.) and type (transporting, conveying, positioning etc.)

iv) How? And Who? Specifying the method in terms of the handling unit (load support, container, weight, number etc.), equipment, manpower, and physical restrictions (column spacing, aisle width, conjestion etc.)

Basic Materials Handling Systems

The flexibility should be introduced in building and services by providing unobstructed floor area and in equipment by mounting them on wheels or skids.

Activity D

Choose a major facility or your organzation and develop a detailed layout for the

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Evaluation of Layout

The evaluation may be done of an existing layout or of an alternative layout. The basis for evaluating the layout might include:

i) the objectives of layout planning
ii) cost comparison with other alternatives
iii) return on investment
iv) intangible factors which must be evaluated on the basis of judgment.
v) productivity evaluation
vi) space evaluation
vii) ranking
viii) pilot plant
ix) sequence demand-straight line-considering the sequence of operations on a variety of parts.
x) Factors analysis by weighing various factors according to their importance.

The optimising evaluation can also be done by using Operation Research Techniques such as

- Linear Programming
- Line Balancing
- Level Curve Concept

Mathematical models express the effectiveness of layout as a function of a set of variables which can be evaluated. Some other mathematical techniques of evaluation are:

- Monte Carlo Method
- Queuing Theory
- Engineering Economy
- Analogues

These are not discussed in details here.

Installation of Layout

The layout is presented in the following ways:

i) The Visual presentation of the layout itself, supplementary details and facts and supplementary charts and displays.

5.10 MATERIALS HANDLING EQUIPMENT

After the simplification of the handling method the selection of equipment is important with respect to the different objectives of speed, efficiency-cost etc. There are both the manual and powered kind of handling equipments. Some of the typical handling equipments are shown in Figure VIII. Apple (1977) has classified the handling equipments into four basic types, viz., conveyers, cranes and hoists, trucks, and auxiliary equipment.

Conveyers

These are gravity or powered devices commonly used for moving uniform loads from point to point over fixed paths, where the primary function is conveying. Commonly used equipment under this category are:

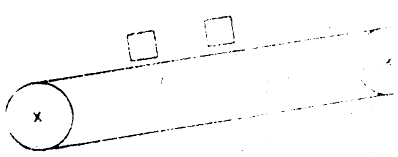
i) Belt Conveyer
ii) Roller Conveyer
iii) Chain Conveyer
iv) Bucket Conveyer
v) Trolley Conveyer
vi) Screw Conveyer
vii) Pipeline Conveyer
viii) Vibratory Conveyer
ix) Chute.

Cranes, Elevators and Hoists

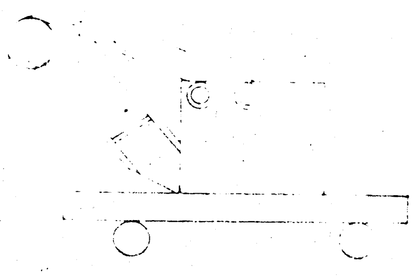
These are overhead devices used for moving varying loads intermittently between points within an area, fixed by the supporting and binding rails, where the primary function is transferring or elevating. Some common examples are:

i) Overhead travelling cra[illegible]
ii) Gantry crane
iii) Jib crane
iv) Elevators
v) Hoists
vi) Stacker crane
vii) Winches
viii) Monorail

Figure VIII: Material Handling Equipment



(a) Belt conveyor



(d) Mobile crane

The different material handling systems can be classified according to the type of equipment used, material handled, method used or the function performed.

Equipment-Oriented Systems: Depending upon the type of equipment used, there are several systems.:

i) Overhead systems
ii) Conveyer systems
iii) Tractor-trailor system
iv) Fork-lift truck and pallet system
v) Industrial truck systems
vi) Underground systems.

Material Oriented Systems: These may be of the following types:

i) Unit handling systems
ii) Bulk handling systems
iii) Liquid handling systems

A unit load consists of a number of items so arranged that it can be picked up and moved as a single entity such as a box, bale, roll etc. Such a system is more flexible and requires less investment.

Method Oriented Systems: According to the method of handling and method of production, the material handling systems can be:

i) manual systems
ii) mechanised or automated systems
iii) job-shop handling systems, or
iv) mass-production handling systems

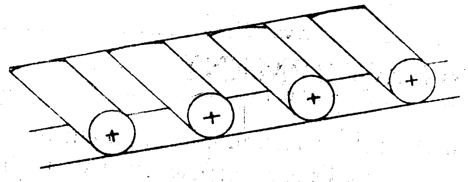
Function Oriented Systems: The systems can be defined according to the material handling function performed as follows:

i) Transportation systems
ii) Conveying systems
iii) Transferring systems
iv) Elevating systems

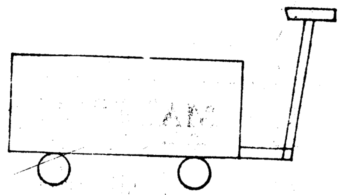
Selection and Design of Handling System

The selection and design of the material handling system should be done alongside the development of the layout as each one affects each other. Hence, an integrated approach to the design process is usable. A computerised technique known as COFAD (Computerised Facilities Design) has been developed for integrated handling system and layout design. The steps to be followed in the selection and design of handling systems are as follows:

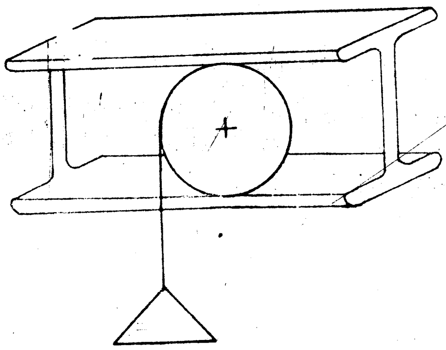
i) Identification of system
ii) Review of design criteria and objectives of the handling system
iii) Data collection regarding flow pattern and flow requirements
iv) Identification of activity relationships
v) Determining space requirement and establishing material flow pattern
vi) Analysis of material and building characteristics
vii) Preliminary selection of basic handling system and generation of alternatives considering feasibility of mechanisation and equipment capabilities
viii) Evaluation of alternatives with respect to optimal material flow, utilising gravity, minimum cost, flexibility, ease of maintenance, capacity utilisation and other objectives of the system design considering various tangible and intangible factors
ix) Selection of the best suited alternative and checking it for compatibility
x) Specification of the system
xi) Procurement of the equipment and implementation of the system



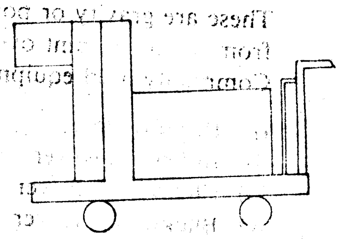
(b) Roller conveyor



(e) Hand trolley



(c) Mono rail



(f) Fork lift truck

Industrial Trucks and Vehicles

These are hand operated or powered vehicles used for movement of uniform or mixed loads intermittently over various paths having suitable running surfaces and clearances where the primary function is manoeuvering or transporting. These include:

i) Fork lift truck
ii) Platform truck
iii) Industrial tractors and trailors
iv) Industrial cars
v) Walkie truck
vi) Two-wheeled hand truck or trolley
vii) Hand stacker

Auxiliary Equipment

These are devices or attachments used with handling equipment to make their use more effective and versatile. Some common examples are:

i) Ramps
ii) Positioners
ii) Pallets and skids
iv) Pallet loader and unloader
v) Lift truck attachments
vi) Dock boards and levelers
vii) Containers
viii) Below the hook devices
ix) Weighing equipment

Activity E

What is the materials handling system used in your organization. Does it offer scope for improvement?

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5.11 SUMMARY

In this unit we have discussed different types of layout problems. The basic types of plant layouts have been identified as product layout, process layout, job shop layout, cellular layout and fixed position layout. The factors to be considered in designing plant layout are outlined as man, material, machine, movement or flow, service facilities, building and flexibility.

The tools and techniques for analysing the flow of materials and the activities have been discussed. Some important tools are, flow process chart, flow diagram, travel chart, REL chart etc. By making use of these tools a systematic layout planning procedure has been discussed starting from the development of plot plan to detailed work place layout. The use of computers in layout planning has been highlighted and computerised techniques named as CORELAP, ALDEP and CRAFT have been outlined. The art of presentation and implementation of the layout has been briefly dealt with. The selection of materials handling system has been presented along with the important types of materials handling equipments. The important concepts in automation in layout and materials handling have been touched upon.

5.12 KEY WORDS

ALDEP: Automated Layout Design Programme

Block Plan: A diagrammatic representation showing internal partitions of departments, columns and area allocation but not machinery, equipment or facilities.

CORELAP: Computerised Relationship Layout Planning

CRAFT: Computerised Relative Allocation of Facilities Technique.

Facility: Any production, operation or service unit is termed as facility, e.g. plant, stores, tank, hospital, machine, equipment, service centre etc.

Flow Diagram: A sketch of the layout which shows the location of all activities appearing on a flow process chart.

Flow Process Chart: It summarises the flow and activity of a component/man through a process or procedure in terms of sequence of operation, transportation.

inspection, delay and storage.

Materials Handling: It is the art and science involving the movement, packaging and storing of substances in any form.

Plant Layout: A plan or the act of planning, an optimum arrangement of industrial facilities including operating equipment, personnel, storage space, materials handling equipment and all other supporting services, along with the design of the best structure to contain these facilities.

Plot Plan: A diagrammatic representation of the building outline, showing its location on the property, the location of external transportation facilities and other items such as tanks, storage areas, parking lots etc.

Process Layout: Also known as functional layout groups together the facilities according to process or function in a department.

Product Layout. Also known as line layout : an arrangement of facilities according to the product; suitable for one type of product.

REL Chart: It indicates the relationship between pairs of departments in terms of closeness rating dependent upon the activities of the department as absolutely essential, essential, important, ordinary, unimportant or not desirable.

SLP: Systematic Layout Planning.

Template: A scaled representation of a physical object in a layout may be of a machine, workman, materials handling equipment, work in process, storage etc.

Travel Chart: It indicates the distance and number of moves between different departments, taken as origin and destination.

5.13 SELF-ASSESSMENT EXERCISES

1 Enumerate the basic types of plant layouts. How does a cellular layout differ from a process layout?

2 What are the different factors that should be considered for designing a plant layout?

3 Prepare a flow chart for overhauling the engine of an automobile.

4 What is the significance of travel charts in layout design? Prepare a travel chart for a hypothetical engineering concern with five functional departments, i.e. foundry, forging, machining, welding and inspection. Given this travel chart proceed to find the locations of different departments.

5 How can the relationships of different departments be considered in preparing a layout? Prepare a REL chart for the different departments of a typical hospital.

6 What is Systematic Layout Planning?

7 What are the different factors that you will consider in determining the space requirement of a particular facility? Allocate the areas to different departments considered in exercise 4 and develop a block plan.

8 Outline the basic logic used in CORELAP, ALDEP and CRAFT. Can the layout generated by these computerised techniques be directly implemented?

9 How will you specify and present a layout developed for the purposes of implementation?

10 What is the importance of materials handling in designing a layout? How will you go about selecting the materials handling system?

11 What are the different kinds of materials handling equipments used? Is a totally automated materials handling system desirable in a job shop ?

5.14 FURTHER READINGS

Apple, J.M., 1977. *Plant Layout and Material Handling,* John Wiley & Sons: New York.

Buffa, E.S, 1983. *Modern Production/Operations Management* , John Wiley & Sons: New York.

Francis, R.L and J.A. White, 1974. *Facility Layout and Location—An Analytical Approach,* Prentice-Hall Inc.: Englewood-Cliffs.

Haynes, D.O. 1958. *Materials Handling Applications, Chilton Company:* Philadelphia.

Immer, J.R. 1950. *Layout Planning Technique,* McGraw Hill Book Company: New York.

Immer, J.R., 1953. *Materials Handling,* McGraw Hill Book Company: New York.

Ireson, W.G., 1952. *Factory Planning and Plant Layout,* Prentice-Hall Inc.: Englewood-Cliffs.

Moore, J.M., 1970. *Plant Layout and Design.* The Macmillan Company: New York.

Muther, R., 1955. *Practical Plant Layout,* McGraw-Hill Book Company Inc.: New York.

Ripnen, K.H., 1960. *Office Building and Office Layout Planning,* McGraw-Hill Book Company: New York.

Waghodekar, P.H. and S. Sahu 1986. A critique of Some Current Plant Layout Techniques, *International Journal of Operations and Production Management,* Vol. 6 (No. 1), pp. 54-61.

UNIT 6 CAPACITY PLANNING

Objectives

After going through this unit, you should:

- understand the concept of capacity and how it is measured
- be aware of the unique problems of capacity planning for services
- know the steps involved in capacity planning
- be familiar with the various methods available for predicting long term capacity requirements
- appreciate the special difficulties encountered in predicting the demand for new and other outputs having a highly uncertain growth rate
- recognise the factors involved in generating alternate capacity plans
- have a feel for economic analysis of different capacity plans
- identify the issues involved in analysing the strategic effects of alternate capacity plans.

Structure

6.1 INTRODUCTION

The operations strategy of an organisation is revealed to a large extent by its investments made in creation of capacity. Creation of capacity almost always requires investments. In manufacturing organisations this is easy to see as the investments required are large. However, even in service organisations, capacity creation requires more space furniture and other accessories including equipment.

Capacity Planning involves giving shape to all the strategic questions that we have raised earlier in the previous units and also our response to these. What are our expectations regarding the growth of the industry and our market share? How accurately can we predict market trends, both in terms of product attributes as well as growth in specific segments—geographical and otherwise? What is our basic stand towards risks? Should our planning be based on an optimistic growth scenario or a pessimistic one? As a strategy, should we create capacity in a few large locations, each with a large capacity or should we operate from many locations each with a small capacity? These are some of the questions that have to be answered while preparing a capacity plan.

There are some other related questions which also affect our capacity plans. What is our policy regarding making up of some temporary short-falls in capacity e.g. by use of overtime additional shifts or holiday work? How much of our requirement can be met by resorting to sub-contracting? What is our policy regarding meeting the market demand? Should we, as a matter of policy try to meet it fully or can we plan for some lost sales at least for some periods of time?

All these strategic issues need to be resolved as a part of capacity planning. It is relatively simple to do an economic analysis of the revenues, costs and investments. However, the other strategic effects of capacity decisions—e.g. the consequences of not having the capacity when it is required or addition of large capacity when the market growth cannot be predicted with much confidence, are more difficult to analyse. We will discuss these issues in this unit.

6.2 WHAT IS CAPACITY?

Capacity is quite an illusive concept and in many cases has to be qualified further. Thus, we find that words like designed capacity, installed capacity, rated capacity and so on are often used. These concepts are based on how we define the capacity of a facility.

Definition of Capacity

Capacity is the limiting capability of a productive unit to produce within a stated time period, normally expressed in terms of output in units per unit of time. However, the limiting capability also depends on the intensiveness of use of the productive unit. By increasing the intensiveness of use, the capacity of a productive unit can be increased without really building new capacity. For example, by working for seven days a week instead of six, or resorting to overtime work, or working two shifts a day in place of one, the capacity of a productive unit can be increased. These alternatives generally come in handy for managers to meet temporary shortfalls in capacity.

When the transformation process in turn consists of many sub-process, the capacity of the productive unit is governed by the capacity of the weakest link viz. the capacity of the sub-process having the minimum capacity. By strengthening the weakest link, the capacity of the entire productive unit can be enhanced. This can be done by investing in 'balancing equipment' to create a better balance between various sub-processes. The same can also be achieved by subcontracting when it is feasible. One can subcontract the complete production as well as subcontract only those jobs for which enough in-house capacity does not exist.

In some situations, especially processing industries, the capacity is further qualified by mentioning how it was established. Thus there can be a licensed capacity of the plant denoting the capacity that has been licensed by the concerned governmental authorities. There can, similarly, be an installed capacity denoting the capacity that has been provided for while the plant was installed. Finally, the rated capacity may be quite different from the other capacities and based on the highest production rate established by actual trials.

Measurement of Capacity

When the productive system produces a single output or when the different outputs are relatively homogeneous, capacity can be measured in number of units of output per unit of time. The capacity of a thermal power plant is expressed in megawatts of power, that of a television unit in thousands of television sets per month and that of a steel mill in million tons of steel in a year.

However, when a production unit produces multiple outputs, with some outputs sharing common facilities and some other outputs using special facilities, measurement of capacity becomes really difficult. An extreme example is a job shop which produces products as per customers' specifications. In such a case the capacity cannot be measured in terms of the number of output units per unit of time. For such organisations, capacity is usually expressed in terms of available units of the limiting resources. For example, the capacity of a job shop can be measured in units of labour hours available per month. The capacity of a hospital can be similarly measured in bed days per month and that of a consultancy organisation in consultation days per year.

Service Capacity

For those organisations whose output is a service of some kind, the capacity can be measured using the concepts outline above. If the service produced is homogeneous, the capacity can be measured in number of services per unit of time—e.g. number of units of power produced per unit of time for a thermal power plant or number of insurance policies serviced per year for an insurance company. Similarly, when the service produced is heterogeneous, it can be expressed by the availability of the limiting resource—e.g. man hours per week for a bank branch, tonne kilometres for a trucking company and so on.

However, service organisations typically face a problem in capacity planning because of the fact that their output cannot be stored. The demand for services is also quite variable and often fluctuates during the course of the day. Service organisations should therefore provide for enough capacity to take care of the peak demand. This can be seen in the demand for electricity or that for banking services or even for public transportation. As the average demand is much less than the peak demand, this means that the organisation produces its output, on an average, at a rate less than its capacity. This amounts to lower capacity utilisation on one side and can give rise to productivity problems on the other.

Activity A

How is capacity defined in your organization? Can it be defined in any other ways? What are the different ways in which the capacity of your organization can be extended?

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6.3 PROCESS FOR CAPACITY PLANNING

In brief, the process for capacity planning involves the following eight steps:

1 Assess company situation and environment to predict future demands, including the possible impact of technology, competition and other events
2 Determine the available capacity
3 Translate predictions into physical capacity requirements
4 Develop alternate capacity plans for matching required and available capacity
5 Analyse the economic effects of alternate capacity plans
6 Analyse the risks and other strategic consequences of alternate plans

7 Recommend a course of action
8 Implement the course of action.

We will discuss these steps in the following sections. However, it may be pertinent to point out that a quantitative analysis of the alternate capacity plans is not enough because, for one, the capacity requirements that are used for this analysis are only estimates and in many cases may not be very reliable and secondly, the strategic effects are not easy to quantify in most cases. The steps listed above highlight the importance of both quantitative (step 5) and qualitative (step 6) analysis.

6.4 PREDICTING FUTURE CAPACITY REQUIREMENTS

Any capacity plan that we prepare is heavily dependent on our assessment of the likely demand of our outputs. However, preparing long-range forecasts of demand is quite difficult. Apart from the general growth in demand of the product due to the trend and cyclical effects, there can be contingencies which affect the demand significantly but are quite difficult to predict. Such contingencies can range from failure of monsoon to wars, oil embargoes or major technological breakthroughs. In general though, mature products are likely to have more stable and predictable growth as compared to products in the introduction or growth phases of their respective product life-cycles.

Multiple Outputs

If a productive unit is producing many outputs, then for predicting future capacity requirements, the demand for each of these outputs has to be forecast. These outputs could be in different phases of their product life cycles. In general, the outputs will have different growth rates and it is possible that some of the outputs are actually in the decline phase of their life cycles.

In general, the total demand for a number of outputs will show much less fluctuation than the fluctuations in the demand for any one of them. This is because the rate of growth of demand for each output is different and it is possible that as the demand for one output accelerates in its high growth phase, that of another output decelerates as it reaches its maturity phase. We might as well note, in passing, that if different outputs have unequal growth rates, the output mix of the organisation will also change with time.

Multiple outputs also provide some kind of a hedge against changes in environmental conditions—especially if the demand for these outputs are independent. As compared to a plant making only one brand of soap, another plant producing more brands and catering to different market segments will have much more stability in its total capacity requirements. In fact, this analysis leads us to the conclusion that better predictions of future demands could be made for those operations which are flexible as compared to the ones which have been designed for specific outputs using continuous flow processing or process industries.

Mature Outputs with Stable Demand Growth

Outputs which are in the maturity phase of their product life cycles exhibit less volatility in their demands. If the life cycle is very long, then the demand growth is steady and the demand can be predicted with great confidence. One can easily give examples of such outputs—steel, fertiliser, sugar, cement, textiles, electricity, hospital services and so on.

Long term forecasts of the demand of an output are made by using causal forecasting methods like regression analysis and econometric models or by using predictive methods like Delphi, market Surveys, Historical analogy and life cycle analysis or else by using non-formal methods like executive opinions and extrapolation.

Regression analysis tries to develop a forecasting function, called a regression equation, wherein the demand for the output is expressed in terms of other variables which perhaps cause or control the demand. For example, the demand for furniture may be expressed as a function of a number of variables such as, new construction activity index for the previous year, new marriages performed during the year, disposable personal income during the year and a trend effect. Although good computer programmes are easily available to carry out the computations involved in regression analysis, it requires considerable time and cost as various hypotheses regarding the effect of variables may have to be tested to develop the regression equation. When used for long term forecasting, the causal variables need to be forecast in future before a forecast for demand is made available by the regression equation.

Econometric forecasting methods are really an extension of regression analysis and include a system of simultaneous regression equations. For example, the demand of an output could be expressed as a function of GNP, price and advertising. The price in turn, is a function of its cost, selling expenses and profit; the cost could be a function of the production and the inventory levels and finally, the selling costs. Instead of one relationship we now have to estimate four and estimate them simultaneously. These methods require high amounts of time and cost.

All predictive methods, including Delphi technique, are qualitative methods which can be used even when historical data regarding past sales etc. are not available. They have a special role in long term forecasting since quantitative methods have strong limitations in predicting contingencies. The Delphi method draws upon a panel of experts in a structured manner to eliminate the possible dominance of the more vocal, more prestigious and the better salespersons in the group. Each expert in the group makes independent predictions in the form of brief statements. The coordinator edits and clarifies these statements and then provides a series of written questions to the experts along with the feedback by the other experts. This process is continued for several rounds. However, a reasonable amount of convergence is achieved in a small number, usually three to four, rounds.

Market surveys and other studies on consumer behaviour provide us with a lot of primary data which can provide insights on factors like what makes a customer buy the product, what features have a high priority in the customers' preference structure, what are the perceptions of the competing products, the likely impact of price changes and so on. Such insights can prove to be extremely useful while the long term demand of the product is being predicted.

Historical analogy and life cycle analysis try to predict the growth of demand of an output by analysing its progress so far along its product life-cycle and also by comparing it with the life-cycle of another similar output. For example, the growth of demand of colour TV sets can be compared with the life-cycle of black and white TV sets and long term predictions of clour TV sets can be made based on such comparisons.

In case of multiple outputs, a similar exercise is to be carried out for each of the outputs and when added, they provide the capacity required throughout the planning horizon. If the outputs are not homogeneous, this might mean different capacity requirements for each sub-process.

Table 1
Projected Capacity Gap or Slack for a Multiple Output Organisation

	Capacity, units per year					
	Current 1987	1989	1991	1993	1995	1997
Predicted Capacity Requirements						
Output 1	10000	12000	14500	17500	21000	25000
Output 2	5000	6500	8500	11000	14500	18500
Machine Shop Capacity (Output 1 Equivalent)						
Requirement	20000	25000	31500	39500	50000	62000
Current	25000	—	—	—	—	—
(Gap) or Slack	5000	—	(6500)	(14500)	(25000)	37000)
Assembly Shop Capacity (output 1 Equivalent)						
Requirement	15000	18500	23000	28500	35500	43500
Current	15000	—	—	—	—	—
(Gap) or Slack	—	(3500)	(8000)	(13500)	(20500)	(28500)

In Table 1 we show h [illegible] :ess in case of a multiple outp[illegible] organisation. Both outputs 1 and 2 require some machine shop operations and then some assembly operations. However, each unit of output 2 requires twice as much machining as a unit of output 1. On the other hand, both the outputs require the same amount of assembly shop time for each unit. In Table 1, the capacities of both the machine shop and the assembly shop have been expressed in terms of units of output 1 using the above mentioned ratios. For example, in 1989, predicted capacity requirements are of 12,000 units of output 1 and 6,500 units of output 2. However, as each unit of output 2 requires twice as much machining time as one unit of output 1, the total capacity requirement of machine shop in 1989 would be equivalent to (12,000 + 2x6,500) i.e. 25,000 units of output 1.

In Table 1, we have predicted the expected capacity requirement for outputs 1 and 2, and used these to find the capacity (gap) or slack. One can also prepare the optimistic and pessimistic predictions.

New Outputs and Prediction of Demand

It is exceedingly difficult to prepare reliable long term demand forecasts for new outputs in their introduction or even rapid growth phases. This may also be the case for some mature products where the capacity planning is dependent on availability of supplies and this could be risky—for instance for petroleum.

As the uncertainty involved in such cases is higher, it is better to try to understand the probability distribution of the demand. One of the simplest ways for this is to estimate an optimistic prediction of demand for the output as well as a pessimistic prediction of demand for the same, over and above the expected predicted demand.

Let us consider a new product which is still in the rapid growth phase of its product life cycle. The growth in sales have been of the order of 80% this year and it is expected to continue to have a high growth rate. Table 2 gives the expected as well as the optimistic and the pessimistic capacity requirements. The optimistic assessment assumes that our market share will increase and when the market itself is growing, the demand for our product could really grow very fast. However, with time there will be a slowdown in the growth rate. On the other hand, the pessimistic predictions assume that due to increased competition our market share will fall even though the predicted demand increases because of the expanding market. It can also be seen that uncertainty, in terms of the difference between the optimistic and the pessimistic predictions, increases as we look further into the future.

Table 2

Projected Capacity Requirements on Expected, Optimistic and Pessimistic Bases

	Capacity, units per year					
	Current 1987	1989	1991	1993	1995	1997
Expected Capacity Requirement	10000	16000	25000	38000	58000	83000
Optimistic Capacity Requirement	10000	20000	35000	60000	96000	145000
Pessimistic Capacity Requirement	10000	14000	19000	24500	32000	42500

Using the capacity predictions of Table 2, we can easily work out the capacity gaps or slacks in different sub-processes. This has been done in Table 3 and 4 for the optimistic and the pessimistic predictions. A quick comparison reveals that if the optimistic predictions come true, then large capacity additions have to be built and the process has to start immediately as there would be a shortfall of 7,000 units per year by 1989 in machine shop capacity. On the other hand, the capacity additions need to be much smaller and slower if the pessimistic estimates were to come true.

Table 3

Projected Capacity Gaps or Slacks for the Optimistic Prediction

	Capacity, units per year					
	Current 1987	1989	1991	1993	1995	1997
Predicted Optimistic Capacity Requirements	10000	20000	35000	60000	96000	145000
Machine Shop Capacity	13000	—	—	—	—	—
Machine Shop Capacity (Gap) or Slack	3000	(7000)	(22000)	(47000)	(83000)	(132000)
Assembly Shop Capacity	10000	—	—	—	—	—
Assembly Shop Capacity (Gap) or Slack	—	(10000)	(25000)	(50000)	(86000)	(135000)

Table 4
Projected Capacity Gaps or Slacks for the Pessimistic Prediction

	Capacity, units per year					
	Current 1987	1989	1991	1993	1995	1997
Predicted Pessimistic Capacity Requirements	10000	14000	19000	24500	32000	42500
Machine Shop Capacity	13000	—	—	—	—	—
Machine Shop Capacity (Gap) or Slack	3000	(1000)	(6000)	(11500)	(19000)	(29500)
Assembly Shop Capacity (Gap) or Slack	—	(4000)	(9000)	(14500)	(22000)	(32500)

Activity B

Prepare capacity forecast for your organisation. Which activities or, processes or sub-organisation will pose slack (or gap) situations?

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6.5 GENERATION OF CAPACITY PLANS

Once the capacity requirements have been worked out, alternate capacity plans, listing the size and timing of capacity additions, can be generated. If the capacity available does not match the capacity required in any year, the capacity plan also mentions whether alternate sources of capacity will be used or whether the plan is prepared with the possibility of lost sales.

Size of Capacity Increments

When there is a growth in predicted demand of a product, the important question is how much of capacity has to be added and when, rather than whether capacity has to be added. Two strategies for capacity addition could be easily formulated: (i) add capacity in small increments but more often, and (ii) add large capacity increments but less often.

Two other related options are: (i) add capacity before the requirement exceeds the capacity available, and (ii) add capacity after the requirement has overtaken the available capacity. Of course, one can have mixed options such as adding a large capacity increment so that the available capacity is much in excess of the likely demand. However, as the demand is continuously growing, it will soon overtake the available capacity and then add another large increment of capacity.

Alternate Sources of Capacity

We have seen above the capacity of any facility also depends on the intensiveness of use. Therefore, a manager has access to a higher capacity without really building additional capacity by increasing the intensiveness of use. This includes alternatives like overtime, holiday work, additional shift working, etc. There is a further possibility of subcontracting a part or all of the transformation processing to outsiders and have access to their capacities as well. However, for specialised and sophisticated processing, subcontracting may not be feasible and similarly, for process industries working round the clock, it may not be possible to increase the intensiveness of use.

By making use of these alternate sources of capacity, one can reduce the cost of carrying a high capacity along with reducing the risk of not using the capacity built. Alternate capacity plans may have capacity gaps which would be met from these alternate sources of capacity.

Cost-Volume Relationships

For a given capacity, unit cost of production decreases with higher volume as the fixed cost gets spread over a larger volume. However, near the capacity limit and marginally above the normal capacity, the unit cost increases as the variable cost per unit starts increasing due to higher costs involving overtime, holiday work, subcontracting, etc. as well as the effect of general congestion at work places and of equipment. In effect, therefore, the unit cost of production will have the shape of a 'U' with the minimum being somewhere near the normal capacity established.

Economies of Scale

A higher capacity plant offers some economies of scale. It is worthwhile going in for greater automation only in a high capacity plant. This, coupled with more sophisticated technology enables a larger capacity plant to produce at a lower variable cost per unit although the fixed cost of production is much higher. The combined effect of these is that a lower unit cost can be achieved in a larger capacity plant.

There are other economies of scale as well. With increase in capacity, the increase in investment in inventories is less than proportional e.g. a 100% increase in capacity would require an increase of about 40%—50% in investment in inventories giving rise to an economy of scale. Similarly, in many process industries, the capacity increases as per the volume of pressure vessels, pipes, tanks, etc. whereas construction costs vary as per the surface area of the same giving rise to an economy of scale in construction costs.

Lost Sales

An alternative to meeting the capacity requirement through additional capacity or alternate sources is to absorb some lost sales. However, lost sales always amount to losing some market share. This is a very risky alternative, especially in the face of competition, while generating capacity plans because market share losses could be permanent.

Although lost sales are not found in capacity plans of commercial organisations, capacity could be perenially found to be below the requirement in case of many infrastructural facilities. This could be seen in power, public transportation, telephones, water supply and other facilities. Even for commercial organisations, when there are sudden spurts in demand growth, there may be no alternative to meeting the demand through lost sales which amounts to absorbing a loss in possible contribution.

Multiple and Anticyclic Outputs

As mentioned in 8.4 above, multiple outputs increase the stability of demand growth. Each output being in a different phase of its respective product life cycle, the demand for some outputs shows decline that of others could be in their growth phases. Consequently, the overall capacity requirement will have much less fluctuation than that for any one output.

A similar concept is useful even when the demand for an output is highly seasonal and varies widely during the course of a year. If possible, the addition of an anticyclic output can help in stabilising the capacity requirement throughout the year. The demand for electric fans is highly seasonal with the peak occurring in summer and the sales in winter coming close to nil. If heat convectors, which require similar production process, are added to the product range, the capacity requirement throughout the year will be more stable as the demand for heat convectors peak in winter. Electric fans and heat convectors are therefore anticyclic and the addition of anticyclic outputs makes it possible to have better capacity

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6.6 EVALUATION OF ALTERNATE CAPACITY PLANS

The alternate capacity plans developed will have to be analysed to find the one which is most desirable for our purpose. This involves a quantitative analysis to find the economic consequences of different capacity plans based on the assumptions made regarding what is going to happen in future. However, there are uncertainties regarding future as well as many strategic effects flowing from capacity plans all of which cannot be quantified precisely. That is why there is a need for quantitative assessment of the risks and other strategic consequences.

Economic Analysis for Mature Outputs with Stable Demand Growth

Establishment of capacity is always an investment and the returns from it accrue over a period of time. That is why some kind of discounted cash flow analysis has to be used so that alternate capacity plans can be compared.

For each alternate capacity plan, the general procedure requires that all the cash flows occurring in different years up to the planning horizon have to be listed. All the costs incurred are cash outflows and the revenues earned are cash inflows. When all these cash flows are discounted at the cost of capital for the enterprise, we get the Net Present Value (NPV) for each capacity plan. The capacity plan having the highest NPV will be the most attractive from an economic perspective.

This basic methodology can be expanded by adding to the list of alternative capacity plans to take care of different locations e.g. when considering capacity expansions and even plans to have vertical integration—both backward (to produce what we are buying from our suppliers) and forward (to use in further processing and assembly what is currently our finished product).

Economic Analysis for Outputs with Highly Uncertain Demand Growth

When the demand growth is highly uncertain, the consequent cash inflows from any capacity plan are not reliable enough to make any conclusions. In such a case, knowledge of the probability distribution of demand is quite useful and in the absence of the detailed distribution, one needs to know the optimistic, expected and pessimistic predictions of demand. For each of these scenarios, the NPV for each alternate capacity plan can be computed. Different and appropriate capacity plans can turn out to be the most economic under each of these scenarios.

A more formal approach for such a situation involves using a decision tree to analyse the various alternate plans. Both the alternatives and the uncertain outcomes are shown on the decision tree. Probabilities are assigned to each of the uncertain outcomes and finally, the tree is folded back to find the best capacity strategy which results in the highest value of some criterion like the expected NPV. When the demand growth is highly uncertain, the choice of a capacity plan is highly dependent on the strategic effects of having an over or an under-capacity.

Risk Analysis of Alternate Capacity Plans

All capacity plans are based on prediction of probable demand and the [illegible] can never be predicted exactly. Thus, there is always some element of risk present in any planning process. What we have said above is that the risks are higher in the case of new outputs than in the case of mature outputs with stable demand.

If demand cannot be predicted exactly, the actual demand will either be low or higher than the predicted demand. In the first case, we are likely to be burdened with over capacity and in the second event we are likely to suffer from an under capacity. We should analyse the likely consequences of both overcapacity and undercapacity.

In each of the following situations the organisation may plan for having an overcapacity rather than an undercapacity if: (a) there are some minimum economic capacity sizes, below which the process becomes uneconomic, (b) the cost involved in establishing capacity is relatively low, (c) subcontracting is very difficult or impossible, (d) the lead time required to establish new capacity is very long, (e) the demand growth is more likely to be nearer the optimistic prediction than the pessimistic one, (f) cost sales are perceived by the trade very negatively and may amount to a more than proportionate drop in market share.

On the other hand, the organisation may plan to add capacity on a conservative basis in each of the following situations if: (a) alternate sources of capacity are easily available, (b) the cost involved in establishing capacity is relatively low, (c) the lead time required to establish new capacity is relatively short (d) the customers are either expected to wait or the lost sales have no long term consequences if the demand cannot be satisfied.

It is difficult to quantify many of the strategic consequences from having an undercapacity or an overcapacity and what is important is to assess how these influence the competitive ability of the organisation.

6.7 SUMMARY

We have looked at the process of capacity planning in an organisation in this unit. We defined capacity as the limiting capability of a productive unit to produce. In case of homogeneous outputs, the capacity can be expressed in units of output per unit of time. However, when the outputs are not homogeneous, the availability of the limiting resource is used to measure capacity.

We have listed an eight step process for capacity planning. One of these relates to the prediction of demand in future. We have discussed some of the methods available for long-term demand prediction which can be used for prediction of demand of mature outputs with stable demand growth. On the other hand, we need to assess the probability distribution of demand infuture for new outputs and others where the demand growth is highly uncertain.

While generating alternate capacity plans, the two primary factors are the size of capacity additions and the timing of such additions. It is necessary to know the alternate sources of capacity, cost-volume relations, economies of scale and the effect of lost sales while generating capacity plans.

Both quantitative and qualitative analyses have their role while analysing the alternate capacity plans recommended for implementation. While quantitative analysis looks at the direct economic consequences emanating from a capacity plan, qualitative analysis evaluates the strategic consequences of ending up with over and

6.8 KEY WORDS

Alternate Capacity Sources: Sources which increase the normal established capacity of any productive unit by increasing the intensiveness of its use e.g. by using overtime, holiday work, additional shift, etc. or by subcontracting the whole or a part of the processing.

Capacity: The limiting capability of a productive unit to produce.

Capacity Gap: The shortfall in capacity available to meet the capacity requirement.

Delphi Technique: A formal, structured method to lead a panel of experts to a consensus rather than a compromise by providing feedback in written form and by eliminating the possible dominance of vocal, prestigious members.

Econometric Forecasting Methods: An extension of regression analysis to include the estimation of a system of simultaneous equations.

Economies of Scale: The reduction in unit cost achieved by employing a higher capacity plant due to lower variable cost per unit from more sophisticated technology, lower capital costs per unit of capacity, lower investment in inventories per unit of capacity etc.

Life Cycle Analysis: Predicting the demand growth of an output by comparing its growth with the product life-cycle of a similar output.

Lost Sales: The excess of demand over the capacity available, which amounts to a loss in contribution and might lead to a permanent fall in market share.

Market Surveys: Surveys of different elements of the market, e.g. customers, dealers, traders etc. to find facts and attitudes towards an output or any of its characteristics.

Mature Output: An output in the maturity phase of its product life cycle.

Regression Analysis: A statistical method used in forecasting with the help of a regression equation which expresses the demand in terms of other variables which presumably control or cause the sales to increase or decrease.

Strategic Effects: Long-term effects of any decision which can influence the ability of the organisation to exist or to grow.

6.9 SELF-ASSESSMENT EXERCISES

1 What is meant by intensiveness of use of a productive unit and how is it relevan while establishing its capacity?

2 Service Organisations usually have to be provided with a higher capacity than the annual or monthly requirement. Why?

3 What do you think are the appropriate methods for predicting future requirements for:
   i) Cement
   ii) Colour television sets
   iii) Pre-cooked noodles
   iv) Petroleum

4 Establishing a minimum capacity and managing with alternate sources like overtime, additional shifts, and subcontracting is always a low-risk strategy. Comment.

5 Electronic toys are slowly becoming popular in the Indian market. The manufacturing process is relatively simple and primarily involves the assembly of many bought-out components. Assembly capacity can be added in relatively small units and is not very expensive as the assembly operations are highly labour intensive.

   If you were to formulate a capacity plan for five years for a unit which is in the business of manufacturing and selling electronic toys, how would you proceed? What kind of alternate capacity plans would you generate and how would you evaluate these plans to decide the one which should be implemented?

6 There are no useful quantitative forecasting models for long-term prediction of future requirements (True/False)

7 For mature outputs with stable demand growth, the capacity gaps are uniform across all departments or sub-process. (True/False)

8 In some situations, absorbing lost sales could turn out to be more economical than installing new capacity. (True/False)

9 It is more economical to plan capacity addition in small increments and more often, than to have large capacity additions and less often. (True/False)

6.10 FURTHER READINGS

Adam, E.E. and R.J. Ebert. 1982. *Production and Operations Management* (2nd edition), Prentice-Hall: Englewood-Cliffs.

Buffa, E.S. 1983. *Modern Production/Operations Management* (7th edition), Wiley Eastern: New Delhi.

McClain, J.O. and L.J. Thomas. 1985. *Operations Management* (2nd edition), Prentice-Hall of India: New Delhi, 1985.

Meredith, J.R. and T.E. Gibbs. 1984. *The Management of Operations* (2nd edition), John Wiley & Sons: New York.

Schmenner, R. 1976. Before You Build a Big Factor, *Harvard Business Review*, Jul-Aug 1976.

Skinner, W. 1978. *Manufacturing in the Corporate Strategy*, John Willey: New York.

BLOCK 4 OPERATIONS PLANNING AND CONTROL

This block deals with problems of production/operations management in different kinds of production systems based on material flow characteristics i.e. Mass Production (Unit 9), Batch Production (Unit 10), Job Shop Production (Unit 11), and finally planning and control of unit manufacture or projects (Unit 12). Thus problems of balancing of assembly lines (Unit 9), optimal layout, aggregate production planning, machine-job allocations, determination of Economic Batch Quantity (Unit 10), priority dispatching rules (Unit 11), Project Planning and Monitoring Techniques based on Network Models for projects (Unit 12) are discussed. Unit 13 discusses the problems of Maintenance Management.

UNIT 9 PLANNING AND CONTROL FOR MASS PRODUCTION

Objectives

After completion of this unit, you should be able to:

- understand the nature of mass/flow production
- identify the situations under which mass production is justified
- appreciate both the desirable and undesirable features of mass production
- see how assembly lines and fabrication lines are designed
- get an idea of how modular production and group technology could be used to advantage in mass production.
- understand the role of automation including robotics in mass production.

Structure

9.1 INTRODUCTION

Kinds of Production Systems: Flow Shops, Job Shops and Projects

As you already know, production involves the transformation of inputs (such as men, machines, materials, money, information and energy) to desirable outputs in the form of goods and services. It is customary to divide production systems into three categories: the flow shop, the job shop and the project. The flow shop exists when the same set of operations is performed in sequence repetitively; the job shop exists where the facilities are capable of producing many different jobs in small batches; the project is a major undertaking that is usually done only once. It consists of many steps that must be sequenced and coordinated.

The flow shop employs special purpose equipment (designed specifically for the mass-scale production of a particular item or to provide a special service). The job shop contains general-purpose equipment (each unit is capable of doing a variety of jobs). The project, like the flow shop, requires a sequence of operations, except that the sequence lacks repetition. Each project operation is unique and seldom repeated. For example, the production line for automobiles is a flow shop; the machine shop that makes hundreds of different gears in batches of 50 at a time is a job shop; building a bridge or launching a satellite in space is a project.

This unit is concerned with the problems of mass production encountered in flow shops. Batch production and its problems are discussed in unit 10, while job shops and projects are handled in units 11 and 12 respectively.

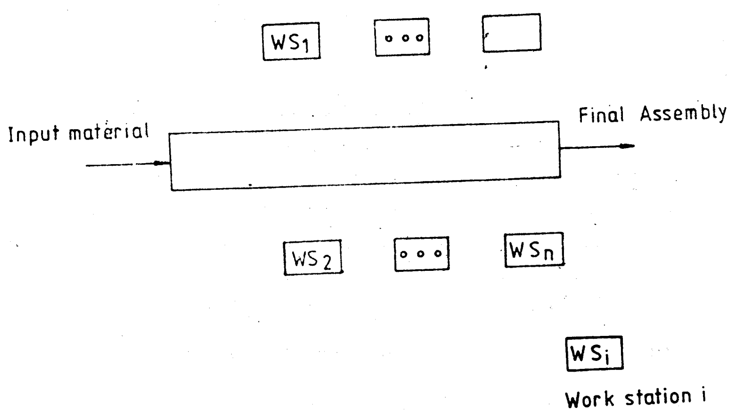
Nature of Mass Production

It was Henry Ford who in 1913 introduced the 'assembly line' and the notion of 'mass production'. It is erroneous to think that mass production means production in millions or for the masses, though this may be an outcome. Mass production refers to the manner in which a product is produced. This involves the decomposition of

the total task into its minutest elements (shown usually on a precedence diagram) and the subsequent regrouping of these elements according to the norms of production. An assembly line consists of work stations in seqrence where at each work station the above carefully designed portion of work is done. Mass production requires that all like parts of an assembly line be interchangeable and that all parts be replaceable, characteristics which permit prodution and maintenance of large quantites.

The assembly line is a production line where material moves continuously at a uniform average rate through a sequence of work stations where assembly work is performed. Typical example of these assembly lines are car assembly, electrical appliancesTV sets, computer assemblies and toy manufacturing and assembly. A diagrammatic sketch of a typical assembly line is shown in FigureI. The arrangememt of work along the assembly line will very according to the size of the product being assembled, the precedence requirements, the available space, the work element and the nature of the work to be performed on the job.

Figure I: A Typical Assembly Line



Material movement between work stations could be **manual,** as for instance when operators sitting in a row pick up the part from the output of the previous operator, work on it and leave it in a bin to be picked up by the next operator; or through the use of **conveyors,** which carry the part at a predetermined speed so that there is adequate time for each work station to complete its allocated share of work. There are various types of conveyors that are used in assembly lines; the most widely used are belt, chain, overhead, pneumatic and screw conveyors.

It may be of interest to note that assembly lines could have varying degrees of automation, starting from the purely manual on the one hand to the fully automated line on the other. However, the underlying principle of the assembly line and mass production remains unchanged, although the labour content may be reduced through robotisation.

9.2 WHEN TO GO FOR MASS PRODUCTION

It is generally agreed that mass production is justified only when production quantities are large and product variety small. The ideal situation for mass production would be when large volumes of one product (without any changes in design) are to be produced continuously for an extended period of time. Thus the rate of consumption (or demand) of the product as compared to the rate of production decides whether continuous or batch production is called for. Obviously, only if the rate of demand is greater than or equal to the production rate, mass or continuous production could be sustained. If the rate of demand is less than the production rate, batch production with suitable inventory buildups could be resorted to.

Apart from the above consideration, the economics of the matter would have to be evaluated before deciding as to whether an assembly line is justified or not. This is illustrated by the following example.

Example 1

As a manager of a plant you have to determine whether you should purchase a component part or make it in the plant. You can purchase the item at Rs. 10 per piece. With an investment equivalent to an annual fixed cost of Rs. 20,000 and a variable cost of Rs. 2.50 per piece an assembly line can be set up to manufacture the part. A third option open to you is to make the part at individual stations with an annual fixed cost of Rs. 10,000 and a variable cost of Rs. 5 a piece. Assuming that the annual demand is expected to be around 3500 units which alternative would you suggest?

Solution

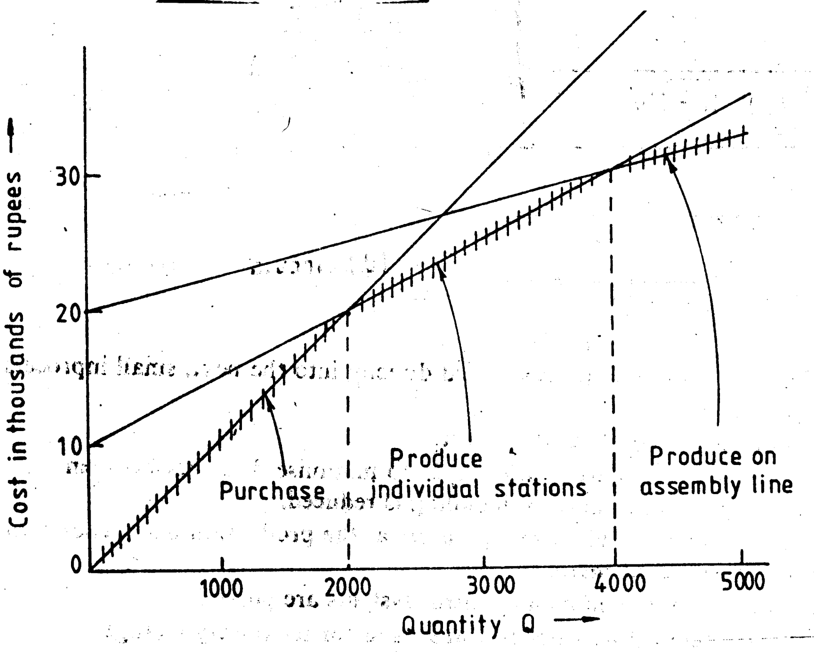
The choice from the three alternatives (purchase, produce at individual stations, or employ an assembly line for production) is simplified by plotting a cost vs. quantity chart for these options. If Q is the quantity purchased or produced then total cost equals Rs. (10Q), if the part is purchased; Rs. (10,000 + 5Q), if the part is made at individual stations; and Rs. (20,000 + 2.5Q) if the part is made on an assembly line. These cost functions are plotted in Figure II and the break-even points at quantity levels of 2000 and 4000 reveal the following decision rules:

For annual requirements in the range 0–2000, it is cheapest to buy,

For annual requirements in the range 2000–4000, it is cheapest to produce on individual stations, and only for annual requirements of 4000 or more, is an assembly line justified.

Thus for an annual requirement of 3500, you should not recommend the installation of an assembly line.

igure II: Costs of the Three Alternatives



Activity A

Think of situations in your daily life where alternatives of the above types exist. Can you analyse them using break-even analysis?

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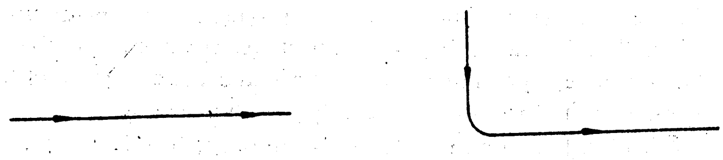
9.3 FEATURES OF A MASS PRODUCTION SYSTEM

A mass production system operating as a continuous flow line exhibits certain desirable and undesirable features. These are summarised below:

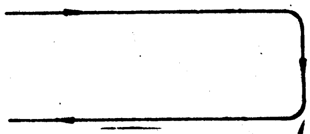
Advantages

1 A smooth flow of material from one work station to the next in a logical order. Although straight line flow is common, other patterns of flow exhibited in Figure III are also employed when constraints on space or movement so indicate.

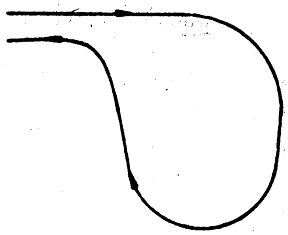
Figure III: Kinds of Flow Patterns



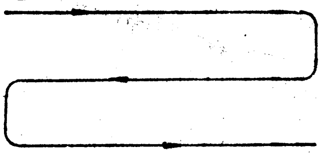
(a) Straight or I flow (b) L – flow



(c) U-flow



(d) Circular or O-flow



(e) Serpentine or S-flow

2 Since the work from one process is fed directly into the next, small inprocess inventories result.
3 Total production time per unit is short.
4 Since the work stations are located so as to minimise distances between consecutive operations, material handling is reduced.
5 Little skill is usually required by operators at the production line; hence training is simple, short and inexpensive.
6 Simple production planning and control systems are possible.
7 Less space is occupied by work in transit and for temporary storage.

Disadvantages

1 A breakdown of one machine may lead to a complete stoppage of the line that follows the machine. Hence maintenance and repair is a challenging job.
2 Since the product dictates the layout, changes in product design may require major changes in the layout. This is often expressed by saying that assembly lines are inflexible.
3 The pace of production is determined by the 'slowest' or 'bottleneck' machine. Line balancing proves to be a major problem with mass manufacture on assembly lines.
4 Supervision is general rather than specialised, as the supervisor of a line is looking after diverse machines on a line.
5 Generally high investments are required owing to the specialised nature of the machines and their possible duplication in the line.

9.4 NOTION OF ASSEMBLY LINES AND FABRICATION LINES

It is useful to consider two types of line balancing problems:

i) assembly line balancing, and
ii) fabrication line balancing.

The distinction refers to the type of operation taking place on the line to be balanced. The term 'assembly line' indicates a production line made up of purely assembly operations. The assembly operation under consideration involves the arrival of individual component parts at the work place and the departure of these parts fastened together in the form of an assembly or sub-assembly.
The term 'fabrication line', on the other hand, implies a production line made up of operations that form or change the physical, or sometimes, chemical characteristics of the product involved. Machining or heat treatment would fall into operations of this type.

Although there are similarities between the problem of assembly line balancing and that of fabrication line balancing, the problem of balancing a fabrication line or machine line is somewhat more difficult than the assembly line balancing problem. It is not so easy to divide operations up into relatively small elements for regrouping. The precedence restrictions are usually tighter in the fabrication line. An assembly operator may easily shift from one assembly job to another, but a machine tool may not be utilised for a variety of jobs without expensive changes in setup and tools.

Some methods by which the balance of fabrication operation times can be achieved are as follows:

1 changing machine speeds
2 using slower machines on overtime
3 providing a buffer of semi-finished parts at appropriate places
4 using mechanical device for diverting parts
5 methods improvement

9.5 DESIGN OF AN ASSEMBLY LINE

The Broad Objective in Design

As you have just seen the two most important manufacturing developments, which led to progressive assembly are the concept of interchangeable parts and the concept of the division of labour. These permit the progressive assembly of the product, as it is transported past relatively fixed assembly stations, by a material handling device such as a conveyor. The work elements, which have been established through the division of labour principle, are assigned to the work stations so that all stations have nearly an equal amount of work to do. Each worker, at his or her station, is assigned certain of the work elements. The worker performs them repeatedly on each production unit as it passes the station.

The assembly line balancing problem is generally one of minimising the total amount of idle time or equivalently minimising the number of operators to do a given amount of work at a given assembly line speed. This is also known as minimising the balance delay. 'Balance delay' is defined as the amount of idle time for the entire assembly line as a fraction of the total working time resulting from unequal task time assigned to the various stations.

Kilbridge and Wester after studying the variation in idle times at stations caused by different assembly line balances concluded that high balance delay for an assembly line system for a specific product is caused by

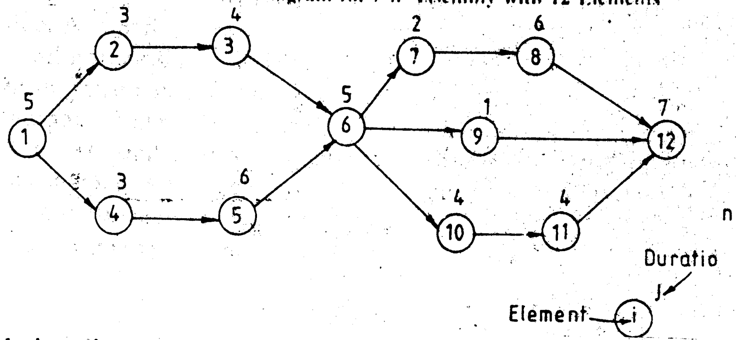
i) wide range of work element times
ii) a large amount of inflexible line mechanisation and
iii) indiscriminate choice of cycle times.

However, as we shall see, the cycle time is often dictated by a specific desired production rate, which may not lead to a low balance delay.

Division of Work into Parts: The Precedence Diagram

The total job to be done or the 'assembly' is divided into work elements. A diagram that describes the ordering in which work elements should be performed is called a 'precedence diagram'. Figure IV shows the precedence diagram for an assembly with 12 work elements. Notice that tasks 2 and 4 cannot begin until task 1 is completed. Moreover, there is no restriction on whether task 2 is done first or task 4. These two tasks are unrelated meaning thereby that they may be done in parallel or even with partial overlap. A task may well have more than one immediate predecessor. For example, in the precedence diagram of Figure IV task 12 has 3 immediate predecessors and cannot begin until all the three work elements 8, 9 and 11 are completed.

Figure IV: Precedence Diagram for a Assembly with 12 Elements



The ordering dictated by the precedence diagram may be the result of technological restrictions on the process or constraints imposed by layout, safety or convenience. The precedence diagram forms the basis for the grouping of work elements into work stations.

Activity B

For a job like mending the puncture of your bicycle tyre identify the work elements and daw precedence diagram.

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Grouping of Tasks for Work Stations and Efficiency Criteria

Depending on the desired production rate of the line, the cycle time (CT) or the time between the completion of two successive assemblies can be determined. This determines the conveyor speed in the assembly line or the time allocated to each operator to complete his share of work in a manual line.

The individual work elements or tasks are then grouped into work stations such that

i) the station time (ST), which is the sum of the times of work elements performed at that station and should not exceed the cycle time, CT.

ii) the precedence restrictions implied by the precedence diagram are not violated.

There are many possible ways to group these tasks keeping the above restrictions in mind and we often use criteria like line efficiency, balance delay and smoothness index to measure how good or bad a particular grouping is. These criteria are explained below:

1 Line efficiency (LE): This is the ratio of total station time to the product of the cycle time and the number of work stations. We can express this as

$$LE = \frac{\sum_{i=1}^{K} S\ T_i}{(K)\ \ (CT)} \times 100\%$$

where

$S\ T_i$ = station time of station i

K = total number of work stations

CT = cycle time.

2 Balance delay (BD): This is a measure of the line inefficiency and is the total idle time of all stations as a percentage of total available working time of all stations.

$$BD = \frac{(K)(CT) - \sum_{i=1}^{K} ST_i}{(K)(CT)} \times 100\%$$

Balance delay is thus (100-LE) as a percentage.

3 Smoothness index (SI): This is an index to indicate the relative smoothness of a given assembly line balance. A smoothness index of 0 indicates a perfect balance. This can be expressed as:

$$SI = \sqrt{\sum_{i=1}^{K} (ST_{max} - ST_i)^2}$$

where

ST_{max} = maximum station time

ST_i = station time of station i

K = total number of work stations.

It may be noted that in designing an assembly line the number of work stations, K cannot exceed the total number of work elements, N (in fact K is an integer such that $1 \leq K \leq N$). Also the cycle time is greater than or equal to the maximum time of any work element and less than the total of all work element times, that is

$$T_{max} \leq CT \leq \sum_{i=1}^{N} T_i$$

Where

Ti is the time for work element i

N is the total number of work elements

Tmax is the maximum work element time

CT is the cycle time.

There is yet no satisfactory methodology which guarantees an optimal solution for all assembly line balancing problems. The emphasis has been on the use of heuristic procedures that can obtain a fairly good balance for the problem. For reviews of procedures available for assembly line balancing refer to Buffa and Kilbridge and Wester. Two commonly used methods for obtaining a good balance for an assembly line balancing problem are presented in the next section.

9.6 LINE BALANCING METHODS

Kilbridge and Wester Method

In this procedure proposed by Kilbridge and Wester numbers are assigned to each operation describing how many predecessors it has. Operations with the lowest predecessor number are assigned first to the work stations. The procedure consists of the following steps:

1) Construct the [illegible]edence diagra[illegible] work elements. In the precedence diagram, lis[illegible] in [illegible]olumn I all w[illegible] that need not follow others. In column II, list work elements th[illegible] [illegible]low those in column I. Contin[illegible] the other columns in the same way. [illegible] [illegible]onstr[illegible]ting the columns the elements within a column can be assigned to wo[illegible] [illegible]ations in any order provided all the elements of the previous column have been assigned.

Select a feasible cycle time, CT. By a feasible time we mean one for which

$$T_{max} \leq CT \leq \sum_{i=1}^{N} T_i.$$

3) Assign work elements to the station such that the sum of elemental times does not exceed the cycle time CT. This assignment proceeds from column I to II and so on, breaking intra column ties using the criterion of minimum number of predecessors.
4) Delete the assigned elements from the total number of work elements and repeat step 3.
5) If the station time exceeds the cycle time CT due to the inclusion of a certain work element this work element should be assigned to the next station.
6) Repeat steps 3 to 5 until all elments are assigned to work stations.

Example 2

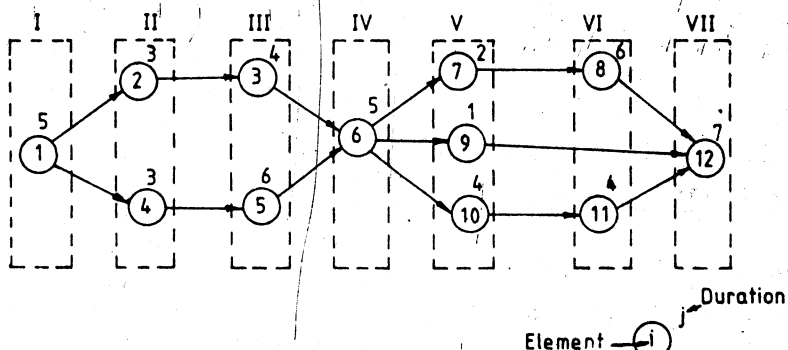
Let us, for illustration, use the Kilbridge-Wester method to balance the assembly line with the precedence diagram shown in Figure IV.

First of all, the 12 elements are assigned to columns as under

element 1	in column	I
elements 2 and 4	in column	II
elements 3 and 5	in column	III
element 6	in column	IV
elements 7, 9 and 10	in column	V
elements 8 and 11	in column	VI
element 12	in column	VII

This is diagrammatically shown in Figure V. Suppose, we want to balance the line for a cycle time, CT=10. We count the number of predecessors for each work element and record it in Table 1. Work element 1 is selected first because it has the least number of predecessors. Therefore, we assign element 1 to station 1. Either

Figure V: Grouping of Work Elements into Columns for Kilbridge-Wester Method



element 2 or 4, each of which has an operation time of 3, can be assigned to station 1, which results in a station time of $8 \leqslant CT$. Element 4 cannot be added to station 1, otherwise the station time will exceed the cycle time; therefore we assign element 4 to station 2 and continue with the above process. The final assignment resulting from an application of this procedure is shown in Table 2.

Table 1
Number of Predecessors for Each Work Element

Work Element i	Number of Predecessors	Ti
1	0	5
2	1	3
3	2	4
4	1	3
5	2	6
6	5	5
7	6	2
8	7	6
9	6	1
10	6	4
11	7	4
12	11	7

Table 2
Assignment of Work Elements to Stations (Kilbridge-Wester Method)

Station	Element i	Ti	Station sum	Idle time
I	1	5	8	2
	2	3		
II	4	3	9	1
	5	6		
III	3	4	9	1
	6	5		
IV	7	2	7	3
	9	1		
	10	4		
V	8	6	10	0
	11	4		
VI	12	7	7	3

$$\text{The line efficiency (LE)} = \frac{50}{6 \times 10} \times 100\% = 83.3\%$$

$$\text{Balance delay (BD)} = 16.7\%$$

$$\text{Smoothness index (SI)} = \sqrt{4+1+1+9+9} = \sqrt{24} = 4.89$$

That the solution obtained above is not the optimal solution can be seen by making some adjustments in the solution of Table 2 to yield the solution of Table 3 for which the cycle time is equal to 9 and the figures for line efficiency and smoothness index are:

$$LE = \frac{50}{6 \times 9} \times 100 = 92.6\%$$

$$SI = \sqrt{1+1+1+1} = 2$$

Table 3

Revised Assignment of Work Elements to Stations (Cycle Time = 9)

Stations	Element i	Ti	Station sum	Idle Time
I	1 2	5 3	8	1
II	4 5	3 6	9	0
III	3 6	4 5	9	0
IV	7 8	2 6	8	1
V	10 11	4 4	8	1
VI	9 12	1 7	8	1

This should cause no concern, for the Kilbridge and Wester method is a heuristic procedure which does not guarantee an optimal solution. It only results in good working solutions with relatively little computational effort. This is also true of the other heuristic procedure to be discussed below.

Helgeson and Birnie Method:

This method proposed by Helgeson and Birnie is also known as the ranked positional weight technique. It consists of the following steps:

1 Develop the precedence diagram in the usual manner.

2 Determine the positional weight for each work element (a positional weight of an operation corresponds to the time of the longest path from the beginning c the operation through the remainder of the network).

3 Rank the work elements based on the positional weight in step 2. The work element with the highest positional weight is ranked first.

4 Proceed to assign work elements to the work stations where elements of the highest positional weight and rank are assigned first.

5 If at any work station additional time remains after assignment of an operation, assign the next succeeding ranked operation to the work station, as long as the operation does not violate the precedence relationships and the station time doe not exceed the cycle time.

6 Repeat steps 4 and 5 until all elements are assigned to the work stations.

Example 3

Let us take up for illustration the balancing of the same assembly line considered previously by the Kilbridge-Wester method. For the precedence diagram shown in Figure IV, and a desired cycle time of 10, we first construct the table of positional weights of all elements as Table 4. For example, the positional weight of operation 6 equals the maximum of (5+2+6+7), (5+1+7), (5+4+4+7) = 20, since there are 3 paths (6→7→8→12, 6→9→12, 6→10→11→12) from the concerned operation to the end of the network. Following the above steps 4, 5, 6 we obtain the assignments of work elements shown in Table 5

The line efficiency and smoothness index for this assignment is:

$$\text{Line efficiency} = \frac{50}{6 \times 10} \times 100$$

$$= 83.3\%$$

(Or equivalently, the balance delay = 16.7%)

$$\text{Smoothness index} = \sqrt{4+1+1+16+4}$$
$$= \sqrt{26} = 5.09$$

Table 4

Positional Weights for the Work Elements

Element	Positional Weight, PW
1	34
2	27
3	24
4	29
5	26
6	20
7	15
8	13
9	8
10	15
11	11
12	7

Table 5

Assignment of Work Elements to Stations (Helgeson and Birnie Method)

Station	Element i	Ti	Station sum	Idle time
I	1 4	5 3	8	2
II	2 5	3 6	9	1
III	3 6	4 5	9	1
IV	7 10	2 4	6	4
V	8 11	6 4	10	0
VI	9 12	1 7	8	2

Activity C

You should expore the possibility of improving the balance of adjustments between work stations as we have done previously with solution obtained by the Kilbridge and Wester method.

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9.7 PROBLEMS AND PROSPECTS OF MASS PRODUCTION

Variable Work Element Times

In both the line balancing methods discussed in the previous section it was assumed that the work element times are constant. In practice, these times may be varying randomly owing to factors like human variability, fatigue or carelessness on the operator's part. Even in the case of machine operations, the set up or positioning time of the part or components could lead to random variations in the individual work element times. Since the assembly line is balanced for a given fixed set of work element times the effects of these variabilities are two-fold.

i) greater idle time at some work stations, and
ii) the reduction of the average production rate of the line.

In designing lines for random work element times with given means and variances, some modification of the deterministic line balancing methods is adopted utilising the additional criterion that the probability of the station time exceeding the cycle time should be kept as low as possible. Some methods of probabilistic assemby line balancing are discussed by Elsayed and Boucher.

Breakdowns at Work Stations

The mass production system consists of a number of stages in series at which some operations are being performed. A failure or a breakdown of one stage or work station will result in failure of the entire production system until repair is completed.

The result would be decreased production rate. This problem is handled in practice by providing:

i) efficient maintenance service so that the broken down units are repaired and put into service as soon as possible.
ii) buffer storage of semi-finished goods between each pair of stages, so that the entire line does not stop due to the failure of one or more units.

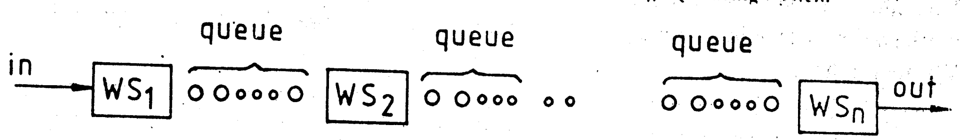
The question of how much buffer storage to allocate between stages is of great practical importance—a higher buffer stock means greater tied up capital but a lower risk of runout and subsequent line stoppage due to breakdowns.

The decision to estimate the size of the buffer can be governed by one or more of the following criteria which consider as to what is the buffer size that:

1 maximises the production rate of the system
2 minimises the total production cost
3 maximises the availability of the production system.

The problem could in general be viewed as a multi-stage queueing system (Figure VI). See for instance Elsayed and Boucher.

Figure VI: An Assembly Line with Buffers as a Multi-stage Queueing System



Multi-product Lines

One of the major disadvantages with assembly lines is their relative inflexibility. A line is usually designed for one product and changes in design of the product are often difficult to accommodate on the line, unless suitable adjustments are made at work stations. But when similar products, in which a large percentage of the tasks are common, have to be manufactured, the possibility of the same production line for the products can be explored. Since tasks are fixed within stations, once balanced, it should be apparent that station times and line efficiencies will vary with the products being produced. A great variety in these efficiencies might dictate that separate lines be utilised. In case a multi-product line is to be designed a common precedence diagram must be developed. For instance precedence diagrams for a two product case are shown in Figure VII. For a cycle time of 10 the optimum solution is shown in Figure VIII. Notice that the line efficiencies are 73% and 100% for products 1 and 2 respectively. A computer assisted approach for multi-product Stochastic Line Balancing is described by Bedworth and Bailey.

Loss of efficiency over single product line but gain in equipment effectiveness is the trade off that must be evaluated in the mixed product line balance.

Figure VII: Precedence Diagrams for a Two Product Line (a) Product 1, (b) Product 2, (c) Combined

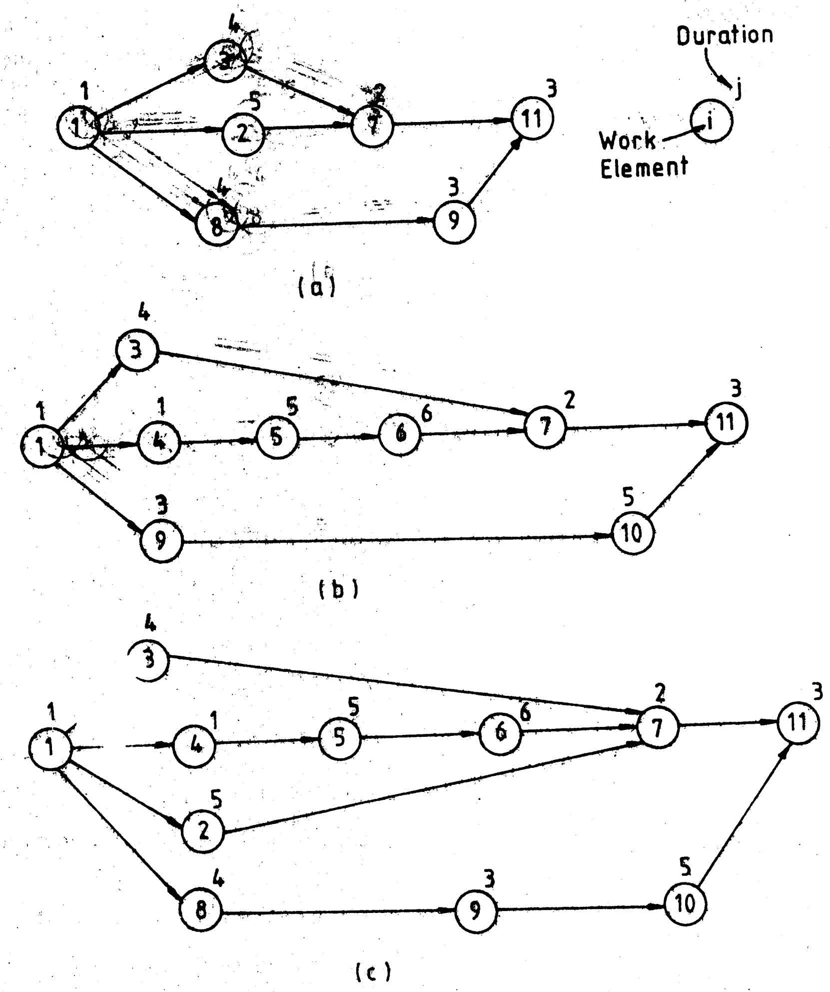
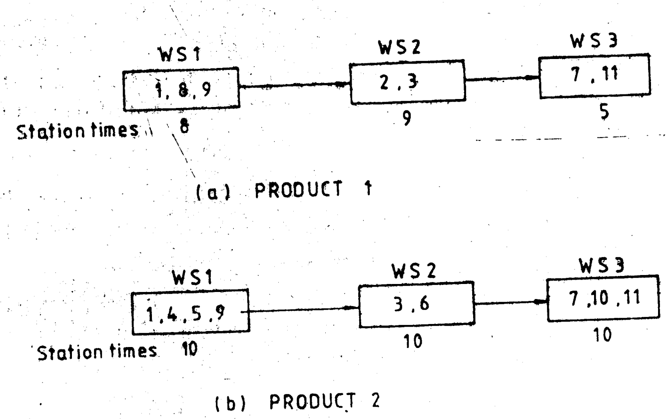


Figure VIII: Work Station Assignment for the Two Product Assembly Line



Group technology: A manufacturing philosophy in which similar parts are identified and grouped together to take advantage of their similarities in design and manufacture.

Job shop: A manufacturing system in which similar machines and equipment are clubbed in departments and each job handled takes its own route. (Generally used for low production volumes with great product variety.)

Line balancing: The problem of assigning tasks to work stations in an assembly line in a way that the task times for all stations are equalised as far as possible.

Line efficiency: The ratio of the actual working time at all stations of an assembly line to the total allocated time at all stations.

Mass production: A manufacturing system based on interchangeable parts and the concept of the division of labour to produce generally large quantities of a product through successive operations/assemblies carried out at a sequence of work stations in an assembly line.

Modular production: The principle employed in modular production is to design, develop and produce the minimum number of parts or operations (called 'modules') that can be combined in the maximum number of ways to offer the greatest number of products or services.

Precedence diagram: A diagram showing the elemental tasks and the order in which they may be performed. This specifies the technological and other restrictions that must be respected while designing an assembly line.

Production system: A means by which inputs (like men, machines, materials, money, information and energy) are transformed into useful goods or services.

Project: A typical production system where production is infrequent (often, only once) characterised by a number of related jobs to be done with precedence restrictions.

Smoothness index: The square root of the sum of squares of idle time at all work stations in an assembly line. This is an index to indicate the relative smoothness of a given assembly line balance.

Station time: The sum of the element times of all tasks allotted to a work station in an assembly line.

Work element: The smallest portion of work identified during the work breakdown analysis of a job. It is uneconomical or technologically absurd to further subdivide the work elements, in designing an assembly line.

Work station: A place or stage in an assembly line where designated work (a combination of work elements) is performed on the part or components of the product.

9.12 SELF-ASSESSMENT EXERCISES

1 What are the key elements of mass manufacture?

2 Draw a precedence diagram for changing a car tyre. Discuss the way in which this job could be done with a flow shop configuration. Suggest a possible division of labour that would produce a reasonable line balance.

3 Design an assembly line for a cycle time of 10 minutes for the following 10 work elements

Elements	1	2	3	4	5	6	7	8	9	10
Immediate Predecessors	—	1	1	2,3	4	4	6	5	7,8	9
Duration in minutes	5	10	5	2	7	5	10	2	5	7

Use

a) Kilbridge and Wester method

b) Helgeson and Birnie method

Calculate the line efficiency, balance delay and smoothness index in both cases.

4 Repeat problem 3 for a cycle time of 12 minutes.

5 Why do we use buffers between stations in assembly lines?

What would be the implications of

a) too large a buffer?

b) too small a buffer?

Suggest a method by which the optimal buffer quantities could be found out.

6 An assembly line is relatively inflexible. Explain how by using the notion of modular production or group technology, flexibility can be attained in a flow shop configuration.

7 Consider the following situation:

A toy manufacturer intends to make 10,000 pieces per year in the 2000 hours of regular time each year. He has identified 16 work elements with the following precedence restrictions and durations.

Element	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Immediate Predecessors	—	1	2,15	3	4	5,12	6,16	1	8	9	10,14	11	8	13	1	5
Standard times (hrs./pc.)	.14	.01	.13	.12	.01	.10	.07	.06	.17	.17	.20	.17	.03	.09	.20	.05

a) Draw a precedence diagram for the assembly of toys

b) Design an assembly line suitable for the toy manufacturer

c) Computer the line efficiency, balance delay and smoothness index for your design in (b) above.

9.13 FURTHER READINGS

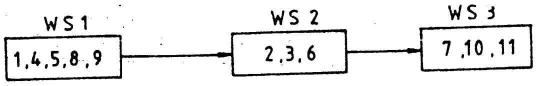
Bedworth, D.D. and J.E. Bailey, 1982. *Integrated Production Control Systems*, John Wiley: New York.

Buffa, E.S., 1968. *Operations Management, Problems and Models*. John Wiley: New York.

Elmaghraby, S.E., 1966. *The Design of Production Systems*. Reinhold Publishing Corporation: New York.

Elsayed, E.A., and T.O. Boucher, 1985. *Analysis and Control of Production Systems*, Prentice Hall: Englewood-Cliffs.

Helgeson, W.B. and D.P. Birnie, 1961. "Assembly line Balancing Using the Ranked Positional Weight Technique", *Journal of Industrial Engineering*, Vol. 12, No. 6., (pp. 394-398)



(c) COMBINED.

9.8 MODULAR PRODUCTION AND GROUP TECHNOLOGY

One criticism of manually operated assembly lines has been that they reduce a man to a mere cog in a machine. Surely you can imagine the boredom, monotony and fatigue of a man who spends all his time tightening the same bolt on a part in an assembly line. It has been found valuable to enlarge the scope of work of the worker so that he assembles a complete 'module', which in turn may be used on an assembly line to assemble a product or a number of different products sharing that particular module. This job enrichment results in greater job satisfaction for the operator by reducing the monotony of the job and giving the operator a sense of accomplishment for assembling a complete module. In modular production we tend to specialise in the production of particular parts or activities that can then be included as components of more than one product or services. The reason for wanting to achieve such commonality is that one part or operation, if used in several products or services, can accumulate sufficient demand volume to warrant investment in a flow shop.

Group technology provides another aspect of the same basic idea. It refers to specialisation in families of similar parts. Hence components requiring primarily turning operations, such as shafts, are collected in one group, while components requiring surface grinding and drilling operations, such as plates are assigned to a different group. These groups become the basis on which a traditional process plant layout can be reorganised into a group technology plant layout in which machines are arranged in such a way that each machine is assigned to the production of only one group of parts. Group technology typically affects only component manufacture, not the assembly stage of production.

For illustrative example of assembly lines using modular production and group technology refer to Salvendy.

9.9 AUTOMATION AND ROBOTICS

Mass production has been assisted to a large extent by automation and robotics in the recent past. Automation refers generally to the bringing together of three basic building blocks: machine tools, material handling and controls. Often a considerable amount of time is spent to load, machine and unload work and to convey it between the single operation machines. This restriction has been partly relieved by the development of the multiple spindle machine. With this machine, a single motor driving several spindles through a gear train allows multiple operations to be performed by one machine. Machining time cycle does not change, but more machining operations can be performed within each cycle. And several machining operations can be performed on one machine by a single operator.

Automatic work piece indexing and transfer of work pieces from station to station has made it possible for one operator to control the work performed at several machining stations. Also the operator is able to load and unload at the load station while machining was going on.

Another trend with automation has been the use of industrial robots to perform some of the functions that were earlier done by manual operators.

An 'industrial robot', as defined by the Robot Institute of America, is a programmable, multi-function manipulator designed to move material, parts, tools or specialised devices through variable programmed motions for the performance of a variety of tasks. What separates an industrial robot from other types of automation is the fact that it can be reprogrammed for different applications; hence a robot falls under the heading of 'flexible automation', as opposed to 'hard' or dedicated automation.

Industrial robots comprise three basic components:

1 The manipulator (or arm), which is a series of mechanical linkages and joints capable of movement in various directions to perform the work task.

2 The controller, which actually directs the movements and operations performed by the manipulator. The controller may be an integral part of the manipulator or may be housed in a separate cabinet.

3 The power source, which provides energy to the actuators on the arm. The power source may be electrical, hydraulic, or pneumatic.

Major reasons for use of robots in industry are increased productivity, adaptability, safety, ease of training, return on investment and greater reliability. Robots are currently in operation in welding and assembly, drilling and routing, inspection, material handling, machine loading, die casting and a variety of other applications.

9.10 SUMMARY

In this unit we have presented the concept of mass production which essentially involves the assembly of identical (or inter-changeable) parts of components into the final product in stages at various work stations. The relative advantages and disadvantages of mass or flow production are discussed and conditions favouring the installation of such a system are identified.

How to design an assembly line starting from the work breakdown structure to the final grouping of tasks at work stations is also discussed using two commonly used procedures—the Kilbridge-Wester heuristic approach and the Helgeson-Birnie approach. Various problems with assembly lines including variable work element times, breakdowns at work stations and multi-product line are discussed.

The concepts of modular production and group technology are introduced to indicate how flexibility can be introduced in mass or flow manufacture. Finally, the role of automation and the use of industrial robots in mass production has been discussed.

9.11 KEY WORDS

Assembly line: A sequence of work stations where parts or components of a product are progressively worked on to produce the finished product.

Balance delay: The total idle time of all stations as a percentage of total available working time of all stations in an assembly line.

Cycle time: The time after which a finished product comes off the assembly line. It would equal the time of the bottleneck operation or the maximum station time.

Fabrication line: A production line made up of machining or other operations rather than assembly of components or parts.

Flow shop: A manufacturing system in which machines and other facilities are arranged on the basis of product flow (generally used for large production volumes and less product variety).

UNIT 10 PLANNING AND CONTROL FOR BATCH PRODUCTION

Objectives

After completion of this unit, you should be able to:

- understand the nature of batch production and the circumstances under which it is used
- appreciate that batch size determination, sequencing and scheduling are the major problems in batch production
- determine the optimum batch sizes for single and multi-product case produced on a single machine
- appreciate the problems of aggregate production planning and master schedule determination
- get an idea of material requirements planning and its function in an organisation
- become familiar with the line of balance as a valuable tool for monitoring and control in batch production
- become aware of new developments like Kanban and Flexible Manufacturing Systems.

Structure

10.1 INTRODUCTION

When a variety of products is to be made and the volumes of production are not large enough to justify a separate line for each product, production in batches is often resorted to. Batch production implies that general purpose machines are utilised for the production of different products. Material flow tends to be more complex in such systems than in mass production systems.

The layout plan for such systems has to be carefully designed keeping in mind the diversity of products and their individual flow patterns and production volumes. Naturally, in such systems the production times are larger as compared to those in mass production. Batch production is distinguished from the Job Shop as follows:

> In batch production a continuous demand for certain products exists, but because the rate of production exceeds the rate of demand, there is a need to produce products in batches. The scheduling problem here is concerned with determining the batch sizes for products and the order in which they should be produced.

In job production a stream of orders has to be processed on common facilities or production centres, each job having its own unique specifications and requirements in terms of production resources. A job may consist of a single item or a batch of identical items. The scheduling problem here is concerned with setting the sequence ... would be processed at each production centre

Of the various problems in batch production we shall, in this unit, address ourselves to:

- the problem of determining optimal batch sizes
- aggregate production planning
- disaggregation of the aggregate plan to determine the master production schedule
- material requirements planning to achieve a given master production schedule
- the problem of production control using the line of balance (LOB) in batch production
- some recent concepts in batch and Discrete Parts Systems.

10.2 FEATURES OF BATCH PRODUCTION

Unlike mass production systems which tend to be organised as product layouts with machines or equipment arranged according to the product flow, batch production normally is done employing a process layout. Here similar machines or equipment are grouped in departments and different jobs will follow their own route depending on requirements. Apart from the greater flexibility afforded by process layouts as compared to product layouts some of the advantages and disadvantages of process layouts are summarised below:

Advantages:

i) Better utilisation of machines is possible; consequently, fewer machines are required.
ii) A high degree of flexibility exists vis-a-vis equipment or manpower allocation for specific tasks.
iii) Comparatively low investment in machines is needed.
iv) There is generally greater job satisfaction for the operator owing to the diversity of jobs handled.
v) Specialised supervision is possible.

Disadvantages:

i) Since longer and irregular flow lines result, material handling is more expensive.
ii) Production planning and control systems are more involved.
iii) Total production time is usually longer.
iv) Comparatively large amounts of in-process inventory result.
v) Space and capital are tied up by work in process.
vi) Because of the diversity of job in specialised departments, higher grades of skill are required.

In addition to these features which are characteristic of the layout generally adopted in batch production, questions like "what should be the size of the batch?" or "how should various batches be sequenced?" arise typically. Although such decisions may be made in practice either in an adhoc manner or by using certain rules of thumb derived from past experience, we demonstrate below a more rational outlook to arrive at the 'optimal' decisions pertaining to batch size.

Kilbridge, M.D. and L. Wester, 1961. "A Heuristic Method of Assembly Line Balancing", *Journal of Industrial Engineering*, Vol. 12, No. 4 (pp. 292-299).

Kilbridge, M. and L. Wester, 1962. "The Balance Delay Problem", *Management Science*, Vol. 8, No. 1, (1962).

Kilbridge, M.D. and L. Wester, 1962. "A Review of Analytical Systems of Line Balancing", *Operations Research*, Vol. 10, No. 5 (pp. 626-638).

Moore, J.M., 1962. *Plant Layout and Design*, The Macmillan Company: New York.

Salvendy, G. (Ed.), 1982. *Handbook of Industrial Engineering*, John Wiley: New York.

Starr, M.K., 1978. *Operations Management*, Prentice Hall; Englewood-Cliffs.

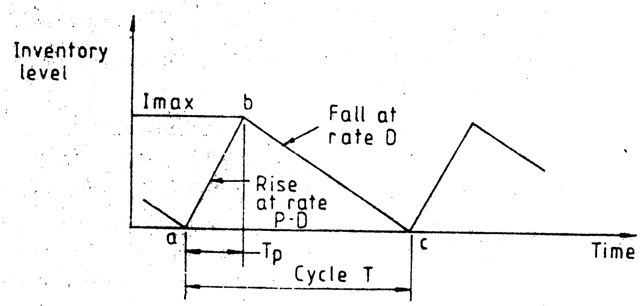
10.3 HOW TO DETERMINE THE OPTIMUM BATCH SIZE

Single Product Case

Let us consider a situation for the production of a single product on a machine under the following set of assumptions.

- **there is a continuous demand for the product at rate D units per year**
- **production rate for the product is P units per year (P > D)**
- **set up cost per batch of size Q is fixed at A (independent of Q)**
- **unit variable cost of production is C per piece**

Figure I: Single Product Model with Constant Demand Rate and no Shortages



- inventory carrying cost per unit per year (Rs./unit/year) = h = i C where i is the annual inventory carrying cost rate
- no shortages are allowed.

Figure I shows the change in inventory level within a cycle T. When production starts at point a, the inventory level will increase at a rate P-D (can you see why?) until the maximum is attained at point b. The inventory level will decrease at a rate D during the rest of the cycle till point c is reached at which a new batch of size Q is initiated and a similar cycle ensues.

It is easy to see from Figure I that

Time to produce a lot Q $= T_p = Q/P$ ... (10.1)

Maximum inventory level $= I_{max} = T_p (P-D)$

$= Q/P (P-D)$

$= Q (1-D/P)$ ... (10.2)

The total cost is built up of two conflicting components—the set up cost (which favours large batch sizes) and the inventory holding cost (which favours small batch sizes). Our approach, therefore, is to develop an expression for the total annual cost in terms of the decision variable (which is the batch size Q in this case) and then to mathematically determine the optimum.

This can be done as follows:

The average cost per cycle of length T is the sum of the set up cost, item variable cost and the carrying cost

$$= A + CQ + h\,T\,I \qquad \ldots (10.3)$$

where I is the average inventory over the cycle T.

The average inventory I over the cycle T may be determined from Figure I as the area of the triangle abc divided by T

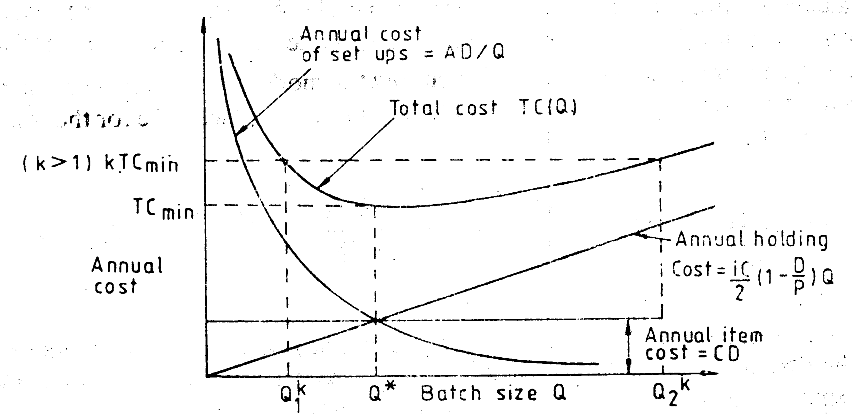
$$I = \frac{1}{2}\,\frac{T\,I_{max}}{T}$$

$$= \frac{1}{2} \times Q\,(1 - D/P) \text{(utilising equation 10.2)} \qquad \ldots (10.4)$$

The total annual cost TC(Q), is obtained by multiplying equation (10.3) by the number of orders per year, D/Q. By substituting h=iC, we obtain

$$TC\,(Q) = \frac{AD}{Q} + CD + i\,C\,I \qquad \ldots (10.5)$$

Figure II: Total Annual Cost as a Function of Batch Size



Substituting for I utilising equation. (10.4)

$$TC\,(Q) = \frac{AD}{Q} + CD + \frac{i\,C}{2}\,Q\,(1 - D/P) \qquad \ldots (10.6)$$

$$\frac{d\,TC\,(Q)}{dQ} = 0 \text{ yields the optimal batch size } Q^* \text{ as}$$

$$Q^* = \sqrt{\frac{2\,AD}{i\,C\,(1 - D/P)}} \qquad \ldots (10.7)$$

The total annual cost (equation 10.6) is plotted in Figure II.

The optimum batch size Q^* determined from the above equation 10.7 may have to be modified in practice to suit procurement, storage or machine capacity constraints which have been ignored in the above model. Figure II illustrates how a range of batch sizes (from Q^k_1 to Q^k_2) may be determined so that the total annual cost does not exceed a certain specified cost level (say k times the minimum cost TC_{min}, $k > 1$). Also notice that because of the relatively steep nature of the total cost function to the left of the optimum Q^*, as compared to the right, Q^k_1 is closer to Q^* than Q^k_2.

Activity A

Determine the optimum batch size for an item produced on a manufacturing facility.with the following data.

Consumption rate : 500 items/month

Production rate : 1500 items/months

Storage costs : Rs. 100 per unit per year

Setup charges per batch : Rs.2000

Interest charges : Rs. 50 per unit per year,

What is the berakup o annual item cost, setup cost and holding cost at the optimum?

Activity B

Extend the model discussed above to include the case when shortages are allowed. after which is it satisfied. Notice that in this situation ther are two decision variables - the batch size and the maximum backorder level.

Multi-product Case

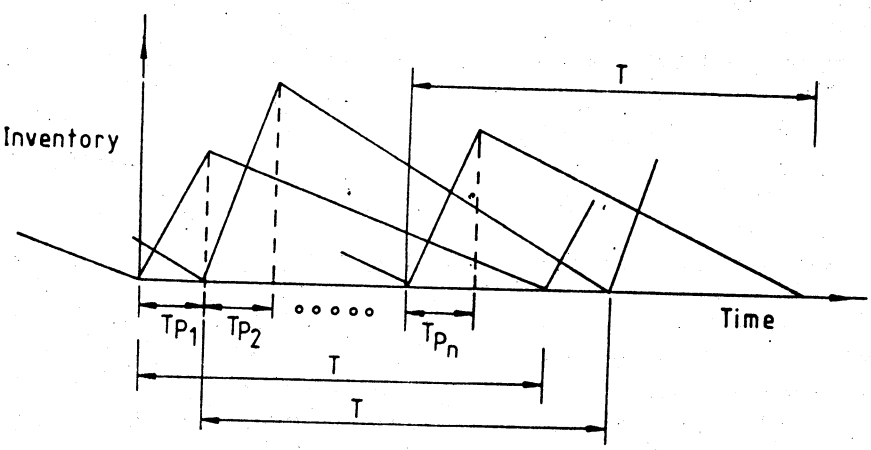
We shall consider a situation where n items are manufactured on a single machine, with the restriction that there is a common cycle time, T for all the items. The n batches are thus phased within the common cycle. Assuming no shortages, the total annual cost for this multi-item case can be estimated as the sum of the total annual cost of each item independently. Extending the model for the single product case by including a subscript j for the jth product (j=1,2.......n) we have for the total annual cost (analogous to TC(Q) in eqn. 10.6):

$$TC(Q_1, Q_2, \ldots Q_n) = \sum_{j=1}^{n} (C_jD_j + \frac{A_jD_j}{Q_j} + \frac{iC_jQ_j}{2}(1-D_j/P_j)) \qquad \ldots (10.8)$$

As seen from Figure III a feasible schedule can be generated with a common cycle T, if the time for production of all batches does not exceed the common cycle time. In the absence of set up time for a lot this is equivalent to:

$$T_{p1} + T_{p2} + \ldots. + T_{pn} \leq T \qquad \ldots (10.9)$$

Figure III: Production of Multiple Batches on a Single Machine with a Common Cycle



Since the time required to produce the batch of jth product = $TP_j = Q_j/P_j$ and because $T = Q_j/D_j$, condition 10.9 may be expressed as:

$$\frac{D_1}{P_1} + \frac{D_2}{P_2} + \ldots\ldots + \frac{D_n}{P_n} \leq 1 \quad \ldots (10.10)$$

Equation 10.10 may be interpreted as a resource feasibility check to determine if all n items can be scheduled on a single machine. In case the left hand side of eqn. 10.10 exceeds one and equals say 2.4 in a particular case, it indicates that 3 (the integer just exceeding 2.4) is the minimum number of machines needed for scheduling all items under the assumption of a common cycle time.

We can convert the annual total cost expression of eqn. (10.8) into the following by using $Q_j = TD_j$

$$TC(T) = \sum_{j=1} \left(C_j D_j + \frac{A_j}{T} + \frac{i\, C_j D_j}{2}\, T \left(1 - \frac{D_j}{P_j}\right)\right) \quad \ldots (10.11)$$

By means of the assumption of a common cycle time we have in effect only one decision variable (T).

The optimum T* can be found by putting $\frac{d\, TC(T)}{dT} = 0$, which yields

$$T^* = \sqrt{(2\sum_{j=1}^{n} A_j) / (i \sum_{j=1}^{n} C_j D_j (1 - D_j/P_j))} \quad (10.12)$$

Once T* is obtained the optimum batch sizes $Q^*_1, Q^*_2, \ldots Q_n^*$ can easily by found out by using $Q_j^* = T^*D_j$, j = 1,.....n.

Example 1

A company is concerned with the production of four products on the same equipment. The relevant data is shown in Table 1.

a) Determine the lot sizes of the products individually.

b) What would be the difficulty in scheduling the above "optimum" lot sizes on the machine?

c) Under the assumption of a common cycle time, determine the lot sizes.

Table 1
Relevant data for four-product production on a single machine

Product j	Demand rate (units/year) D_j	Production rate (units/year) P_j	Inventory Cost Rs./unit/year $i\,C_j$	Set up cost (Rs.) A_j
1	1500	12,000	Rs. 50.00	Rs. 90
2	1134	5,000	Rs. 108.00	Rs. 210
3	2016	6,667	Rs. 75.00	Rs. 165
4	2716	8,000	Rs. 67.50	Rs. 135

Assume that there are 240 working days in a year.

Solution

a) Under this condition the individual lot sizes may be determined by using eqn. 10.7, that is

$$Q^*_j = \sqrt{\frac{2\ A_j\ D_j}{i\ C_j\ (1 - D_j/P_j)}}$$

The results are summarised in Table 2.

Table 2
Individual Economic Lot Sizes for the four Products

Product j	Economic lot size Q^*_j	Production days per lot (Q^*_j/P_j)	Cycle time T_j^* in days $= (Q^*_j/D_j)$
1	78.6	1.57	12.6
2	75.5	3.62	15.9
3	112.8	4.06	13.4
4	128.3	3.85	11.3
Total		13.10	

b) A look at Table 2 indicates that scheduling the four products on the machine in sequence would take a minimum of 13.10 days (the total of the production days for all the lots). Note that an economic lot of product 4 will last only 11.3 days whereas a lot of product 2 will last 15.9 days. Thus there would be uncontrollable shortages and surplus with this scheme of scheduling.

This difficulty is overcome when we consider a common cycle time for all the products.

c) Under the common cycle category we obtain the solution by using eqn. 10.12. Computations are simplified if we tabulate the numerator and denominator terms needed under the radical sign on the right hand side in eqn. 10.12. This is shown in Table 3. The common cycle equals 0.0557 year ($=0.0557 \times 240 = 13.37$ working days) out of which 13.26 days are utilised for the production of the four product lots as indicated in Table 3.

Table 3
Results under a common of cycle policy

Product j	Set up cost A_j	$(1 - D_j/P_j)$	$i\,C_jD_j\,(1 - D_j/P_j)$	$Q^*_j = T^*\ D_j$	Production days per lot (Q^*_j/P_j)
1	90	0.8750	65,625.00	84	1.68
2	210	0.7732	94.695.40	63	3.02
3	165	0.6976	105,477.10	112	4.03
4	135	0.6605	121,089.50	151	4.53
Total	600		386,887.00		13.26

You could also check that the feasibility condition of eqn. 10.10 is in fact satisfied

$$\left(\frac{D_1}{P_1} + \frac{D_2}{P_2} + \frac{D_3}{P_3} + \frac{D_4}{P_4}\right.$$

$$= 0.1250 + 0.2268 + 0.3024 + 0.3395 = 0.9937 < 1).$$

Activity C

In the multi-product batch size determination under a common cycle we assumed that there was no time required to set up a batch. Think of the consequences in the following two cases:

a) If there were set up times but these were independent of the sequence of production.

b) If there were set up times which were dejpendent on the sequence of production.

You mav like to consult some of the feferences given at the end (especially 4,5).

10.4 AGGREGATE PRODUCTION PLANNING

The Purpose

Customer demand enters the production system as units of products. Aggregate production planning is concerned with developing the work force and machine time allocation to meet a given demand schedule over the planning horizon (generally the next 3 to 6 months). The purpose of this exercise is to produce an 'aggregate' plan in terms of the overall production of all products combined such as production in tons of steel or litres of paint which would have to be 'disaggregated' to yield individual product schedules.

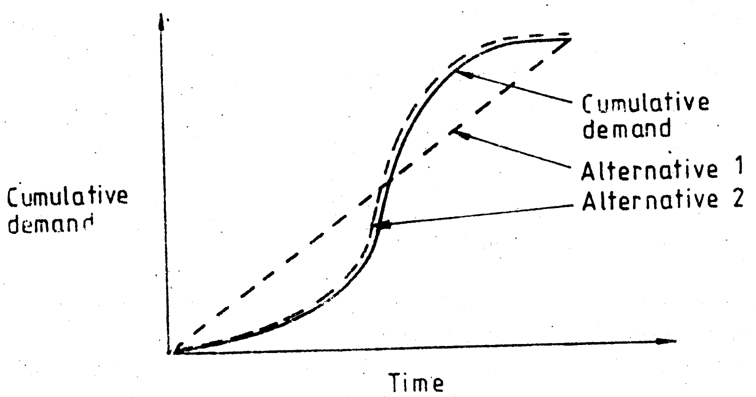
When planning work force and related activities to conform to a given demand schedule, it is necessary to balance the cost of building and holding inventory against the cost of adjusting activity levels to fluctuations in demand. Figure IV shows a hypothetical cumulative demand pattern and two alternative production strategies.

Alternative-1 uses a constant work force level (i.e. constant production output rate). Since the production rate is greater than the expected demand rate in the earlier production periods, cumulative production will exceed cumulative demand resulting in a significant inventory carrying cost. Conversely significant shortage cost may result when the cumulative demand exceeds the cumulative production.

Alternative-2 is a strategy to produce as per demand so that the inventory carrying costs are minimised. This alternative requires constantly adjusting the work force levels or paying significant overtime cost during the high demand periods.

These are two extreme alternatives. The optimal alternative is the one that minimises the total cost of the inventory and the cost of adjusting the work force level. The

Figure IV: Two Alternative Production Schedules for Meeting Demand



primary output of the aggregate planning process is a master schedule, which describes the number of units to be produced during each period and the work force levels required by period.

A Brief Review of Approaches

Perhaps the simplest approach to aggregate production planning is graphical in which the cumulative demand is plotted as shown in Figure IV and alternative production plans (shown as dotted lines) are compared in terms of their costs and the most economical one is adopted. This approach suffers from the drawback that it chooses the best plan from the ones considered and not from 'all' possible plans which in fact could be infinitely large and difficult to conceive.

The above limitation is to some extent taken care of in mathematical optimisation models. The approach for finding the optimal alternative (master schedule and work force level) in such a case is to develop a total cost function which contains the major cost components of the production facility. This cost function is to be minimised while subject to constraints. The linearity or non-linearity of the cost function and constraints determines the solution approach to the problem. Multi-period production planning models can be treated as network flow problems and solved by special procedures (See for instance, Johnson and Montgomery).

Other methods for dealing with the aggregate production planning problem could be heuristic rules or computer search procedures. A review of approaches to aggregate production planning may be found in Buffa, Eilon, Elsayed and Boucher.

Example 2 (adopted from Elsayed and Boucher)

A chemcial plant manufactures two types of products A and B with either regular production time or through planned overtime. Products use the same equipment and are scheduled into production one at a time. Demand over the next 4 months is 100, 90, 110 and 100 units for product A and 200, 190, 210 and 200 units for product B.

The initial inventory levels are 36 units of A and 220 units of B. It takes 1 plant hour to produce a unit of product A and 0.40 plant hour to produce a unit of product B.

Associated production costs are:

Cost of regular production, C_R	= Rs. 100/plant-hour
Cost of overtime production, C_O	= Rs. 150/plant-hour
Inventory carrying cost charge, C_I	= Rs. 40/plant-hour/month

Production capacities for regular time and overtime are:

Regular time	= 160 plant-hours/month
Overtime	= 40 plant-hours/month

Determine the aggregate production plan in terms of plant hours for these products, such that the total production and inventory costs are minimised. The management desires a planned final inventory target of 80 plant hours.

Solution

This problem can be structured as a transportation problem with unit costs as shown in Table 4. Plant hours of demand are computed from the demand data and plant-hours conversion factors. For example, in period 1 the demand of 100 units of product A and 200 units of product B is equivalent to (100x1+200x0.4)=180 plant-hours of aggregate demand. Similar method can be used for other periods.

Table 4
Transportation cost matrix for Example 2

Production period	Period of Demand 1	2	3	4	Final Inventory	Capacity (Plant-hours)
Period-1						
Initial Inventory	0	C_I	$2C_I$	$3C_I$	$4C_I$	124
Regular time	C_R	C_R+C_I	C_R+2C_I	C_R+3C_I	C_R+4C_I	160
Overtime	C_O	C_O+C_I	C_O+2C_I	C_O+3C_I	C_O+4C_I	40
Period-2						
Regular time	—	C_R	C_R+C_I	C_R+2C_I	C_R+3C_I	160
Overtime	—	C_O	C_O+C_I	C_O+2C_I	C_O+3C_I	40
Period-3						
Regular time	—	—	C_R	C_R+C_I	C_R+2C_I	160
Overtime	—	—	C_O	C_O+C_I	C_O+2C_I	40
Period-4						
Regular time	—	—	—	C_R	C_R+C_I	160
Overtime	—	—	—	C_O	C_O+C_I	40
Demand (plant-hours)	180	166	194	180	80	

A planned final inventory of 80 plant-hours is considered a desirable target by management, which still leaves 124 plant-hours surplus over the 4 month planning horizon.

The solution to this very special transportation problem (with no entries below the main diagonal) can be obtained very simply by proceeding to fill the demands of periods 1, 2.....in order by the cheapest available sources. Applied to the example-problem yields the solution shown in Table 5.

Table 5
Solution for Example 2

Production source	Period Demand 1	2	3	4	Final Inventory	Unutilised Capacity	Capacity (Plant hours)
Period-1 Initial Inventory	(124) 0	40	80	120	160	0	124
Regular time	(56) 100	(6) 140	180	220	(54) 260	(44) 0	160
Over time	150	190	230	270	310	40 0	40
Period-2 Regular time		(160) 100	140	180	220	0	160
Overtime		150	190	230	270	(40) 0	40
Period-3 Regular time			(160) 100	140	180	0	160
Overtime			(34) 150	(6) 190	230	0	40
Period-4 Regular time				(160) 100	140	0	160
Overtime				(20) 150	(20) 190	0	40
Demand (plant hours)	180	166	194	180	80	124	924

Disaggregation to a Master Schedule

The production facility considered in example 2 is a chemical plant which is shared by products A and B. Simultaneous production is not possible. Therefore, we should plan the production of each product by alternating the use of the facility between products. A disaggregation of example 2 requires the determination of the batch size of products A and B that will be produced each time a change-over occurs.

The necessity and desirability of disaggregation is situation dependent. In situations where product demand estimates are likely to differ from actual values, plant management may proceed to set hiring policies based on aggregate plant hour production requirement, with the assumption that forecast errors for individual products will be offset in the aggregate.

In situations where demand estimates are precise it is reasonable to consider a complete disaggregation of their production plan to the individual product level. When such disaggregation is done, the resulting output is called a master schedule, a schedule of the time bound completion of production.

Let us assume that in Example 2 the demand forecast by product is reasonably precise and we wish to disaggregate the plan. The aggregate solution has minimised two costs the production cost and the inventory carrying cost. Given the solution the only remaining cost to be considered is the set up cost incurred each time production is switched between products. With only two products to be considered, a simple approach to minimising set up cost is to minimise the total number of set ups scheduled over the planning horizon. One way to achieve this and thus obtain a disaggregated master schedule is to simulate production runs using the following simple decision rule.

Set up and produce one product until the other product's inventory runs out. At that time set up the second product and run it until the first product's inventory runs out.

Application of this procedure to Example 2 yields the Master schedule shown in Figure V.

It should be clear that the simple rule above would not work for the general case with greater than two products. Procedures for disaggregation in such cases may be found in Elsayed and Boucher.

10.5 MATERIAL REQUIREMENTS PLANNING

Overview and Problem Definition

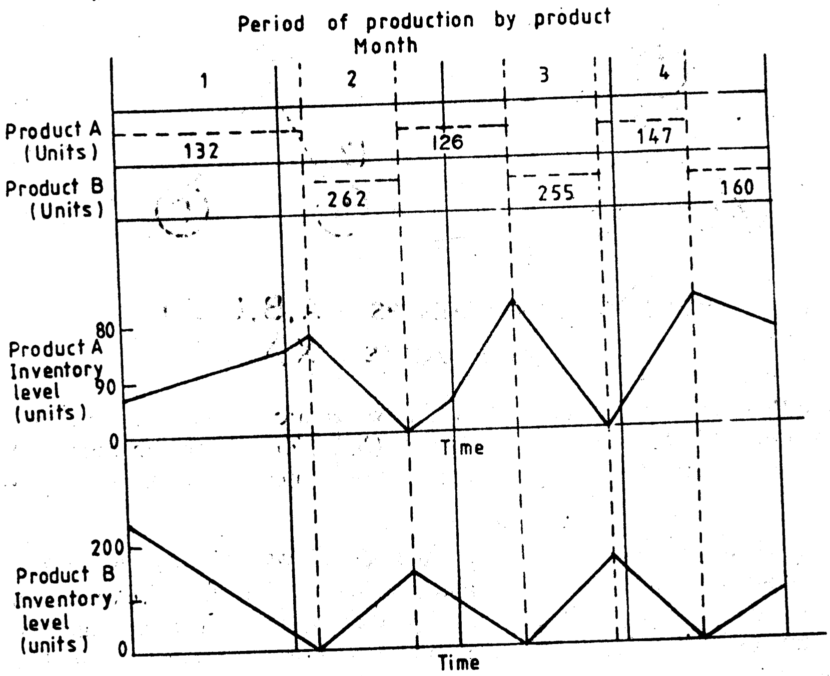
By using the methods of aggregate production planning and subsequent disaggregation we can determine the weekly master schedule for end-products. The requirements of sub-assemblies, components, and raw stock items related to those end-products can be simply derived from the end-product demands. The manufacturing routing sheets and product bills of materials describe the departmental routings and production times to manufacture the sub-assemblies and components. Using these data bases in conjunction with a schedule of end-product requirements, it is possible to compute the timing of production for each component to meet the given end-product schedule. This, in effect, is the objective of a Material Requirements Planning (MRP) system. Thus, given a master schedule of end (or final) product, MRP computes the timing of all the sub-assembly, component and raw material production and purchasing activities required over the specified production horizon to meet the master schedule of the end-product. Moreover, it does so in such a way as to attempt to minimise work-in-process inventory.

Owing to the large amounts of data storage (a typical batch production facility may purchase/produce 20,000 to 100,000 components) retrieval and computational requirements practical MRP systems have to be computerised.

Parts Explosion Requirements

From the master schedule of end-product production the requirements for purchased and manufactured components and sub-assemblies must be determined. This is referred to as 'parts explosion'.

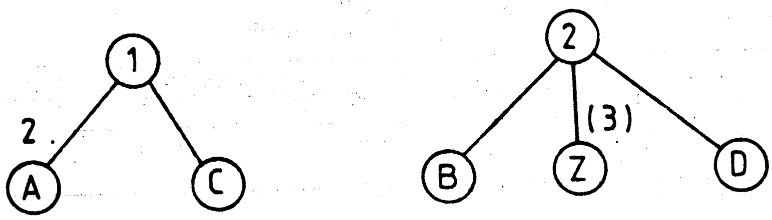
Figure V: Disaggregated Plan and the Resulting Master Schedule for Example 2



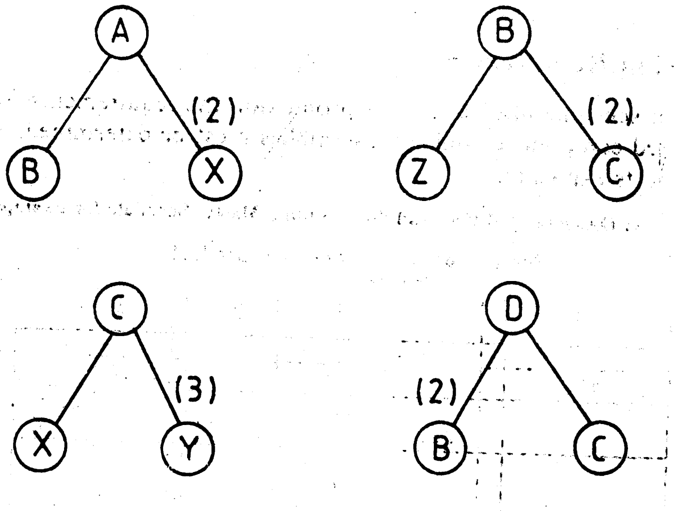
Master schedule (units)

Product	Month 1	2	3	4
A	100	87	79	139
B	0	262	255	160

Figure VI: Product Structure for two End Products



Two end products 1 and 2



Four subassemblies (A, B, C, D)
Three parts (X, Y, Z)

Suppose there are 2 end-products (1 and 2) which are assembled from four sub-assemblies (A, B, C, D) and three parts (X, Y, Z) as shown in Figure VI. The numbers in parentheses indicate the quantity of an item required, otherwise, the quantity is 1.

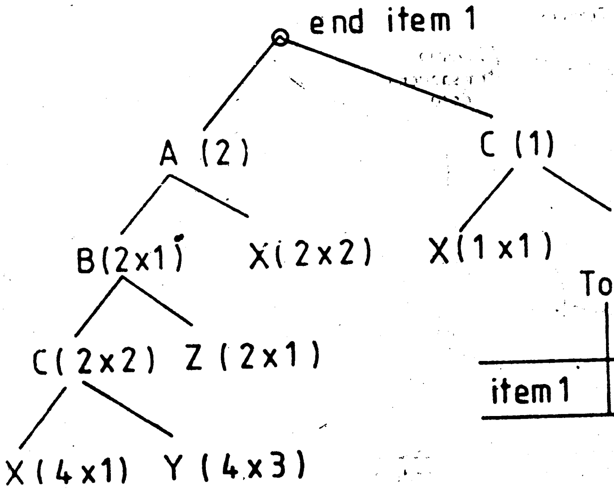
We can easily determine the level of an item as follows: Treating the end items at level 0, sub-assemblies A and D are placed at level 1 since they are directly used for the assembly of level 0 and items 1 and 2 and are not used at other higher levels. Notice that C, B and Z cannot be placed at level 1 since they are required as inputs for assembly of D, A and B, respectively. Similarly, level 2 consists of B; level 3 consists of C and Z, and, finally, level 4 consists of X and Y. Based on this level structure the "Bill of Materials Matrix" is shown in Table 6. The rows of this matrix are the 'how constructed files' and the columns are the 'how used files'. For instance, the row corresponding to end-product 2 shows that each unit of this product requires 1 unit each of sub-assemblies D and B and 3 units of the part Z. The column for C shows that C is used in production of end-product 1 and sub-assemblies D and B in requirements of 1, 1 and 2 respectively.

Table 6
Bill of Materials Matrix

Level	Item	End-Product		Sub-assemblies				Parts (Components)		
		1	2	A	D	B	C	Z	X	Y
0	1			2			1			
	2				1	1		3		
1	A					1			2	
	D					2	1			
2	B						2	1		
3	C								1	3
	Z									
4	X									
	Y									

Now if we need to find out the sub-assemblies and components needed for making 20 units of end-product 1 the information that is immediately available from the bill of materials matrix is that 40 units of A and 20 units of C are needed (since from row 1 we see that 1 unit of end-product 1 requires 2 units of sub-assembly A and 1 unit of sub-assembly C). This is only the primary or direct dependent demand. Each of the A and C units would need their components and so on. This is shown schematically in Figure VII where the total requirements of all sub-assemblies and components of end-item 1 are derived. By doing a similar exercise for all the items we can compute total requirements matrix in which a particular row corresponds to the total requirements of that particular item. The total requirements matrix R for the two products example considered earlier is shown in Table 7. Notice that the first row is the total requirements for end-product 1 as derived in Figure VII. The total requirements matrix has 1s on the main diagonal.

Figure VII: Computing Total Requirements for End Item 1



Total requirement for end item 1

	1	2	A	D	B	C	Z	X	Y
item 1	1	—	2	—	2	5	2	9	15

Table 7
Total Requirements Matrix, R

	1	2	A	D	B	C	Z	X	Y
1	1		2		2	5	2	9	15
2		1		1	3	7	6	7	21
A			1		1	2	1	4	6
D				1	2	5	2	5	15
B					1	2	1	2	6
C						1		1	3
Z							1		
X								1	
Y									1

It is this matrix that is used to compute the total production requirements for any given demand. For instance, if at any point of time the demand of items (1, 2, A, D, B, C, Z, X, Y) is (20, 30, 0, 10, 0, 5, 0, 0,0) the total requirements can be found by multiplying row 1 of the total requirements matrix R by 20, row 2 by 30, row 4 by 10, row 6 by 5 and summing up the columns. This yields the total production vector:

(20, 30, 40, 150, 365, 240, 445, 1095)

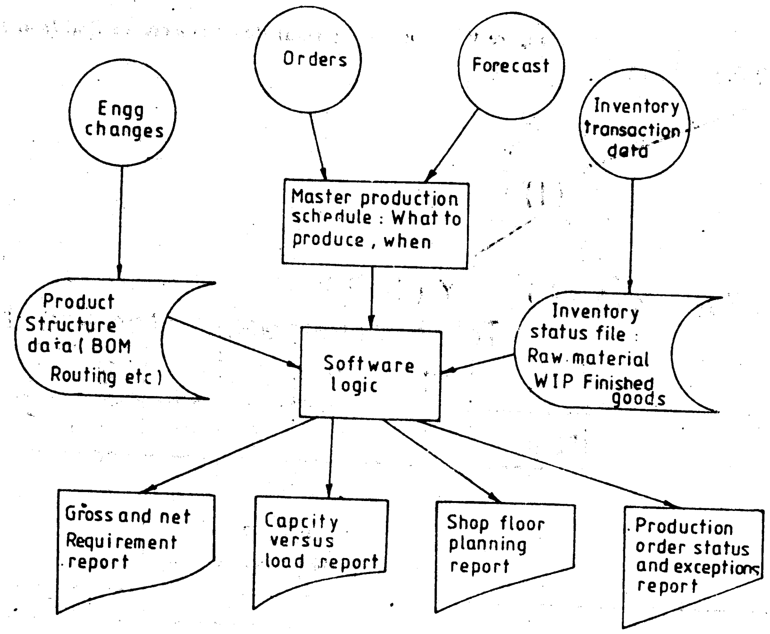
This would be the basic information of how many of which components/ sub-assemblies to have in order to meet the end item demands. However, this information has to be properly dovetailed with current inventory status, production lead times and the end-item demand schedule (or the master schedule) to be able to generate information on which components sub-assemblies should be produced in a given period. This is essentially what an MRP system does.

MRP System in Practice

The major advantage of the MRP approach is its ability to plan discrete parts production for a very complex production system. MRP simply tries to schedule all the activities required to meet a given master schedule, while holding down work in process inventory.

Many commercially available MRP software packages provide a number of informative reports as shown in Figure VIII.

Figure VIII: Typical Structure of an MRP Based Planning System



The major inputs to the system are:

i) the master production schedule specifying what to produce and when
ii) the product structure data including bill of materials, routing files with manufacturing/procurement lead times.
iii) the inventory status file for raw material work in process, and finished goods.

Among the outputs from the package, the 'gross and net requirements report' indicates the timing of order releases required to meet the master schedule.

The 'capacity versus load report' determines whether resources required by the work centres are available to produce these orders. This is useful in planning overtime/sub-contracting.

The 'shop floor planning report' is a listing of jobs by due date where the due date indicates when macnining at that department should be completed in order to meet the schedule indicated by the gross and net requirements report. The shop floor supervisor will then release jobs to machines taking into consideration the hours of machining required and the due dates for the items.

A typical commercial system provides additional information in the form of 'Exceptions reports' indicating jobs to be expedited or de-expedited as a consequence of delays in production of components. De-expediting holds down work in process inventory.

In fact an MRP system has to be tailor made to the needs of the organisation, though most of the above features alongwith any special requirements are generally provided for.

10.6 THE LINE OF BALANCE (LOB) FOR PRODUCTION CONTROL AND MONITORING

The line of balance (LOB) is a production control technique suitable for batch production. This technique is used where there is splitting of batches to study the progress of jobs at regular intervals, to compare progress on each operation with the progress necessary to satisfy the eventual delivery requirements and to identify those operations on which progress is unsatisfactory.

The four stages involved in the use of the technique are:

i) Obtaining the 'delivery schedule' for the product as shown, for example, in Table 8.

ii) Constructing the 'operation programme' to depict the lead times of intermediate operations shown on a chart similar to Figure IX. In this chart, for example, items A and B are assembled (operation 4) 13 days before the final product and this assembly after additional operations is assembled to item C (operation 14) 2 days before the final product is ready.

Table 8
Delivery Requirements

Week No.	Delivery of finished items required	Cumulative delivery
0	0	0
1	12	12
2	14	26
3	8	34
4	6	40
5	10	50
6	12	62
7	14	76
8	16	92
9	18	110
10	22	132

iii) At each review date a 'programme progress chart' is drawn. This shows the number of items that have completed each operation and is obtained by checking inventory levels. For example, at week 4, 40 items should have been delivered or cleared operation 15 of the example being considered. Figure X shows the programme performance at week no. of 4.

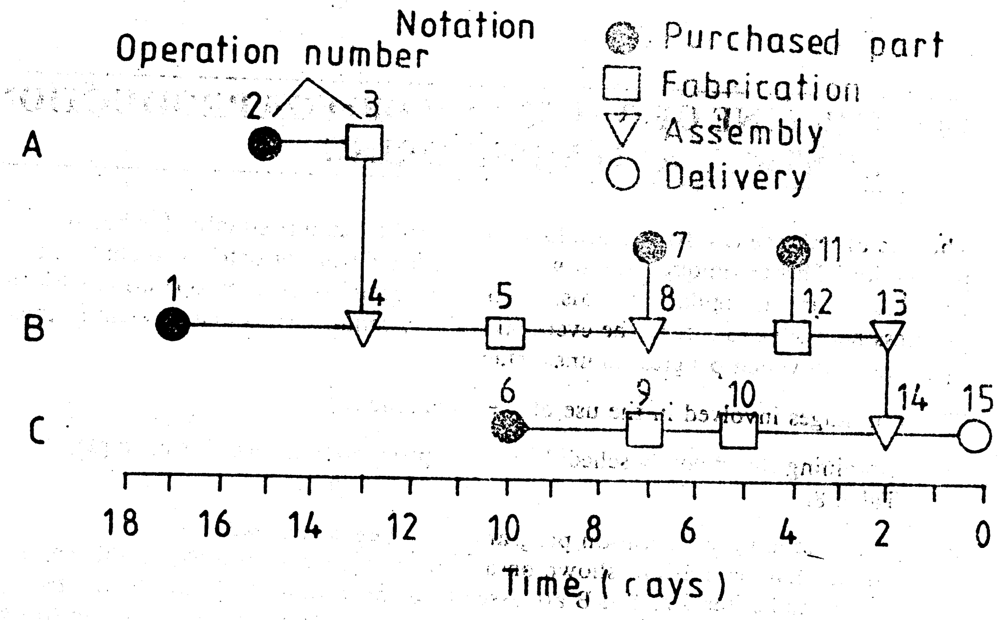
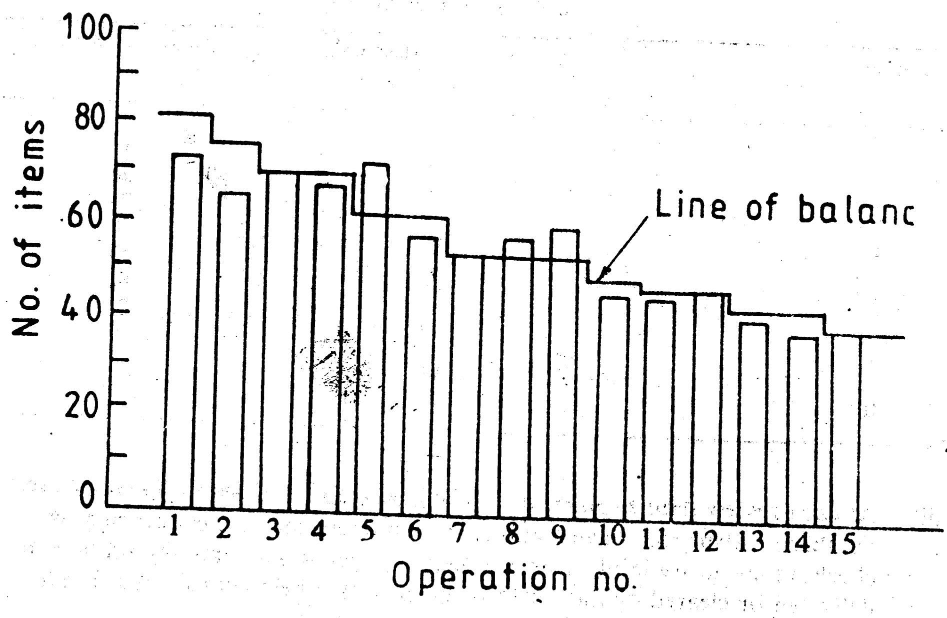


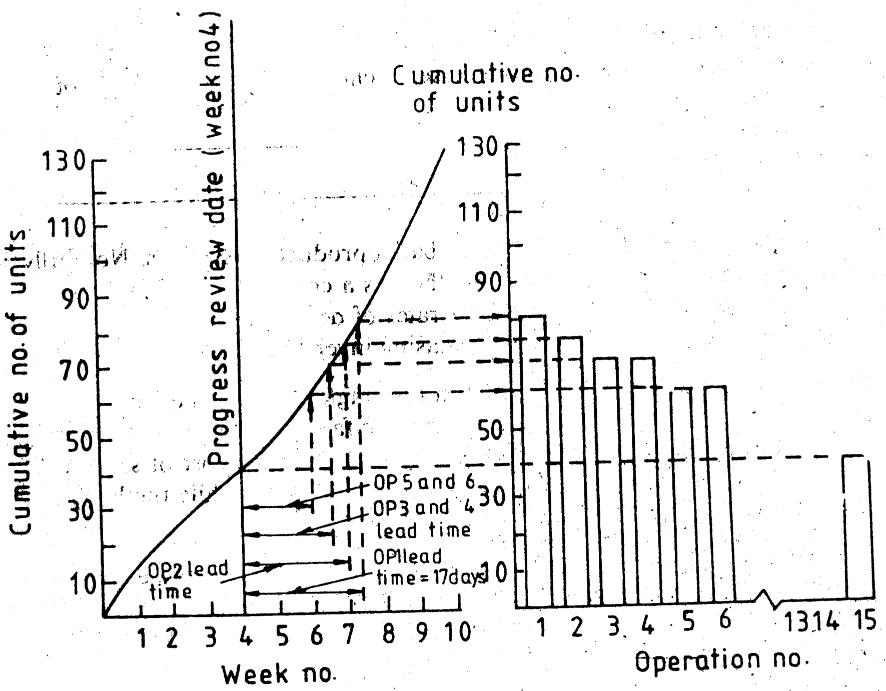
Figure X: Programme Progress Chart (As at week no. 4)



Since the object of the exercise is to compare actual progress with the scheduled or planned progress. The information of Figure X must be compared to the required progress. This is done by constructing a line on the programme progress chart which shows the requisite number of items which should have been completed at each operation at the time of review. This line—the **line of balance** (LOB)—can be constructed by using a graphical procedure as shown in Figure XI. The rationale behind the construction is that at the review date the cumulative number of items ready for each operation must make allowances for the lead time of that particular operation.

iv) Analysis of progress is finally done to identify shortages and pinpoint the specific operations non-conforming to schedule. For instance, in Figure X the requisite number of completed items have been delivered to the customer (operation 15 = 40), but both operations 13 and 14 are in short supply and unless deliveries during the next week are expedited shortages

Figure XI: Construction of Line of Balance



The LOB technique is an example of management by exception since it deals only with the important or crucial operations in a job, establishes a schedule or plan for them and attracts attention to those that do not conform to this schedule. It is particularly useful where large batches of fairly complex products, requiring many operations, are to be delivered or completed over a period of time.

10.7 PROBLEMS AND PROSPECTS OF BATCH PRODUCTION

In batch production systems the in-process inventories and the lead times tend to be large. As we have seen MRP is a vehicle to control the discrete parts production planning and also to reduce work in-process inventory. However, the drawback of MRP is that it is expensive to implement as it requires the capability of a mainframe computer, technical support professionals, and MRP software. Instead of designing production control tools for a complex production system, attempts have been made to simplify the system itself. One example of this is Kanban developed in Japan and being implemented at Takahama plant of Toyota. Kanban emphasises the reduction in production lead time and in-process inventory by specifying shorter production runs of any single product. Kanban is characterised by quick change tooling to reduce set up times. Production control is decentralised. Production activity is regulated by Kanban cards. Conflicts are handled by management and supervisory intervention on the shop floor. Further details of Kanban may be found in Elsayed and Boucher.

Another major development with respect to the complicated problems of batch manufacturing has been the development of Flexible Manufacturing Systems (FMS) in an attempt to apply computer controls to production scheduling, the control of machines and the movement of materials in a discrete parts manufacturing environment.

FMS may be defined as general purpose manufacturing machines, which are quite versatile and capable of performing different types of operations, linked together by material handling systems. Both the machines and the material handling systems are under the control of a central computer system. There are two main objectives of employing FMS:

i) to permit machining of any desired mix of parts in a given time period, and
ii) to reduce the work in process and increase machine utilisation in small-lot manufacturing.

10.8 SUMMARY

In this unit we have presented the features of batch production systems. Normally we resort to batch production of products when there is a continuous demand for products and the production rates exceed the rates of demand. Continuous production would obviously lead to ever increasing inventory build-ups in such cases.

The problems of finding the batch size in both the single product and the multiproduct situation (with the same manufacturing facility) have been considered. Essentially, the approach is to balance two conflicting costs: the cost of set up and the inventory carrying cost, where the former tends to decrease while the latter increases with larger batch sizes.

Aggregate production planning to economically meet a demand schedule over a planning horizon (of say a few months to a year) has been discussed and illustrated through a small example. Disaggregation to obtain the master schedule is also indicated.

A problem, once the master schedule is obtained, is to plan for procurement and production of various components and sub-assemblies in time—this is done through Material Requirements Planning (MRP). How to obtain the demand for parts has been illustrated in parts explosion. Subsequently, the structure of a practical MRP system and the various reports that may be generated are highlighted.

The LOB technique for production monitoring has been discussed next, pointing out the usefulness of this management by exception tool for production managers.

Finally, some developments in areas of discrete parts manufacturing have been indicated with a brief discussion of Kanban and Flexible Manufacturing Systems.

10.9 KEY WORDS

Aggregate Production Planning: Allocation of work force size and production level to meet the forecasted demands of goods and services over the planning horizon. This is generally done in terms of an aggregate product representing the combined needs of the various products.

Batch Production: A production situation where production takes place in lots or batches as opposed to continuous production. Justified when rate of production exceeds the rate of demand. Determination of batch sizes and sequencing or scheduling of batches in multiple product situation are the key decisions in batch production.

Line of Balance (LOB): A production control device effective in batch production to compare progress on each operation with the progress necessary to satisfy the eventual delivery requirements (not to be confused with 'line balancing' used for designing assembly lines in mass production).

Master Schedule: A detailed product by product production plan showing the quantities of each product to be produced in each period of the planning horizon.

Material Requirements Planning (MRP): This is generally a computer-based system for drawing up detailed production/procurement schedules for various parts, sub-assemblies needed to meet a given master schedule of the end item. It utilises the product structure, processing information like production/procurement lead times and inventory status in a bid to produce the best plan.

Parts Explosion: A particular product is generally composed of sub-assemblies and parts which in turn could be traced to items at the next level in a typical tree-like product structure. The problem of finding the demand of all components, sub-assemblies for a given demand of the end product is referred to as 'Parts Explosion' The problem could be complicated as a component or sub-assembly may be needed at different levels of the same or different end products.

10.10 SELF-ASSESSMENT EXERCISES

1 Distinguish between mass and batch production. Under what conditions is batch production justified?

2 A product may be made in the plant or purchased from an outside vendor. The inventory carrying cost per unit is Rs. 5 per day and no shortages are to be allowed. Given the information in the following table, what is the best policy for an annual demand of (a) 30,000 units and (b) 20,000 units.

	In-plant	Vendor
Production per day (units)	200	8
Lead time (days)	4	9
Cost per units (Rs.)	500	540
Order cost (Rs.)	1000	700

3 A company is to produce three products on the same machine using a common cycle policy. What should be the respective batch sizes and the total annual cost given the following data?

	Product-1	Product-2	Product-3
Production per year (units)	6000	12000	4500
Demand per year (units)	2000	3000	1500
Set up cost	Rs. 500	Rs. 400	Rs. 600
Inventory Carrying cost per unit per year	Rs. 400	Rs. 700	Rs. 300

4 The packaging division of a paint shop used the same automatic filling machinery for packing 3 grades of paint called A, B and C. Demand for each brand over the next six weeks is as follows:

Units demanded (X10³)

Week	A	B	C
1	100	50	100
2	100	80	80
3	200	100	150
4	150	120	80
5	200	50	80
6	200	100	100
Initial Inventory	200	100	150

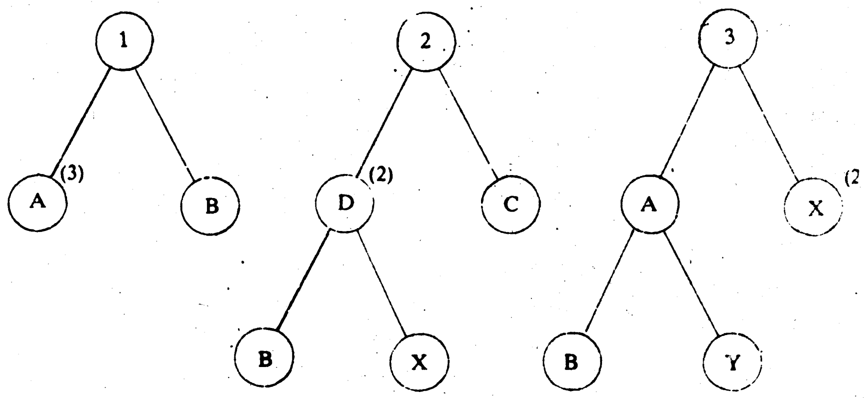
The filling machinery is operated for 40 regular time hours per week maximum and overtime is limited to 20% of the scheduled regular time hours.

Owing to different viscosities of the paint brands the standard number of tins filled per hour is as follows.

Brand	Standard Tins filled per hour
A	9800
B	7200
C	6900

Costs per hour of regular time an overtime are Rs. 200 and Rs. 400 respectively. The inventory carrying cost rate is 40% per annum. What is the optimal aggregate production plan?

5 Three end products 1,2,3 are composed of sub-assemblies A,B,C,D, and components X,Y as shown in the following product structures



(numbers in parentheses show the number of units needed for assembly to the next higher level).

a) Construct the Bill of Materials matrix

b) If 5,2 and 1 units of end items 1,2,3 are required compute the vector of dependent demand resulting directly from end product demand.

c) Compute the total requirements matrix for the above case.

10.11 FURTHER READINGS

Bedworth, D.D. and J.E. Bailey, 1982. *Integrated Production Control Systems,* John Wiley New York.

Buffa, E.S., 1968. *Operations Management: Problems and Models*, John Wiley: New York.

Eilon, S., 1975. Five Approaches to Aggregate Production Planning, *AIIE Transactions*, Vol. 7, No. 2, (pp. 118-131).

Elsayed, E.A. and T.O. Boucher, 1985. *Analysis and Control of Production Systems*, Prentice Hall: Englewood-Cliffs.

Johnson, L.A. and D.C. Montgomery, 1974. *Operations Research in Production Planning, Scheduling and Inventory Control*, John Wiley: New York.

Orlicky, J., 1975. *Material Requirements Planning*. McGraw Hill: New York.

Peterson, R. and E.A. Silver, 1979. *Decision Systems for Inventory Management and Production Planning*, John Wiley: New York.

Turban, E., 1968. The Line of Balance—A Management by Exception Tool, *Journal of Industrial Engineering*, Vol. XIX, No. 9, (pp. 440-448).

UNIT 12 PLANNING AND CONTROL OF PROJECTS

Objectives

After completion of this unit you should be able to :

- describe a project in terms of its activities
- represent the inter-relationships among the activities as network
- differentiate between CPM and PERT
- compute activity times, critical paths and slacks
- use the above information for the time management of the project
- use PERT when activity times are probabilistic
- specify project cost curve and crashing of the activities for reduction in the time duration of the project
- schedule resources

Structure

12.1 INTRODUCTION

We are sure that, both in your professional career and in your personal life, you have handled projects. In this unit we will deal with efficient management of projects. We will describe a project as consisting of inter-related activities. Networks will be used as visualisation of these inter-relationships. A successful implementation of the project will involve planning, coordination and control of the activities constituting the project. We will discuss the time-management of project using Critical Path Method and, subsequently, in situations where activity times are probabilistic, Programme Evaluation and Review Technique (PERT). We shall also describe the relationship between cost and time for implementation of the projects. Each project involves consumption of certain raw materials and use of certain resources. We shall briefly look into the resource allocation problems.

While this unit will outline methods and techniques which are useful in Project Management, a successful implementation of a project will depend on the skill and efficiency of the manager in using these techniques.

12.2 PROJECTS

Before we formally define projects, it will be a good idea if you describe, in your own words, your impression of the word project.

Activity A

In the space provided (or on separate sheet) write down your impressions of the term project. Also prepare a list of a few projects, which you have handled.

....

....

....

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Now consider the following two situations:

1 Preparing tea

2 Arranging for a tea party

If we look at the above two situations, then arranging for a tea party will require preparing tea as one of the tasks. In fact, arranging for a tea party will require organisation of other tasks, such as issuing invitations, procurement of snacks, procurement of cutlery, table arrangement, serving tea, etc. You will agree that arranging for a tea party is a much more complex task consisting of a large number of simpler tasks or activities such as preparing tea. We will call arranging for a tea party as a project while we will refer to individual tasks such as preparing tea as activities. A list of the activities for this project is as follows:

Example 1

List of activities for the project **Arranging a tea party:**

A Procure material

B Prepare snacks

C Arrange for the cutlery

D Prepare tea

E Set table with snacks and cutlery

F Serve tea

G Clean cutlery

We shall also make following observations:

a) Each activity needs physical time for its completion.

b) Certain activities are inter-related in the sense that tea cannot be actually served until its preparation is completed.

c) Each activity will require one or more of the resources such as manpower, equipment, raw material, etc.

d) A project will be completed only if all of its activities are completed.

We will describe formally an **activity** as a physical independent action which requires time for its completion and will consume one or more of the resources, and a **project** as a set of inter-related activities that are organised for a common goal or objective.

Activity B

With the above definition in mind, identify at least one project with which you have been associated and list the activities of that projects.

....

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....

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Some of the examples of projects are: erection of a manufacturing plant, preventive maintenance of a chemical plant, launching of a space vehicle, construction of a building, etc. These projects have a very large number of activities and can be successfully completed only if the various activities are properly planned, time schedules are prepared, resources allocated and a proper control is exercised during the implementation. Project management essentially deals with these aspects of the project.

12.3 NETWORK REPRESENTATION OF PROJECTS

First step in the management of the projects is to understand the inter-relationship between the various activities which constitute the project. The activities may be inter-linked with each other in various ways. For example, the activities preparation of tea and preparation of snacks may be inter-linked with each other by the type of resource required (in this case a gas stove). On the other hand, the activity serving tea cannot be started unless and until the activity preparation of tea is completed. Unlike the other example this dependence cannot be freed by providing additional resources. Thus in any feasible time-schedule, activity serving tea has to be scheduled only after the completion of the activity preparation of tea. This kind of interdependence will be referred to as precedence requirement. An activity B is said to succeed activity A if, in any feasible time-schedule, B has to be scheduled only after completion of A. Then, A is said to be the predecessor of B.

Project Networks are used to visually depict through arrow diagrams these precedence requirements.

Drawing Project Network

The input required to draw project network is the list of the activities and their precedence requirements. When considering the precedence requirements, only immediately preceding activities will be listed. These are also called immediate predecessors. Consider the precedence requirements of the Example 1.

To start the activity prepare snacks, material has to be procured and hence A will precede B. Similarly A will also precede C. Activity E can start only when A, B, D are completed. However, as A precedes B, it is not necessary to list A as the preceding activity to E. Thus, B, D as a set of preceding activities to E, is sufficient to enforce all the precedence requirements. For the above example, you may check that the list of precedence requirements is as follows.

Activity C

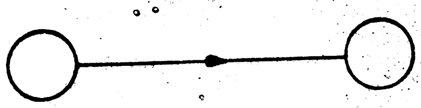
For the example I, verify the following list of predecessors.

Table I

Lst of predecessors for example		Immediate Predecessors
All preceding	-	-
Activities	A	A
C	A	A
D	-	-
E	A,B,D	B, D
F	A,B,C,D,E	C, E
G	A, B, C, D, E, F	F

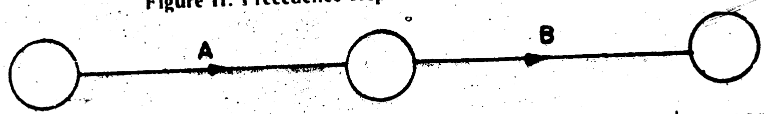
From the list of precedence activities, project network is drawn using arrows. Each activity is represented as an arrow, which is a line with a small circle at each end called node. Figure I represents one such activity.

Figure I: Activity in a Network



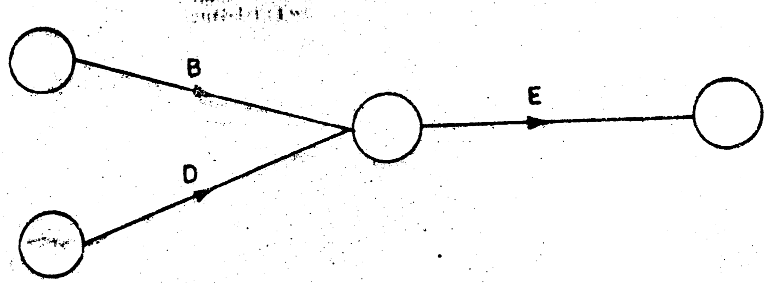
If an activity A precedes another activity B then the end node (circle) of activity A is merged with the start node (circle) of activity B. Thus the following diagram, will represent the precedence requirement A precedes B.

Figure II: Precedence Representation



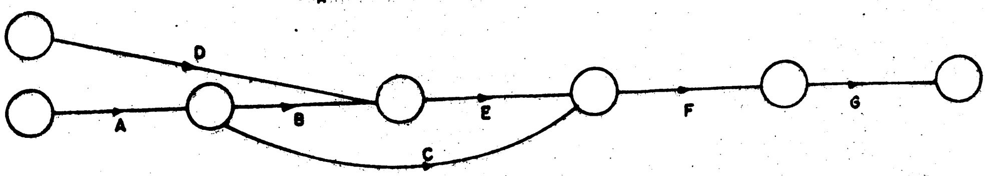
If an activity such as activity E in the project arranging a tea party has more than one predecessor (B, D in this case) the end points of all the predecessors are merged with the start node of this activity. Thus Figure III represents B and D precede E.

Figure III: Two Activities Preceding One Activity



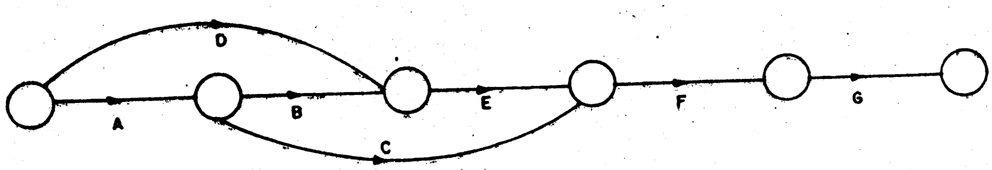
Using the above method the project network for the project arranging a tea party is as in Figure IV.

Figure IV: Network for Preparing Tea



For further convenience, the starting node of all the activities with no predecessors are joined together, as they can be started at the same time. With this modification the network will look like as follows:

Figure V: Correct Network for Preparing Tea



The node (or circles) in the arrow diagram are referred to as event. Events are well defined points in time, at which an activity can be started.

As another example consider a project with following precedence requirement:

Example 2

Activity	Immediate Predecessors
A	—
B	—
C	—
D	C
E	A,B
F	E,D
G	D
H	F,G

Activity D
Try to draw a network for the example 2.

While you will be able to draw the diagram upto the activity F without any problem (Figure VI), you will find difficulty in correctly showing G, which has only D as its predecessor. Representation in Figure VII is not correct, as in it both D and E are required to precede G while it can start as soon as D is completed.

Figure VI: Partial Network for Example 2

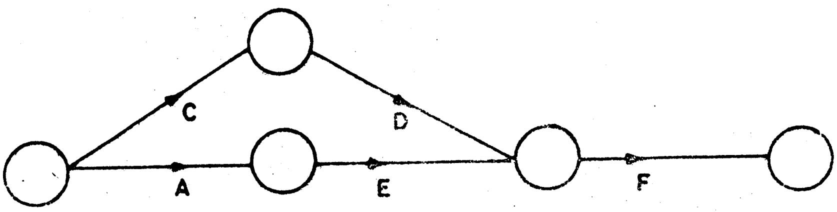
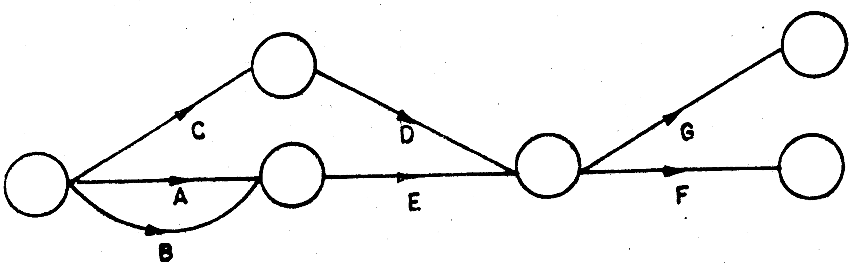
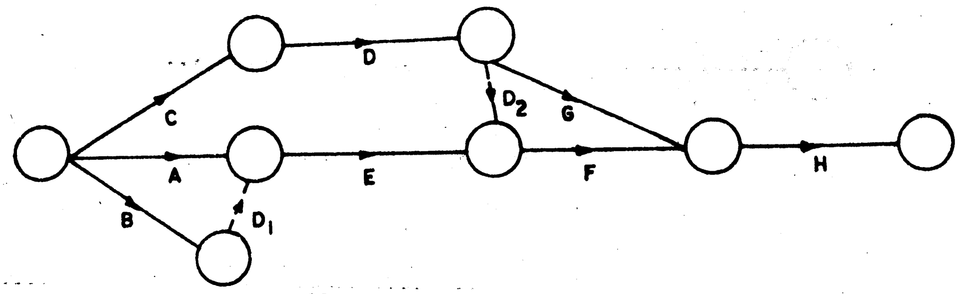


Figure VII: Incorrect Precedence Representation for Example 2



The correct representation is shown in Figure VIII.

Figure VIII: Correct Network for Example 2



The dotted arrows are called dummy activities and are activities which take zero time. Thus the activity F can be started only when both D and E are completed but G can be started as soon as D is completed. In addition another dummy is added after activity B. The purpose here is to make sure that one pair of events connects only one activity.

Thus in project network dummy activities are added to:

1 Ensure correct precedence relationship.

2 Make sure that two events are joined at most by one arrow.

Node Labelling

Once the network is drawn, it is a good practice to label the events systematically. A standard procedure is as follows:

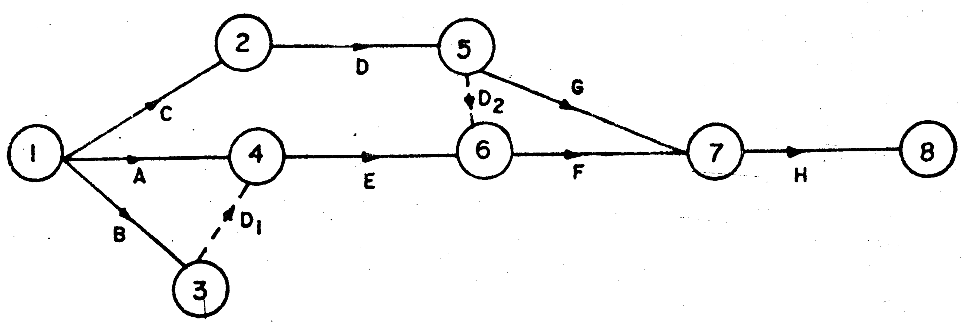
1 A start event is the one which has arrows emerging from it but none entering into it. Find the start event and number it 1.

2 Delete all the arrows emerging from all numbered events. This will create at least one new start event out of the remaining events.

3 Number the new start events as 2, 3 and so on.

4 Repeat steps 2 and 3 until end event is reached. Consider the diagram in Figure VIII. The above procedure will lead to the following node numbering.

Figure IX: Node Numbers for the Network for Example 2



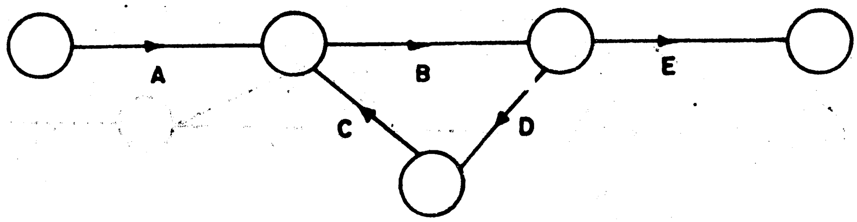
Activity E

Number the nodes of the Figure V.

Activity F

Consider the network shown in Figure X. Try to number the node as per procedure. You will find that step 2 canot be carried out. This impoies that the precedence relationship is not correct. Look at the precedence requirement of activity B, C, D. Do you see any inconsistency?

Figure X: Network for Activity 2



12.4 TIME MANAGEMENT OF THE PROJECT

One of the major requirements of the project management is a feasible time-scheduling of the various activities with the objective that project is completed at the earliest possible time. Feasibility of time-schedule will require that an activity be scheduled only when all its predecessors are scheduled. For preparation of such a schedule, information will be needed about the duration in which the various activities can be completed. The duration of each activity is referred to as activity time. Depending on the nature of the activity times, the projects will get classified in two categories:

1 Projects in which activity times can be estimated with sufficient certainty, for example—building a house, or erecting a plant.
2 Project in which there is high degree of uncertainty about the activity times. For example—launching a space vehicle, developing a new product, etc.

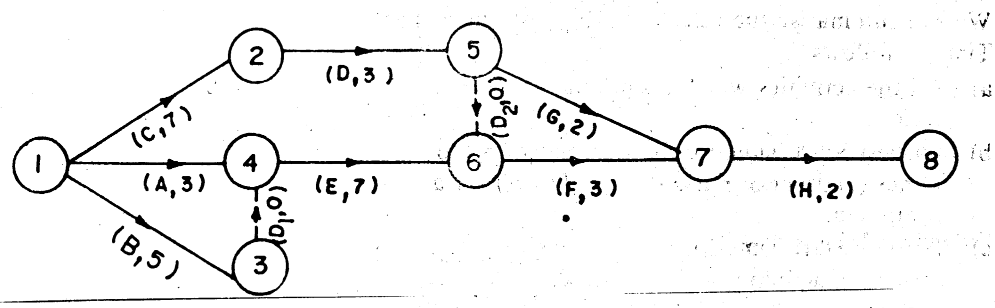
Time Management of the project is the first case is usually done by using Critical Path Method (CPM) and in the second case using Programme Evaluation and Review Techniques (PERT).

Activity G
Consider a simple activity like preparing tea. Estimate activity time for this activity, clearly writy down the method which you have used for arriving at this estimate.
Repeat this for following activities:
a) Changing puncturd wheel of a scooter.
b) Getting a cheque encashed from the Bank.
c) Completing this exercise (befor completing it).
d) Travelling from youf home to office.
e) Preparing a report for your boss.
f) Travelling from your home to a new place (Which you have not visited before.)
Summarise various method which can be used to arrive at the activitv times.

12.5 CRITICAL PATH METHOD *(CPM)*

In this method it is assumed that activity durations are deterministic or are known with certainty. The method will compute the earliest possible start time and latest possible start time for each activity. In addition it will identify the critical activities. These activities are critical in the sense that if completion of any of these activities is delayed even by a short period of time, the whole project will be delayed. For other activities, slacks (floats) will be computed which will give some idea of the relative importance of these activities in terms of their time-management. To illustrate the computations at various times we will discuss the example 2 whose network representation with node number is shown in Figure XI.

Figure XI: Network with Activity Times for Example 2



Let the activity times of activities A, B, C, D, E, F, G, H be 3, 5, 7, 3, 7, 3, 2, 2 weeks respectively.

Figure XI shows the project network with activity times. In this Figure (C,7) on the arrow 1,2 indicates the activity name C and its duration as 7 weeks.

Computations of Early Start and Early Finish Times for the Activities

Once the network is developed and the activity times are compiled, we wish to compute the earliest time by which an activity can be started. For any activity (j) we shall refer this time as ES(j). Let the activity time for the activity j be denoted by T(j). In example 2 activity A, B, C can begin at time zero. Hence we can assign ES(A)=0, ES(B)=0, ES(C)=0. You may note that all the three activities can start at the same time, Earliest time by which an activity (j) can be completed will be denoted by Earliest Finish Time, EF(j). As the activity time for activity (j) is T(j) then, its Earliest Finish Time EF(j) is,

Thus,

$$
\begin{aligned}
EF(j) &= ES(j) + T(j)\\
EF(A) &= 0 + 3 = 3\\
EF(B) &= 0 + 5 = 5\\
EF(C) &= 0 + 7 = 7
\end{aligned}
$$

Activity D can be started only when activity C is finished, while activity E can be started only if both the activities A and D_1 are finished. We can compute the times associated with these activities as follows:

$ES(D) = EF(C) = 7 \quad EF(D) = ES(D) + T(D) = 7+3 = 10$

$ES(D_1) = EF(B) = 5 \quad EF(D_1) = ES(D_1)+T(D_1) = 5+0 = 5$

$ES(E) = \text{maximum}(EF(A), EF(D_1)) = \text{maximum}(3,5) = 5$

$EF(E) = ES(E) + T(E) = 5+7 = 12.$

Similarly,

$ES(G) = EF(D) = 10 \quad EF(G) = 10+2 = 12$

$ES(D_2) = EF(D) = 10 \quad EF(D_2) = 10+0 = 10$

$ES(F) = \max(EF(D_2), EF(E)) = \max(12,10) = 12,$

$EF(F) = 12+3 = 15$

$ES(H) = \max(EF(G), EF(F)) = \max(15,12) = 15. \quad EF(H) = 15+2 = 17$

ES (H) = max EF (G), EF (F) = max (15.12) = 15, EF (H) = 15 +2 = 17.

Thus the activity H will be completed on the 17th week and hence the project can be completed by the 17th week from its start.

You may note that while all the activities together require 32 weeks but they can be completed in 17 weeks as some of them can be completed simultaneously. However, as the precedence relationship require certain activities to run sequentially, the project cannot be completed before 17th week.

We can summarise the rules for computations of Early Start Time and Early Finish Time as follows:

a) All the activities which do not have any preceding activity can be started at time zero.

b) Earliest Start Time for an activity can be computed only if the Earliest Finish Times (and hence Earliest Start Times) for all its preceding activities are computed.

c) Earliest Start Time for an activity (j) is the earliest time by which all its preceding activities are completed,

ES (j) = largest finish time among all its preceding activities

= maximum {EF (i)} over all preceding activities i

Critical Path

A path in a network is a sequence of activities which have to be completed sequentially due to precedence requirements. Thus C, D, F, H is a path and so are (A, E, F, H), (B, D, E, F, H), (C, D, D$_2$, F, H). Time duration of the path is the sum of the activity times of the activities forming the path. The path or paths with the largest time duration in the network is (are) called critical path(s). All the activities on the critical path(s) are called critical activities. The earliest time by which a project can be completed is the time duration of the critical path(s). If an activity on the critical path is delayed the whole project will get delayed. Thus for timely completion of the project it is essential that all critical activities be started at the earliest start time and be completed in the planned duration.

For each of the paths mentioned above, compute its length. Which are the critical paths?

Activity I

Consider the example 2 again with difference that the activity time of activity G is changed to 3 weeks and of D to 5 weeks. Recompute the length of each path. How many paths are cricical?

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A method of computing critical path(s) can be to enumerate all the paths in a network and to compute the time duration of eacn of these paths and then to select the path(s) with largest time duration. However, in a large network such enumeration will take large amounts of computation time even on very fast computers. Another mechanism will be to identify those activities which are critical. This can be done by finding the Latest Start Time for each activity. This is the time by which if the activity is started, the project will be completed in time. For critical activities Latest Start Time and Earliest Start Time will be identical.

Computations of Latest Start Time and Latest Finish Time of Activities

Latest Start Time of an activity j, LS(j) is the time by which, if it is started the project will get completed in time. Any delay beyond this time in the starting of the activity or in its execution will delay the completion of the project. In our example, if the project has to be completed by 17th week, the activity H has to be finished by 17th week. Hence if the latest finish time of the activity H, LF(H), is 17 weeks,

$$LF\ (H) = 17$$

and $LS\ (H) = 17 - T\ (H) = 17 - 2 = 15$

It may be noted that for activity H :

$$ES\ (H) = LS\ (H) = 15$$

However, activity G can be completed by 15th week, without delaying the project as in that case H can still be started on the 15th week and completed by 17th week.

Hence, $LF\ (G) = LS(H) = 15 \quad LS\ (G) = 15-2 = 13$

While for the activity G ES(G) is 10, LS(G) is 13 weeks. Thus it is possible to delay the start of G upto 13th week without delaying the project completion.

Similarly,

$$LF\ (F) = 15 \quad LS\ (F) = 15-3 = 12 \quad LF\ (D_2) = LS\ (F) = 12$$
$$LS\ (D_2) = 12-0 = 12$$
$$LF\ (E) = LS\ (F) = 12 \quad LS\ (E) = 12-7 = 5$$

However, latest point in time by which the activity D should be completed is the point in time such that both D_2 (hence F) and G can be started by their Latest Start Time.

Thus $LF\ (D) = \text{minimum}\ \{LS\ (D_2),\ LS\ (G)\} = \{13, 12\} = 12.$

$$LS\ (D) = 12-3 = 9$$

If D is not completed by 12th week, F has to be started later than its Latest Start Time resulting in the project delay.

Similarly,
$$LF\ (C) = LS\ (D) = 9 \qquad LS\ (C) = 9-7 = 2$$
$$LF\ (A) = LS\ (E) = 5 \qquad LS\ (A) = 5-3 = 2$$
$$LF\ (D_1) = LS\ (E) = 5 \qquad LS\ (D_1) = 5-0 = 5$$

The table gives the ES, LS, EF, LF for all the activities. In the fifth column, the difference between LS and ES is listed as **slack.**

Table 2
Computations of Activity Times

Activity	Activity Duration	ES	EF	LS	LF	S
A	3	0	3	2	5	2
B	5	0	5	0	5	0
C	7	0	7	2	9	2
D	3	7	10	9	12	2
E	7	5	12	5	12	0
F	3	12	15	12	15	0
G	2	10	12	13	15	3
H	2	15	17	15	17	0
D_1	0	5	5	5	5	0
D_2	0	10	10	12	12	2

The activities B,G,E,F,H are critical and will form the critical path. We can summarise the procedure for the computation of latest start and latest finish time for the activities as follows:

a) All the activities without any successor are required to be completed by the time project is completed and hence for all these activities

$$LF(j) = \text{Project completion time}$$
$$LS(j) = LF(j) - T(j)$$

b) The latest an activity can be completed without delaying the project is the time such that all its succeeding activities can be started latest by their latest start time

$$LF(j) = \underset{\text{overall successor } i}{\text{maximum}} \{LS(i)\}$$

and $LS(j) = LF(j) - T(j)$

c) Latest Start Time for an activity can be computed only if the Latest Start Times of all its successor have been computed.

In all we have observed that all activities, for which Early Start Time and Latest Start Time are same or which have zero slack, are critical activities and the path(s) formed by these activities will be the critical path(s).

Slack (Float)

In the computation of the activity times, we observed that slack or total float in an activity is the difference between its Latest Start Time and its Earliest Start Time. It signifies the delay which is permitted in the completion time of that activity without affecting the project completion. The delay can be either due to delay in completion of its preceding activities or in the execution of this activity itself. You may note that while both the activities C and D have slack of 2 days each, both of them cannot be delayed simultaneously. If C is completed 1 week late i.e. on 8th week then slack available on D will be only one week. In some cases it may be useful to compute free slack (float) which is the slack available in an activity such that early start of the successors are not affected. In other words, free slack is the delay which, if occurs, will not effect the early start of the successors. By this definition, the free slacks for the various activities for the example 2 are as follows:

$$\text{Free slack (C)} = ES(D) - EF(C) = 7 - 7 = 0$$

$$\text{Free slack (D)} = \begin{bmatrix} ES(D_2) - EF(D) \\ \\ ES(G) - EF(D) \end{bmatrix} = \begin{bmatrix} 10 - 10 \\ \\ 10 - 10 \end{bmatrix} = 0$$

$$\text{Free slack (G)} = ES(H) - EF(D) = 15 - 12 = 3$$

$$\text{Free slack (A)} = ES(E) - EF(A) = 5 - 3 = 2$$

On other activities free slack will be zero. Why ?

The total slack and free slack can be effectively used for better management of projects. For example, if there is a resource constraint then it will be better to

12.6 PROGRAMME EVALUATION AND REVIEW TECHNIQUE *(PERT)*

Critical Path Method (CPM) is an effective tool for project planning and control when activity times are known with certainty. However, in certain projects like Research and Development projects, it seems unrealistic to assume that we can know with certainty the time durations in which the activities can be completed. In such cases PERT can be used.

Time Estimates in PERT

In PERT for each activity, three time estimates are made. These estimates are:

a) Most Likely Time (TM): The time which is taken most frequently by the activity.

b) Optimistic Time (TO): The time by which activity can be completed, if everything went well.

c) Pessimistic Time (TP): The time by which the activity will get completed even under adverse conditions

Activity J

For the activity, 'prepare a report for the boss' estimate the three times. The TO will be the time under most favourable conditions, i.e. when all data is available, report is short etc., while TP will be the time under most adverse conditions, i.e. when data has to be compiled and reports is a long report. TM will be the time which is taken by most of the reports.

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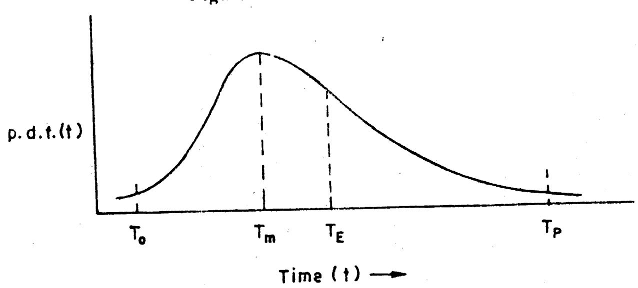
From the above time estimates expected time of the activity (j), TE(j), is computed using following relationship:

$$TE(j) = \frac{TO(j) + 4TM(j) + TP(j)}{6}$$

The expected time for an activity represents the average time it would take if the activity is performed over and over again. It is different from most likely time. The above relationship is based on the fact that the probability distribution function of the activity time can be approximated by a Beta distribution which is of the shape shown in Figure XII.

Figure XII: Beta Distribution



Further, consider two distributions with the following activity times,

	Activity A	Activity B
TO	3	2
TM	5	.4
TP	7	12

Both the activities have same expected time of 5 weeks but there is a higher degree of uncertainty associated with Activity B. This variability can be measured by computing the standard deviation of the activity, SD(i), as

$$SD(i) = \frac{TP(i) - TO(i)}{6}, \text{ thus, } SD(A) = \frac{7-3}{6} = 4/6$$

$$SD(B) = \frac{12-2}{6} = 10/6$$

Variance is defined as the square of the standard deviation and hence

$$V(i) = [SD(i)]^2 = \left[\frac{TP(i) - TO(i)}{6}\right]^2$$

For the example 2 the three time estimates, expected time and the variance of the activities are given in the Table 3.

Table 3
Estimates of the Activity Times

Activity	TO	TM	TP	TE	SD	V
A	1	2	9	3	4/3	16/9
B	2	4	12	5	5/3	25/9
C	4	6	14	7	5/3	25/9
D	1	3	5	3	2/3	4/9
E	1	8	9	7	8/3	64/9
F	2	3	4	3	2/3	4/9
G	1	2	3	2	1/3	1/9
H	1	2	3	2	1/3	1/9

Time of the Project Completion

Unlike CPM, in the case when there is uncertainty in activity times, it is not possible to compute the time of completion of the project with certainty. Instead, we shall estimate the expected time and variance of the project completion time. The expected project completion time E(T), can be computed as the length of critical path in the CPM, when activity times are replaced by the expected times (TE) of the activities. As in the case of example 2, TE are same as the activity time in Figure XII, the expected time of the completion of the project is 17 weeks. Further a crude estimate of the variance of the completion time can be obtained by adding the variances of the activities on the critical path.

Thus V (completion time) = Sum of variances of the activities on the critical path

$$= V(B) + V(E) + V(F) + V(H)$$

$$= \frac{25}{9} + \frac{64}{9} + \frac{4}{9} + \frac{1}{9} = \frac{94}{9} = 10.44$$

$$SD\ (\text{Completion time}) = \sqrt{V} = \sqrt{10.44} = 3.23$$

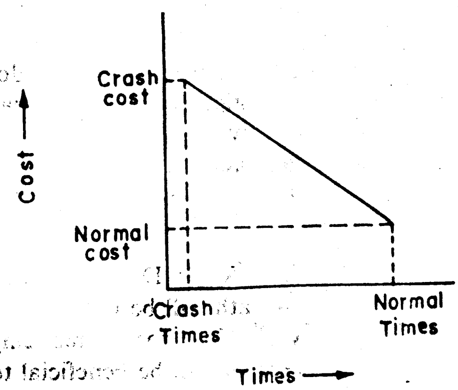
Probability estimates of the completion time of the project can be made using the fact that the project completion time has normal probability distribution with mean as expected completion time and Variance as variance of the Critical Path.

Further analysis of the network can be done using Simulation from which an estimate of the probability that an activity will become critical can be obtained. This is called critical index of the activity.

12.7 TIME COST RELATIONSHIP AND PROJECT CRASHING

In addition to time-management, cost plays an important role in any project. The project costs can be classified in two groups: direct activity costs and indirect project costs. Direct activity costs are those components of the cost which can be directly linked with the activity. Thus direct labour, material consumed, rental charges for the equipment etc. will form part of these costs. Usually, the activity durations can be reduced by increasing the direct activity cost. For example, by asking the labour to work with OT or with efficiency bonus for faster work etc.

Figure XIII: Times Cost Relationship for an Activity



Crash time is the minimum possible time in which the activity can be completed and the cost associated with this time is the crash cost. Normal cost is the cost incurred when activity is completed in its normal time (or the time used as activity time in the critical path computations).

On the other hand, **indirect costs** are the overheads associated with the entire project including loss of revenue/benefits due to late completion of the project. This cost will decrease directly with the decrease in the project completion time. An **optimal** project completion time will be the time for which sum of these two costs is minimum. To obtain the optimal time, we have to compute direct activities cost when project duration is reduced by one unit time each time. This is called project crasing. We shall explain the project crashing by the following simple example.

Example 3

Let the information regarding project be summarised in Table 4.

Table 4
Data for Example 3

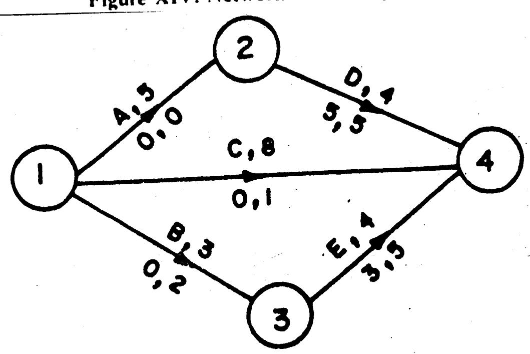
Activity	Preceding activities	Normal time (week)	Crash time (week)	Normal Cost (Rs.)	Crash Cost Rs.
A	—	5	4	600	800
B	—	3	1	400	600
C	—	8	5	900	1200
D	A	4	2	600	1200
E	B	4	3	500	700

We shall assume that cost of crashing an activity by 1 week

$$= \frac{\text{Crash cost} - \text{Normal cost}}{\text{Normal time} - \text{Crash time}}$$

The project network is shown in Figure XIV.

Figure XIV: Network for Example 3

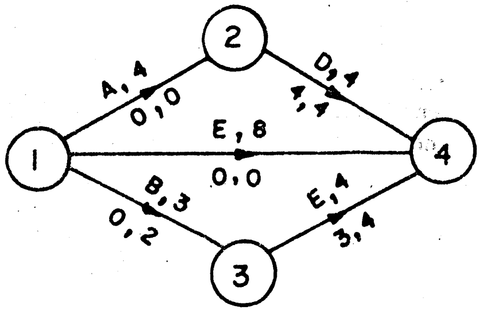


In Figure XIV, E,4/3,5 denote Activity E, T(E) = 4
ES(E) = 3 LS(E) = 5. For this example project completion time T is 9 weeks and the direct activity cost is Rs. 3000 (600+400+900+600+500).

If the project completion time is to be reduced by 1 week, it can be done only by reducing the activity duration of one of the activities on the critical path. If there are more than one critical parts then at least one activity on each path has to be crashed. You may note that reducing activity time of any activity other than critical activities will not reduce the length of critical path and hence the project duration cannot be reduced.

In our example critical path consists of activities A and D. If the duration of either A or D is reduced by 1 week the length of this path will be reduced to 8 weeks and hence project duration will be reduced to 8 weeks. The cost of reducing the activity A by 1 week is Rs. 200 and of D Rs. 300 and hence it will be beneficial to crash activity A by 1 week. So for T=8, direct activity cost is Rs. 3200 (3000+200). Further the new project network is shown in Figure XV.

Figure XV: Network for Example 3 with Crashing



Both the paths A-D, and C are critical in this network. To reduce the project duration further, at least one activity on each of the critical paths has to be reduced. It implies that activity C with either activity A or activity D has to be crashed. However, it is not possible to crash activity A as already it is being done in its crash time and no further reduction is possible. Hence, we can reduce the project duration by 1 week by crashing C and D, which will cost Rs. 400. We can repeat this process for further reduction in the project duration. We can summarise the method for reducing the project completion time as follows:

Step 1: Compute for each activity

Cost of reducing activity time by one unit time

$$= \frac{\text{Crash cost} - \text{Normal cost}}{\text{Normal time} - \text{Crash time}}$$

Step 2: Identify all the critical paths. Select one activity on each critical path (same activity can be on more than one critical paths) such that the total cost of crashing all these activities by one unit time is minimum among all such combinations of the activities. Further the activities selected should be such that their current activity time is higher than the crash time, i.e. no activity reduction in activity duration can take place beyond its crash time. If there is at least one critical path, on which none of the activities can be crashed, then no further reduction in the project completion time can take place. In that case stop.

Step 3: Reduce the activity time for the activities selected for crashing by unit time period and recompute the Early Start Time, Late Start Time and critical paths for the network.

Step 4: Repeat Step 1 to Step 3.

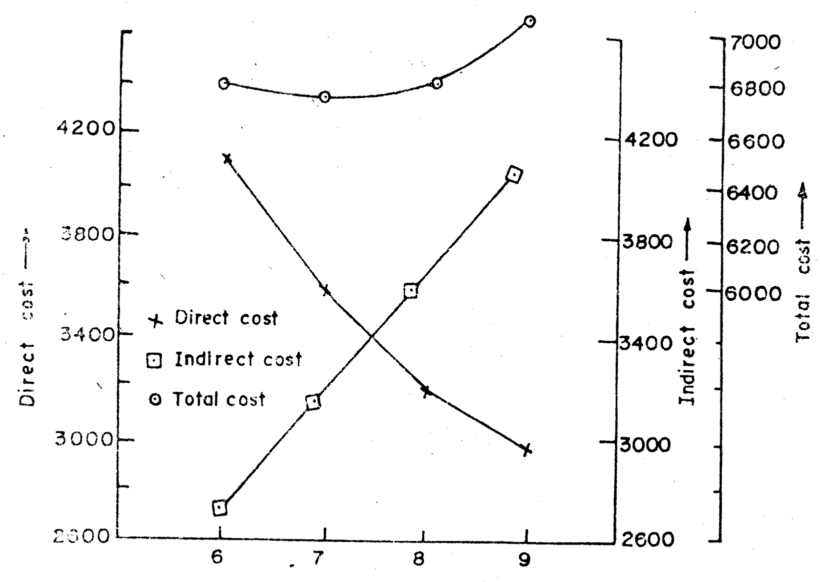
Using the above method the computation for the example 3 are as follows:

Table 5
Project Crashing

Current Project Completion time	Critical Path(s)	Activities which can be crashed	Cost of crashing	Activities selected	Cost	Total Cost	Time
9	A-D	A,D	200,300	A	200	3200	8
8	A-D	D	300	D	300		
	C	C	100	C	100	3600	7
7	A-D	D	300	D	300		
	C	C	100	C	100	4100	6
	B-E	B,E	100,200	B	100		
6	A-D	—	—	—	cannot be crashed		
	C	C	100				
	B-E	B,E	100,200				

The direct project cost curve is given in Figure XVI. If the indirect project costs are Rs. 450 per week, then the optimal project duration will be 7 weeks.

Figure XVI: Project Time-cost Relationship



12.8 RESOURCE ALLOCATION

The analysis up to this point has been based on the assumption that if its predecessors were completed, an activity could begin. Underlying this assumption is the fact that sufficient resources will be available to start activities simultaneously.

However, in actual practice some of the resources may be available in limited quantities. Examples of such resources are expensive equipment, skilled manpower, finances etc. For example, let each of the activities A, B, C, D, E in the example 3 require 2 carpenters and let there be only 4 carpenters available. It is obvious that activities A, B, C cannot be started at 0 time period as, they will require 6 carpenters. In fact, only 2 of these activities can be selected. Third activity can be started only when one of these two will get completed. Depending on which two activities are selected, project completion time will change. An efficient manager will like to apportion resources in such a way that increase in project duration is as low as possible. Many heuristic methods (simple rules) have been developed for such resource allocation problems. While such method cannot guarantee that the solution obtained is best possible, they usually provide good solutions. A simple heuristic rule will be as follows:

Step 1: Allocate resources serially in time. That is, start on the first time period and schedule all activities possible with the resources available, then do the same for the second time period and so on.

Step 2: When several activities compete for the same resources, give preference to the activities with the least slack. Recompute the slacks in all the activities.

Step 3: Reschedule non-critical activities, if possible, to free resources for scheduling critical or non-slack activities.

The computation for Example 3 are shown in Table 6. This project will get completed in 12 weeks instead of 9 weeks as scheduled earlier.

Table 6
Resource Allocation

Week	Activities which can be scheduled	Activity time	slack	Carpenter needed	Carpenters allocated	
0	A	5	0	2	2	
	C	8	1	2	2	
	B	3	2	2	—	
1	A	4	0	2	2	
	C	7	1	2	2	
	B	3	1	2	—	
2	A	3	0	2	2	
	C	6	1	2	—	(reschedule)
	B	3	0	2	2	
3	A	2	0	2	2	
	C	6	0	2	2	
	B	2	0	2	2	
4	A	1	1	2	2	T = 10
	C	6	0	2	2	
	B	1	1	2	—	(reschedule)
5	D	4	1	2	—	
	C	5	0	2	2	
	B	1	0	2	2	
6	D	4	0	2	2	
	C	4	0	2	2	
	E	4	0	2	—	
7	D	3	1	2	2	(T = 11
	C	3	1	2	—	(reschedule)
	E	4	0	2	2	
8	D	2	1	2	—	(reschedule)
	C	3	0	2	2	
	E	3	0	2	2	

9	D	2	0	2	2	
	C	2	0	2	2	
	E	2	0	2	—	(reschedule)
10	D	1	1	2	2	
	C	1	1	2	—	(reschedule)
	E	2	0	2	2 T = 12	
11	C	1	0	2	2	
	E	1	0	2	2	

12.9 PROJECT UPDATING AND MONITORING

For effective use of the above techniques it is essential that project progress should be continuously monitored. As and when there is a change in time schedule of any activity, the project network should be updated and new time schedule finalised.

Now a days with most of the computers, including PCs, well written CPM/PERT packages including project crashing and resource allocation are available. These packages will provide all the necessary information needed for efficient project management.

12.10 SUMMARY

Projects are non-repetitive large tasks. A systematic way of describing a project is through identification of activities and their inter-relationships. These inter-relationships can be visualised using arrow diagrams or networks. Project management deals with time-scheduling and resource allocation for these activities. If the activity times are deterministic then Critical Path Method can be used as a systematic method to compute early start and late start times of activities and to identify critical activities. The slacks associated with each activity can be used for better control of the project. When activity times are probabilistic, PERT is an effective tool. In this method three time estimates are made for each activity and these are used to compute expected project completion time and its variance. Project duration can be reduced by incurring additional cost in executing activities. A project cost-time relationship can be obtained using Project crashing. This can also be used to obtain the optimal project duration. Resource allocation is one of the major problems in project management. A simple heuristic is suggested to handle this problem.

12.11 KEY WORDS

Projects: Set of activities which are inter-related with each other and are to be organised for a common goal or objective.

Activity: Physical independent action which requires time for its completion and will consume one or more of the resources.

Event: Point in time schedule at which an activity can be started (or is finished).

Activity Time: Physical time required to complete an activity.

Immediate Predecessor: An activity which should immediately precede the given activity in any feasible time schedule.

Project Network: A visual representation of the interdependence between different activities of a project.

Earliest Start Time: The earliest time at which an activity can begin. All the activities preceding the given activity should be completed by this time.

Latest Start Time: The latest time by which the activity can be started without delaying the project completion time.

Earliest Finish Time: The earliest time by which an activity can be finished.

Latest Finish Time: The latest time by which an activity can be completed.

Total Slack (float): The length of time up to which an activity can be delayed without affecting the start of the succeeding activities.

Free Slack (float): The length of time up to which an activity can be delayed without affecting the starts of the succeeding activities.

Critical Path: The longest sequence of activities on path in the project network. The time it takes to traverse this path is the estimated project completion time.

Critical Activities: Activities on critical path. Any delay in execution or start of these activities will delay the whole project.

CPM: Project management technique used when activity times are deterministic.

PERT: Project management technique used when activity times are probabilistic.

Optimistic Time: Time by which an activity can be completed, if everything goes well with it.

Pessimistic Time: Time by which an activity will get completed under adverse conditions.

Most Likely Time: Most frequently occurring time for an activity.

Expected Activity Time: The average activity time.

Variance: Measure of the deviation of the time distribution for an activity.

Crashing: The process of reducing an activity time by adding resources and hence usually increasing cost.

Normal Cost: Cost associated with an activity when it is completed in normal time.

Crash Cost: Cost associated with an activity when it is completed in the minimum possible time (crash time).

Resource Allocation Methods: Allocation of resources to the activities such that project completion time is as small as possible.

Updating: Revision of the project schedule after partial completion with revised information.

12.12 SELF-ASSESSMENT EXERCISES

1 Under what circumstances would you use PERT as opposed to CPM in project management? Give some example of projects where each would be more applicable than the other.

2 What do you understand by slack? Construct an example and show how you can use the knowledge of slacks for better project management.

3 Identify the information needed for the project crashing. For a project with which you are familiar, try to identify the various items of information. Criticise the various assumptions made in the crashing method.

4 Draw the complete CPM network according to the following table:

Activity	Starts at Event	End at Event
1–2	1	2
1–3	1	3
1–4	1	4
2–3	2	3
2–4	2	4
3–4	3	4

5 Draw the following logic network:
Activities C and D both follow A
Activity E follows C
Activity F follows D
E and F precedes B.

6 In putting a job together to run at a data-processing centre, certain steps need to be taken. These jobs can be described as follows:

Job	Time (minutes)	Immediate predecessors	Description
A	180	—	Design flow chart and write FORTRAN statements
B	30	A	Punch control cards
C	20	A	Punch comment cards
D	60	A	Punch programme cards
E	10	B,C,D	obtain brown folder
F	20	B,C,D	Put deck together
G	10	E,F	Submit deck

a) Draw a critical-path scheduling diagram and indicate the critical path. What is the minimum time to completion?

b) What is the free slack of job C?

c) Assuming the table accurately represents the jobs to be done and their times, if you were performing this project, would the minimum time to completion obtain above be the minimum time for you to complete the project. If yes, what conditions would change your answer? If no, why not, and what would the correct time be?

7 The following table lists a set of nine activities together with their sequence requirements, estimated activity times, and the daily number of men required for each activity. These nine activities make up a complete project.

Activity Code	Code of Immediate Predecessor	Time Required (days)	Men Required per day
A	—	10	3
B	—	8	4
C	—	5	7
D	A	6	5
E	B	4	2
F	C	10	4
G	F	4	3
H	F	8	3
I	D, E,G	7	3

UNIT 13 MAINTENANCE MANAGEMENT

Objectives

Upon completion of this unit, you should be able to:

- relate the importance and objectives of maintenance management
- understand the pattern in which failures and breakdowns take place
- realise existence of different systems of maintenance
- realise the need for letting unplanned emergency maintenance remaining an 'exception rather than a rule'
- comprehend that the efforts involved in maintenance planning and control are worth it, even though this calls for greater amount of record keeping and subsequent analysis
- realise that formal costing and budgeting would encourage prediction and preplanning of maintenance activities
- identify the need for some control indices for improving the maintenance service of an organisation.

Structure

13.1 INTRODUCTION TO MAINTENANCE MANAGEMENT

Since time immemorial when man used primitive tools and machines to carry his loads, to draw his water, to till his land and to fabricate his building materials, he has been faced with the prospect of maintaining these assets until such time as he considered their useful life to be ended. Maintenance is very important to extend the useful life of an asset. It is quite a challenge. In our country, there is no dearth of manpower but rather scarce limited capital to spend for capital equipment. Some studies have shown equipment utilisation to be as low as 30% in quite a few cases. Proper maintenance management could improve existing capacity utilisation rather than going in for additional capacities to meet the ever increasing demand of a large number of products and or services. In industry maintenance function is usually given a low status and considered to be a third rate job; this is rather unfortunate. The function of carrying out maintenance is such an obvious necessity that the subject has been taken for granted over the centuries without much thought being given to its importance in our everyday lives.

Maintenance is usually viewed only as a repair function. It is, however, "a combination of any actions carried out to retain an item in, or restore it to, an acceptance condition". In fact maintenance keeps or ensures that the entire production system is kept reliable, productive and efficient. All departments of a production system may have been designed beautifully without giving due consideration to maintenance management. The end result is obvious. Organisations like the National Productivity Council and others are playing a vital role in propagating the importance of Maintenance Management of all the assets of the organisation. In fact, all organisations must be having some assets, and hence the need for proper maintenance and 'physical assets management' which is synonymous with the word 'Tero-technology' which we shall discuss now.

13.2 TERO-TECHNOLOGY

The concept of tero-technology grew from the study of maintenance practices. It is synonymous with total maintenance. It takes into account all aspects of plant machinery from **Design to Discard,** viz. design, manufacture, installation, commissioning, maintenance, replacement and removal of the plant/equipment plus the feedback of performance for the equipment manufacturer. Tero-technology envisages application of a combination of managerial, financial, engineering and other practices applied to physical assets in pursuit of economic life-cycle costs. It is concerned with the specification and design for reliability and maintainability of plant, machinery, equipment, buildings and structures. This total life-cycle concept enables a proper equipment evaluation and selection so as to give an overall low life cycle concept. This gives rise to huge potential for savings in terms of cost effectiveness of replacements on considerations of the whole life-cycle. 'Design audit' consists of carrying out critical scrutiny of the designs by the operating and maintenance engineers independent of the design process so as to ensure reliability and maintainability of plant and machinery and to identify weaknesses in designs requiring modifications. The word 'tero-technology', itself stems from the Greek root 'terein'—'to look after', 'to guard over', 'to take care of'. In fact the principles of tero-technology as discussed above can be applied, to a greater or lesser extent, to any physical asset in any organisation, no matter what the size or degree of complexity of either asset or organisation.

13.3 OBJECTIVES OF MAINTENANCE

Very loosely, some define maintenance as any work undertaken by a maintenance worker. In manufacturing organisations, the term 'works engineering' has been commonly used to embrace installation, commissioning, maintenance, replacement and removal of plant, machinery etc. However, when considering service organisations, municipalities and the armed services, the term is seldom encountered. Fortunately, the term 'tero-technology' covers all these situations, though it would take yet some time for an universal acceptance of a term like 'tero-technology manager'. However, the manager of the maintenance function whether the job title is estates manager, works manager, chief engineer, plant engineer, building manager, maintenance manager—is attracting greater attention then ever before.

The principal objectives of maintenance activity are as follows:

a) To maximise the availability and reliability of all assets, especially plant equipment and machinery, and obtain the maximum possible return on

a) Use this information to develop a network diagram.
b) Determine the earliest start (ES), earliest finish (EF), latest start (LS), and latest finish (LF) times for each activity.
c) List the activities on the critical path.
d) What is the earliest finish time of the project without resource constraints (assuming that we have an unlimited number of men)?
e) Assume that we have only 11 men available but that each man is completely interchangeable. That is, any man can do any task. Also assume that the activities much use exactly the number of men and days specified. For example, you cannot use twice the manpower and complete the activity in one-half the time. Now determine (if possible) a schedule of activity starting times that will allow these 11 men to complete the project by the earliest finish date. If this is not possible, show a schedule that will finish the project as soon as possible with 11 men. (Start with day 1, not day 0).

12.13 FURTHER READINGS

Bhatnagar, S.K., 1986. *Network Analysis Technique,* Wiley Eastern Limited: New Delhi.

Moder, J.J., C.R. Phillips, and E.W. Davis, 1983. *Project Management with CPM and PERT,* 3rd ed. Van Nostrand Reinhold: New York.

Wiest, J.D. & F.K. Levy, 1978. *Management Guide to PERT/CPM with GERT/PDM/DCPM and other Networks.* Prentice Hall of India: New Delhi.

where T_{up} = the cumulative time of operation in the normal working state and T_{down} = the cumulative downtime.

13.5 TYPES OF MAINTENANCE SYSTEMS

Maintenance work can be either planned or unplanned. Let us now discuss the different types of maintenance systems.

Emergency Maintenance: An unplanned maintenance which is necessary to put in hand immediately to avoid serious consequences, for instance loss of production, extensive damage to assets or for safety reasons. Emergencies should remain exceptions rather than the rule. To ensure such a possibility, it is better to have planned maintenance systems.

Planned Maintenance: Maintenance organised and carried out with forethought, control and records to a predetermined plan. Planned maintenance can be split up into essentially two main activities namely preventive and corrective.

Preventive Maintenance: Also termed 'Diagnostic or Predictive Maintenance' is maintenance carried out at pre determined intervals, or to other prescribed criteria and is intended to reduce the likelihood of an equipment's condition falling below a required level of acceptability. You try to anticipate failure and then attempt to prevent its occurrence by taking preventive actions. The proverbial saying 'prevention is better than cure' or 'A stitch in time saves nine' is the basic philosophy of Preventive Maintenance. Preventive maintenance can be done on machines either when running or during shutdown.

Running Maintenance: Maintenance which can be carried out when the item is in service.

Shutdown Maintenance: Maintenance which can only be carried out when the item is out of service. Further preventive maintenance can be time-based or condition-based.

A Time-based Preventive Maintenance: This policy is effective when the failure of any item of an equipment is time dependent (in the third stage of the bath tub failure curve of Figure I) and the item is expected to wear out within the life of the equipment. Moreover the total costs of replacement of the item should be substantially less than those of failure replacement repair.

Condition-based Maintenance is carried out in response to a significant deterioration in unit as indicated by a change in a monitored parameter of the unit condition or performance. It is here that one can make use of predictive maintenance by using a technique called SIGNATURE ANALYSIS which is intended to continually monitor the health of the equipment by recording systematically signals or information derived from the form of mechanical vibrations, noise signals, acoustic and thermal emissions, changes in chemical compositions, smell, pressure, relative displacement and so on. Scientific collection of these informative signals or signatures, diagnosis and detection of the faults, if any, present by a thorough analysis of these signatures based on the knowledge hitherto acquired in the field, and judging the severity of the faults for decision-making, all put together, is called 'Signature Analysis'. The technique [illegible]ves the use o[illegible] electronic instrumentation specially designed for the purpose [illegible] capacities, [illegible]es of application and design features. Vibration and no[illegible]e sign[illegible] [illegible]he most ver[illegible]le parameters in machine condition monitoring techniques. Periodic vibration checks reveal whether troubles are present or impending. Vibration signature analysis reveals which part of the machine is defective and why. Sound or noise analysis is somewhat similar to vibration analysis. A stock pulse meter is used to monitor the condition of roller bearings.

Condition-based maintenance thus reduces injuries and fatal accidents caused by machinery as the conditions of machinery are indicated well before hand. It enables the plant to be stopped safely when instant shutdown is not permissible. Moreover, it permits advanced planning to reduce the effect of impending breakdowns and be in time to have necessary spare parts available. However, condition monitoring is not always used because it involves high manpower and monitoring costs and, furthermore, it is difficult to monitor some parameters.

Corrective Maintenance: Maintenance carried out to restore an item which has ceased to meet an acceptable condition. It involves minor repairs, that may crop up between inspections.

Design-out Maintenance is yet another policy which is practised frequently in developed countries. This is discussed in greater detail later on in this unit. The policy here aims at minimising the effect of failure and at eliminating the cause of maintenance. In essence, an attempt is made to pinpoint the defects in the design of the equipment. Poor design of many an equipment leads to frequent breakdowns. Also an appropriate choice of tribological materials might eliminate the need for subsequent lubrication frequencies.

13.6 MAINTENANCE PLANNING AND CONTROL: PREPARATION

Total maintenance planning embraces all activities necessary to plan, control and record all work done in connection with keeping an installation to the acceptable standard by devising appropriate maintenance systems. In a fully controlled situation, the time spent on emergency work, viz. the 'unplanned' portion, could well be less than ten per cent of the available man-hours in the maintenance department. The administrative control of maintenance work is very significantly altered when changing from emergency maintenance methods to a policy of planned maintenance. This brings in some increased amount of paperwork.

Maintenance Request

The most important single document in the organisation of maintenance we shall henceforth call the 'maintenance request' which is alternatively termed as work order, work requisition, job card or work ticket etc. As a prerequisite for planning the maintenance function, it is necessary to know exactly what the labour force is doing, and how long each task takes.

The maintenance request by the production staff details the defect or work believed to be required. Hopefully, the 'cause' should have been identified 'before' or 'after' rectifying the fault so as to help planners for conducting subsequently studies for critical analysis and the all important function of 'designing-out' maintenance (provided reliable documented information exists). The maintenance request provides all the information necessary as regards the type of labour employed, and the time labour has taken to do the job. (Timesheets are often oriented/biased towards the worker).

Assets/Facility Register

The first step of a planned maintenance procedure is to establish what is to be maintained. This requires the need to establish an Assets/Facility Register. Each asset must be identified in terms of name and code; description; reference numbers pertaining to manufacturers, suppliers (if any), users, location with provision for changes if item is interchangeable or mobile and suppliers' details. When the items investment.

b) To extend the useful life of assets by minimising wear and tear and deterioration. This is particularly relevant for our country as opposed to developed countries which would find replacement more economical than maintenance.

c) To ensure operational readiness of all equipment required for emergency use at all times, such as standby units, fire fighting and rescue unit etc.

d) To ensure the safety of personnel using facilities

From the line managers' point of view, the reasons for improving maintenance methods include: (i) protecting the buildings and plant, (ii) increased utilisation and reducing downtime, (iii) economising in the maintenance department, (iv) maximising utilisation of resources, (v) maintaining a safe installation, (vi) preventing wastage of tools, spares and materials, (vii) providing cost records for future budgeting.

Moreover, each day we are witnessing a trend towards increased mechanisation, computerisation and greater automation, though it might seem to be a distant thought in Indian conditions. Whatever be the level or degree of automation, there will always be an increasing responsibility for the maintainer of the assets. Some of the reasons for this are:

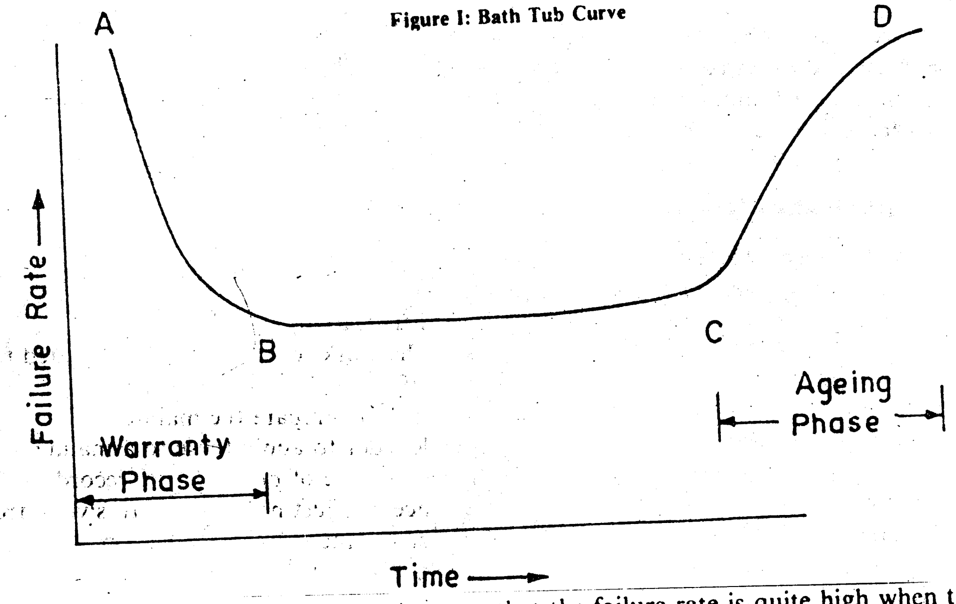
1) Plant output capacities are raised, making downtime (viz. when the plant is out of operation) more costly.
2) Dependence on control systems can produce total disruption of output when one machine or some element in a process fails.
3) The possibilities for operator's intervention to compensate for machine errors or failures are decreased.

The effects upon the maintenance department include a new requirement for new skills in repair of computer controls, the need for an improved multi-disciplinary working coupled with the requirement for a systems approach to maintenance. By systematic maintenance, it is possible to achieve substantial savings in money, material and manpower, as every effort is directed towards avoiding catastrophic failure. Failure or plant breakdown could create problems such as a loss in production time, rescheduling of production, spoilt materials because of sudden stoppage of process, which could possibly damage components, failure to recover overheads because of loss in production hours, need for overtime, need for subcontracting work and temporary work shortages etc.

13.4 FAILURE ANALYSIS

Let us now spend some time in understanding how failures take place. Failure analysis plays a vital role in taking decisions pertaining to maintenance planning and control for effective management subject to the budgetary constraining for such an activity. It is important to identify the nature and occurrence of failures with respect to time. This will be highly significant in designing and ensuring adequate reliable performance. It is seen that the failure rates pattern can be depicted as a b h tub curve as shown in Figure 1.

Figure I: Bath Tub Curve



It is the usual experience with equipments that the failure rate is quite high when the equipment is new or newly installed. The failure rate is greater during the initial starting period of infancy but after this initial phase is over, the failures are relatively quite low. Such a behaviour can be approximated to a 'hyper exponential distribution' as shown in Figure I. Such behaviour is a sign of the design defects or installation defects. Therefore, those that had these inherent defects failed when the equipments were run. Those that failed much later were those that did not have the design or installation defects. This is somewhat similar to the infant mortality in humans.

At the other extreme, many equipments fail due to 'ageing' and wear out. The failure or death may be at a 'mean' or 'average' age, though some could fail earlier and some later. Such a failure pattern because of wearing out could be represented by a symmetrical bell shaped normal distribution.

We have seen the 'infancy' and the 'old age' phenomenon. In between these two extremes also equipments may fail, but it is neither due to inherent design or installation defects nor due to being worn out. The cause is external to the equipment and therefore probability of failing is constant and independent of the running time. This phenomenon can be approximated to a 'negative exponential' distribution. This is again similar to the behaviour in humans, where they may die due to external causes such as an epidemic or traffic-accidents while they are neither old nor infants.

The three distributions mentioned above, namely hyper-exponential, negative exponential and normal, can be combined into one distribution, termed as the 'weibull' distribution (named after Weibull who developed it). Hence the bath tub curve depicting the failure rate can be represented by a weibull distribution. Weibull distribution calculations are very lengthy and tedious. Fortunately weibull graphs are available (though not very common) for determining mean time between failure (MTBF). This would provide good data for determining system reliabilities, availabilities, expected lives etc. Failure statistics can also be used in the diagnosis of the nature of a recurrent equipment failure and also in the prescription of solutions to maintenance problems.

The prime objective of maintenance is to increase the availability and reliability of a piece of equipment. The availability (A) of a plant can be defined as

$$A = \frac{T_{up}}{T_{up} + T_{down}}$$

are recorded either in a register or in a card-index form, they could be classified and sub-divided in terms of asset usage/availability, technical groups or maintenance methods. Sometimes certain items may be subject to statutory inspections. The assets-register is the information centre of the planned maintenance system.

Maintenance Schedules

Next we must decide how these assets or facilities are to be maintained. A 'maintenance schedule' must be prepared for every item listed in the assets/facility register. A typical maintenance schedule card indicates grade of labour required, frequency of the work to be done, details of the work to be done and estimated time for the execution of the work. A mistake so often made is when companies setting up a planned maintenance scheme for the first time prepare the maintenance schedules for all the plant first, and then endeavour to apply these to a maintenance programme on a specific starting date. In the absence of plant-history records, this method of approach is doomed to failure, since it is just not possible to switch from emergency maintenance methods (which is usually the rule rather than an exception) to planned preventive maintenance overnight.

Work/Job Specifications

Having prepared our maintenance schedules we must prepare the work/job specifications which are compiled from the maintenance schedules and are a means of communication between the engineer and the tradesman (or the person who would be carrying out the job). Precise specifications for the activities on the maintenance schedule vary in depth and presentation according to the system, the local labour requirements, the complexity of the items to be maintained etc.

It should define specific items on the machine requiring attention and clearly indicate the required action e.g. inspect, check, gauge. It should give guidance in respect of **method,** however appropriate it might be. The objective is to maintain to a required standard without forgetting on the safety aspect concerning both the tradesman and operators.

Programming Annual and Weekly Planned Maintenance Programmes

Having prepared our maintenance schedules and built up a workload from our job specifications, we are now in a position to commence the preparation of an annual maintenance programme to decide when the planned productive maintenance jobs shall be carried out. Over a period of time, planned maintenance significantly reduces the demands on the maintenance department for such major overhead work to be carried out during annual shutdown periods (for which we could make use of Network Techniques like PERT/CPM). The weekly planning maintenance programme can be derived from the annual planned maintenance programme. However, tactical planning is required at the weekly level by interacting with the production planning and control section especially. Unforeseen circumstances sometimes arise, however careful the forward planning, which make it impossible to release a machine/asset according to the weekly programme charted out. It is important to communicate the weekly planning programme, at least a week ahead, to all concerned.

Inspection Report

One of the important forms of maintenance is to carry out inspection at the right time and duly record the data so as to produce an inspection report. This form/document is used only for reporting the results of planned productive maintenance inspections, as set out in the job/work specifications. The inspection report closely resembles the maintenance request, discussed earlier on. It is imperative that inspection reports must be used by and for maintenance supervision and planned maintenance controller and his staff prior to filling the history records (to be discussed next).

History Records

The last operation in our planned maintenance procedure is to build up a detailed historical record of the results of maintenance on every machine receiving it. Plant history records should be properly updated so that they can be referred to and made use of more meaningfully. Traditionally, history records have been 'written up' by records clerks from timesheets or work orders.

The operation of an effective maintenance records system provides information about: (i) the percentage of planned work achieved in the period, (ii) ratio of planned to unplanned work, (iii) downtime for the period, (iv) maintenance requirement comparisons between individual assets, between types of asset, or between groups of assets, (v) indicators for reliability of the products of particular manufacturers, (vi) trends in spare-parts consumption, (vii) equipment failure patterns, (viii) performance details for personnel, by individual or by trade group.

Records are kept in many different ways ranging from card files to computerised devices.

Planned Lubrication

Some form of lubrication routine is rightly considered to be an essential part of plant maintenance by most firms, yet this is a responsibility which is frequently relegated to an oiler greaser who may have little or no training before being provided with an oil can, a grease gun and a dubious supply of lubricants. Lubrication schedules are usually provided by the planning engineers of oil companies. The schedules include information about the number of application points, frequency of each application, method to be used, e.g. grease gun, oil can etc., the amount and type of lubricant required. Planned lubrication should be an integral part of planned maintenance, and, because of its utmost importance, daily and weekly lubrication tasks should usually be carried out separately from the mechanical and electrical schedules. Monthly lubrication tasks and oil changing should be usually fully integrated with the maintenance schedules.

To ensure a smooth implementation of planned lubrication techniques, you could adopt a 3-phase procedure. In the first phase, a survey of all plant that require lubrication is carried out to establish WHAT has to be lubricated. The second phase establishes WHEN lubrication has to be done and the third phase is to conduct the OPERATION by establishing HOW lubrication is to be carried out.

Work Priority

Most of us, at some time to a greater or lesser degree, come up against the problems of deciding job priority. Obviously maintenance work of an emergency nature, required to keep production going or to reduce downtime, once incurred, should be given the first or topmost priority. However, with planned maintenance, hopefully, emergency cases are reduced to just about 10% of all cases. But still some method of priority fixing must be established preferably. After 'emergency', a 'machine running' priority could be thought of. In this case the machine is running, but attention is required to maintain efficient operation or for safety reasons. Yet the least priority could be labelled 'not applicable' if the request for maintenance work is not relevant to a machine stoppage, and also for most work involving civil and building trades. It is usually found that these three priority levels are found to be adequate and acceptable in most instances. If however, the problem persists, it becomes necessary to devise a PRIORITY INDEX based on two important group factors, namely.

a) Work priority factors where all work done by maintenance department personnel is separated into 10 classes, most important being class 10 and the least important being class 1. Emergency Maintenance-I, II and III, Modification, Capital, Sundry and Special Maintenance, and Housekeeping are respectively ranked from 10 down to 1.

b) Facility priority factor in which each facility, plant, building etc. is placed in one of 10 classes, most important being class 1. Key services, key production plant, flowline or process plant, multi-production machines, standby services, mobile transport, buildings and roads, machines (low utilisation), building, roads, offices and furniture fittings are respectively ranked from 10 down to 1.

To obtain the PRIORITY INDEX for any job, multiply 'work priority' class by the 'facility/machine priority' class. You can note that 10 classes have been chosen so that the priority index for each job can be expressed as a percentage priority.

For example, emergency maintenance for a key service sub-station equipment, the priority index would be (10x 10) = 100%. For an emergency repair to a leaking roof (building) over a production machine, the priority index would be (10x4) = 40%.

Safety

The observance of safety at work is essential at all times. The general rule is always 'safety first'. Some of the main safety considerations when carrying out a maintenance management task are the following:

a) Guards are supplied by plant manufacturers or subsequently fitted by the company: Safety steps should be taken to ensure that these are not tampered with resulting in potential hazards. In fact, condition and security of easily accessible guards must always be included in job specification as items for regular checks at planned preventive-maintenance inspections.

b) Protective Clothing such as helmets, gloves, goggles, gas masks etc. must be given full consideration especially in chemical and allied industries. You must preferably include the need for wearing protective clothing in the maintenance request or the work/job specification.

c) Power isolation by the use of appropriate fuses might be necessary while effecting certain types of maintenance tasks. Water and compressed air supplies can usually be isolated and locked off where necessary. Gas lines may have to be purged before any welding is permitted.

d) Pressure vessels, piped power, lifting appliance should have some type of a 'permit' system to open and/or blank off.

e) Permit to work for carrying out maintenance tasks should remain valid for a specific appropriate period only. A copy of the certificate should be posted or affixed in such a place that it is not possible for anyone to start up the plant or machine before referring to it.

13.7 MAINTENANCE PLANNING AND CONTROL: OPERATION

So far we have dealt with the aspects of management organisation that are related to the needs of the engineering function. Now let us come to the decision-making aspect. If management is to be truly effective and objective, it must be provided with reliable, timely, and appropriate information. This aspect is highly desirable. Unfortunately, this facility is very sadly lacking in the field of maintenance management.

Routine Analysis—Labour and Costs

Let us now discuss some of the problems that arise in the implementation of the system designed in the earlier section. It is essential to set up operational procedures for **routine analysis** of the results of maintenance work in order to improve the level of work planning and control through better control of resources in the form of labour and materials. Plant and machinery may be wearing out or be obsolete, and inherent design faults, uptill now accepted, will be highlighted by the routine analysis. The analysis might reveal the changes in plant performance as a result of planned productive maintenance. Many different types of analysis could be carried out, but it is good to remember that a successful operation scheme is one that retains simplicity and some amount of flexibility.

You could conduct a **weekly analysis** by scanning all completed maintenance requests, subsequent inspection reports and the total repair time and downtime costs calculated. The weekly analysis of direct maintenance labour is in hours number of jobs, and indicates:

i) Maintenance hours activity and maintenance request jobs by cost centre, types of work and trade group.
ii) Inspection reports by cost centre and trade group.
iii) Total inspection report hours by trade group.
iv) Total downtime by trade group.
v) Booked time by cost centre:
vi) Total booked time, unbooked time and clocked time by trade group.
vii) Unbooked time as a percentage of clocked time.
viii) Overtime hours worked and expressed as a percentage of clocked time.
ix) Number and total wages of maintenance personnel employed by trade group.

The planned maintenance controller watches closely for any significant variations in inspection hours achieved, emergency maintenance hours incurred, downtime hours incurred, unbooked hours recorded and overtime hours worked and as a percentage of clocked hours.

It is difficult to obtain really accurate maintenance labour costs because these depend on so many diverse and variable factors, such as time booking accuracy, overtime, tradesman/unskilled labour ratios, dependent labour charges, workshop overheads, general overheads etc.

One simple approach is suggested as follows. Every four weeks, total wages paid, plus dependent labour charges, plus overhead charges are divided by the total clocked hours for the period; the resultant maintenance labour hour cost rate is directly applied to the time booked to each cost centre, and each plant number or job number during the period.

It is important to impress upon maintenance workers that they should book only the time they actually spend on a job (including travelling time, collecting tools and stores for the specific job only). Some waiting time could be unavoidable in maintenance jobs. It may be happening that unbooked or overbooked time could arise because of insufficient work to occupy a maintenance man full time; careless or inaccurate time booking on the maintenance request or inspection report; loss of a maintenance request or inspection report; absence from shop floor while attending training courses which may not have been recorded by the foreman/superintendent. It might also be helpful to prepare a weekly summary of all emergency maintenance jobs done during the period.

A plant group analysis could also be done. Machines are deliberately placed in groups and types of sub-groups to facilitate identification and enable the analysis of results to establish trends of breakdowns and where maintenance performance during the pre-period was unsatisfactory. By scrutinising the results of maintenance by plant/job number, it becomes a simple matter to select say the 'top ten' machines that have involved the largest amount of emergency and corrective maintenance and downtime during the period. It would be worth recording chronologically the 'top ten' and see which machines keep appearing in the list. For such 'critical' machines drastic and long term action may be called for to 'design out' the maintenance problems. It should be anticipated that the top ten analysis might reveal no significant pattern after say 2 years or so. This will leave the weekly analysis and the plant group analysis as the only two routines that will continue to be required.

Work Measurement, Manning and Workloading

Most engineering managers would agree that work planning in maintenance is both possible and desirable. However when it comes to setting certain standards or norms through work measurement for the largely non-repetitive nature of maintenance work, one encounters very divergent and strongly held views on the subject. Incentives might motivate the maintenance workers to carry out their tasks effectively and efficiently. Different organisations have different remuneration schemes for direct production workers and indirect maintenance staff.

Certain aspects ought to be borne in mind when applying work study techniques to maintenance engineering. It is a wasted effort to put a standard on a job that can be eliminated through 'design out' maintenance. It is futile to standardise a planned preventive maintenance job if the worker does not have the correct tools, spare parts or materials. It is normally impractical or excessively costly to cover more than about 60% of the jobs. Installation and administration costs are high and can exceed the resultant benefit. Increased labour productivity remains largely a problem of reducing lost time between maintenance jobs, i. e. unbooked time.

Work measurement applied to maintenance may have advantages if applied in the right environment, but maintenance planning and control techniques must be applied first. Perhaps work sampling schemes could be employed to arrive at the total work content. Then accordingly appropriate manning levels could be estimated. An organisation that has a clear cut maintenance planning system would hopefully have a very small percentage of emergencies occurring. In such well established planned productive maintenance situations, manning and workloading are not problematic. In fact, in case of planned overhauls you could resort to the use of network techniques of PERT/CPM which you have learnt in unit 12.

13.8 MAINTENANCE PLANNING AND CONTROL: PROGRESSION

Critical Analysis: As maintenance records are being built up and sufficient statistical data become available, a point is reached when you can attempt to carry out some type of a CRITICAL ANALYSIS. It would be seen that the Pareto Principle comes in handy once again, viz. the principle of 'the significant few and trivial many.' A critical breakdown analysis (Figure 11a) reveals that a small percentage (about 10%) of equipment would significantly contribute to about 70% of the breakdown time. Such category of equipment could be the so called critical 'A' type. A defect analysis (Figure 11b) could also be done. It would be seen here again that a few, say 10% defects contribute to about 70% of the breakdown times.

Figure II (a) : Criticality Analysis

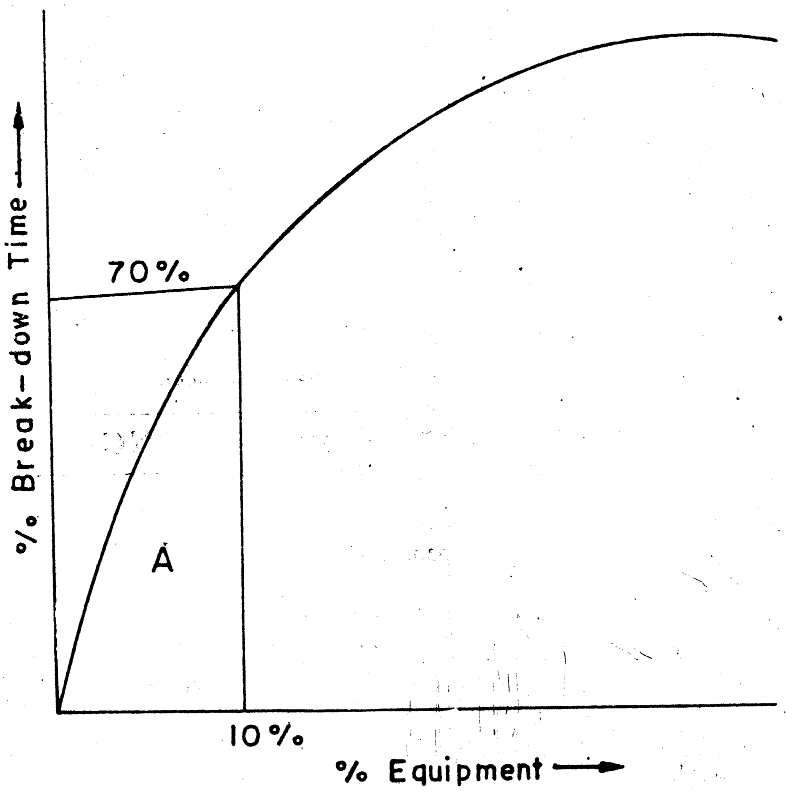
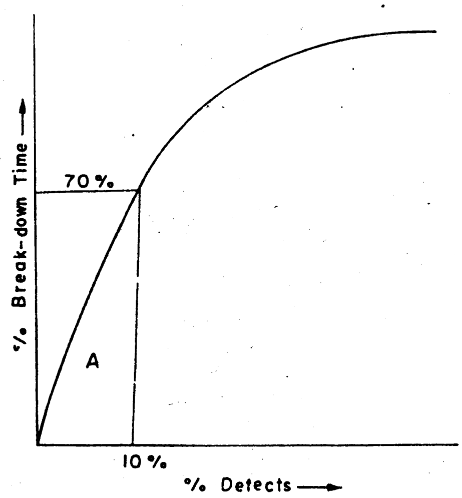


Figure II (b) : Defect Analysis



One then needs to concentrate on the critical A types of equipments and the critical A* types of defects and accordingly devise suitable preventive maintenance management schemes and design out maintenance, whenever feasible. A simple way for attacking a maintenance problem is essentially a 3 step procedure.

Step 1: Can it be eliminated? If yes, then no problem. If no, go to next step.

Step 2: Can it be simplified? If yes, then no problem. Otherwise, go to next step.

Step 3: Can it be improved? If yes, then no problem. Otherwise you have hardly any other option.

Lubrication problem—Costly and time-consuming maintenance operations of greasing the suspensions, steering and transmission components on a modern motor car, which used to number a dozen grease points or more, has now been **eliminated** by design on most models.

For machines requiring a constant supply of grease to moving parts through a multitude of often inaccessible individual grease nipples have been through the 3 step procedure, replaced by the piping of such points in groups of battery plates and thereby reducing the number of locations at which grease must be applied. Step 2 involved the piping up of all grease points to an automatic lubricator thereby simplifying maintenance and also improving quality of service. Where it proves technically impossible to design out lubrication completely or to simplify it by automatic methods, one may be confronted with grease and oil sealing problems; these can be improved by better designs of housing and sealing methods. The penny saved on capital expenditure can be pound foolish when it has to be spent ON MAINTENANCE.

13.9 MAINTENANCE COSTING AND BUDGETING

Costing and budgeting for the maintenance department embraces the provision of financial information on labour and materials expenditure, its allocation to the various cost centres together with manpower resources and the development of objectives with programmes and budgets for meeting them. The basis for cost control is provided by the use of cost account codes. Typical major code headings might include (a) capital projects, (b) planned preventive maintenance, (c) workshop services. The costs attributable to the cost codes consist broadly of wages and salaries, overhead charges, materials costs, transport costs and sundry items.

The overhead charge made upon maintenance is made up of charges occurring within the maintenance department plus the overhead charges reflected from other departments like administration, general management etc. Charges arising within the department include services' rent and rates, transportation and insurance.

A budget could then be charted on the basis of the different types of costs estimated for different heads. A budget might show

Maintenance labour	20%
Maintenance materials	40%
Fuel costs	25%
Overheads	15%

When producing a departmental business plan, it is necessary to include in the budget a set of objectives and strategies for implementing the planned maintenance programmes, completion of certain capital works and the operation of a planned overhaul programme. One objective for the department ought to be the reduction of resources allocated to corrective and emergency maintenance and an increase in planned preventive work.

Cost reports can be analysed for variances of actuals versus planned. In this connection it is relevant to introduce a 'life-cycle cost' concept of an asset. It includes the initial costs (the total costs of procurement and setting to work), the costs of ownership during the life-cycle, and the costs of downtime. Initial costs include the costs of services, commissioning, product support and ancillary equipment. The cost of ownership include the annual costs of operation and maintenance, multiplied and factored for the life term, together with salvage value (when asset is disposed). The costs from downtime includes loss of use, repair costs and consequential damage, and will provide evidence for replacement decisions. One needs to suitably account for inflationary trends, if they exist.

Once fully understood, formal costing and budgeting would be extremely useful not only in predicting and controlling expenditure but in encouraging the prediction and preplanning of activity with the necessary resourcing to meet the plan.

13.10 MAINTENANCE PERFORMANCE INDICES

Unlike direct production which can be rated in terms of output of any particular machine, no such analytical yardstick is available for rating maintenance. In maintenance you should essentially strive to maximise availability and reliability of the machines/assets and minimise downtime. Maintenance though a support function, is certainly linked to increase in the productivity of the system in the long run. Chandra has proposed some indices as below, which might help management achieve their objectives more effectively and efficiently.

i) Maintenance productivity index = $\dfrac{\text{The output of product}}{\text{The cost of maintenance effort}}$

ii) Maintenance cost index = $\dfrac{\text{Maintenance cost} \times 100}{\text{Capital cost}}$

iii) Downtime index = $\dfrac{\text{Downtime hours} \times 100}{\text{production hours}}$

iv) Waste index = $\dfrac{\text{Quantity of Waste produced} \times 100}{\text{Quantity of total output}}$

(This is somewhat similar to 'wastivity' which, however, gives a more comprehensive conceptualisation of waste rather than just think of output waste. This would be discussed in the unit on Waste Management).

v) Breakdown Maintenance Index = $\dfrac{\text{Total hours spent on breakdown} \times 100}{\text{Total man hours available}}$

vi) Level of Maintenance = $\dfrac{\text{Total hours spent on scheduled maintenance} \times 100}{\text{Total man hours available}}$

vii) Inspection of effectiveness = $\dfrac{\text{Standard minutes of work saved on improved inspection}}{\text{Total standard minutes of inspection carried out}}$

Through inspection we should be able to reduce the volume of maintenance to the lower possible extent.

viii) Technical Competence Ratio = $\dfrac{\text{Annual saving in labour and material costs resulting from additions or modifications made during the year}}{\text{Total annual maintenance cost}}$

Considerable capital savings can be effected by utilising work study and value engineering techniques at the design stage.

ix) Overtime hours Ratio = $\dfrac{\text{Overtime hours worked}}{\text{Total maintenance man hours}}$

Overtime hours worked is indicative of the failure of planning. Emergencies should be reduced to a bare minimum.

13.11 SUMMARY

In several cases in industry, cost of unscheduled stoppage on an equipment is very high in terms of money and any breakdown or accident could cost a good deal in terms of money and human injury. Maintenance has not only to reduce scheduled stoppage time but attempt to avoid unscheduled stoppages and breakdowns by frequent performance checking, testing and providing inspection and skilful repair when required to ensure better service, availability and reliability. There are various types of maintenance management schemes. It is imperative that you use the appropriate technique by evaluating the cost-benefits of each alternative. There is a need for an effective spare parts inventory management policy and an overall necessity of adopting a systems approach. The effectiveness of production is highly dependent on the quality of maintenance service facility. Perhaps good care, caution and foresight at the design stage itself might make the concept of maintenance redundant. All effects should be to devise schemes so that emergency maintenance remains an exception rather than the rule. With the ever increasing need for reliable data and information for purposes of criticality analysis etc., computers might be in greater demand in future to help in more effective and efficient maintenance management

13.12 KEY WORDS

Breakdown: Failure resulting in the non-availability of an item.

Corrective Maintenance: Maintenance carried out to restore (including adjustment and repair) an item which has ceased to meet an acceptable condition.

Downtime: The period of time during which an item is not in a condition to perform its intended function.

Emergency Maintenance: Maintenance which is necessary to put in hand immediately to avoid serious consequences.

History Cards: Record of usages, events and actions as appropriate relating to a particular item.

Maintenance: A combination of any actions carried out to retain an item in, or restore it to, an acceptable condition.

Maintenance Programme: A list allocating specific maintenance to a specific period.

Maintenance Planning: Deciding in advance the jobs, methods, materials, tools, machines, labour, timing and time required.

Maintenance Schedule: A comprehensive list of maintenance and its incidence.

Overhaul: A comprehensive examination and restoration of an item, or major part thereof, to an acceptable condition.

Planned Maintenance: Maintenance organised and carried out with forethought, control and records to a predetermined plan.

Preventive Maintenance: Maintenance carried out at predetermined intervals, or to other prescribed criteria, and intended to reduce the likelihood of an item not meeting an acceptable condition.

Running Maintenance: Maintenance which can be carried out while the item is in service.

Shutdown Maintenance: Maintenance which can only be carried out when the item is out of service.

Tero-technology: It is a combination of management, financial engineering and other practices applied to physical assets in pursuit of economic life-cycle costs; it is concerned with the specification and design for reliability and maintainability of all assets, with their installation, commissioning maintenance modification and replacement, and with feedback of information of design, performance and costs.

the systems and procedures. Recently these concepts have been applied to non-traditional areas such as urban slum development programmes, staff welfare motivation enhancement and courtesy improvement plans.

Reasons for Poor Value

One of the important reasons behind poor value in products, systems and procedures that we come across is the lack of organised effort in devising such systems. Many times the designs are created under highly compressed time frame and the designer may play safe by giving product designs with sole emphasis on technical feasibility and may prescribe thicker, costlier materials and other unnecessary features which are not needed by the customer. Sometimes, ad hoc decisions get permanency due to lack of review of product designs. Often lack of consultation with others contributes to poor value. Lack of information, wrong beliefs, habits and attitudes are some of the other reasons.

14.2 HISTORICAL PERSPECTIVE

Value Engineering had its origin at the General Electric Company (GEC). As a result of World War II, many materials were in short supply and L.D. Miles was associated with a committee to identify substitute materials without sacrifice in quality and performance. He organised a formal methodology in which a team of people examined the functions of products manufactured by GEC. Through team-oriented creative techniques they made changes in products to lower their cost without affecting their utility and quality. This methodology was given the name Value Analysis (VA). L.D. Miles who wrote his book in 1961 is generally recognised as the father of Value Engineering. Miles found that many of the substitutes used were providing equal or better performance at lower costs.

The first organisation to initiate a formal VE programme was Navy Bureau of Ships in 1954. In 1959, Society of American Value Engineers (SAVE) was set-up to propagate the philosophy of Value Engineering. Many companies in USA, UK, Japan, etc. subsequently set-up formal VE programmes. The Department of Defence in US encouraged application of VE in defence projects. A number of success stories of VE/VA are reported.

In India, VE/VA is now a well recognised programme and many organisations in military and navy as well as in other public and private sectors have set-up directorates or cells of Value Engineering. A professional society Indian Value Engineering Society (INVEST) came up to create awareness in VE/VA and they publish a journal, organise conferences and provide other services. It is now considered as an effective management tool.

14.3 FUNCTIONS AND VALUE

Types of Values

The term 'Value' is used in many different ways and is frequently confused with the monetary price or cost of an item. However value is not synonymous with cost. Value may be perceived as the ratio of the sum of positive and negative aspects of an object. Thus value can be considered as a composite of quality and cost. It is more in terms of worth or utility. Thus a ratio of quality to cost can be treated as the value of a product. If its costs can be reduced for same quality or quality can be improved with same cost, then the value improvement can be said to occur. The term value can be divided into following types:

a) **Use Value:** The properties and qualities which accomplish a useful purpose or service.
b) **Esteem Value:** The properties, features or attractiveness which cause us to want or own it.
c) **Cost Value:** The sum of labour, material and various other costs required to produce it.
d) **Exchange Value:** The properties or qualities which enable us to exchange it for something else we want.

Types of Functions

VE discipline deals with the functions of items, products, systems and procedures. It is a functional approach, a customer-oriented approach. Identification of the functions, therefore, constitutes an important aspect of VE. The term 'function' is used to mean the purpose or use of a product.

Functions can be of two types:

a) Basic functions—the primary purpose of a product.

b) Secondary functions—other purposes not directly accomplishing the primary purpose but supporting it or resulting from a specific design approach.

Many a time poor value may result in because the functions have not been precisely understood and redundant or unnecessary functions have been imposed.

Value Tests

VE is essentially a questioning attitude looking at the function and costs. L.D. Miles designed a set of value tests to ascertain whether there is a scope for value improvement. If these value tests are honestly applied, there is bound to be room for improvement in most of the products, systems and procedures that we come across. Some of these questions which can work as thought-starters for developing better value alternatives could be as follows:

1 Can the design be changed to eliminate the part?
2 Can you purchase it at lower cost?
3 Does it need all its features?
4 Is there anything better for the intended use?
5 Can a usable part be made by a lower-cost method?
6 Can a standard part be used?
7 Is it made on proper toolings considering the quantities involved?
8 Are there any newly developed materials that can be used?
9 Can two or more parts be combined into one?
10 Can any specifications be changed to effect cost reduction?

Activity A

Choose any product, system or procedure that you are very well conversant with in
your day-to-day life and apply the above tests to find out if there is a scope for value improvement in it

....

Identification of Poor Value Areas

By applying the value tests we may come across poor value areas which are responsible for unnecessary costs. These could be in the design of the product, procurement, handling and storage of materials, production processes, packaging and distribution of the final product. Once we are able to identify poor value areas, we can focus our attention on these so that these unnecessary features can be eliminated.

Another way to identify the poor value areas is through function cost matrix approach. If a function is relatively less important but accounts for a larger percentage of product cost then it is a potential area for value improvement. By determining alternative cheaper ways to achieve that function we can reduce the cost and improve value.

In simple terms a soundly conducted Value Analysis programme should essentially provide answers to the following questions:

1 What is the item?
2 What does it do?
3 How much does it cost?
4 Can anything else do the same thing?
5 How much does that cost?

UNIT 14 VALUE ENGINEERING

Objectives

Upon completion of this unit you should be able to:

- understand the concept of value engineering
- differentiate between value and cost
- see value engineering in historical perspective
- appreciate the role of value engineering in cost reduction and performance improvement
- identify poor value areas in products and systems
- learn about the value engineering job plan
- appreciate the role of some of the techniques of value engineering
- study some cases to see the improvements in product value through value engineering techniques.
- identify the behavioural and organisational issues involved in value engineering.

Structure

14.1 BASIC CONCEPTS IN VALUE ENGINEERING

Value Engineering and Value Analysis

Value Engineering (VE) or Value Analysis (VA) is an important and powerful approach for improvement in the performance of the products, systems or procedures and reduction in costs without jeopardising their function. The terms VE and VA are used almost interchangeably. Other terms used to convey the same concepts are Value Assurance and Value Management (VM).

L.D. Miles defined Value Analysis in his book **Techniques of Value Analysis and Engineering** (1961) as "an organised creative approach which has for its purpose the efficient identification of unnecessary cost i.e., cost which provides neither quality, nor use, nor life, nor appearance, nor customer features". Various other definitions are proposed such as "an organised systematic study of the function of a material, component, product or service, with the objective of yielding value improvement through the ability to accomplish the desired function at the lowest cost without degradation in quality". Thus the basic objective of VE/VA is to achieve equivalent or better performance at a lower cost while maintaining all functional and quality requirements. It does this largely by identifying and eliminating hidden, invisible and unnecessary costs. We may simply perceive VE as the systematic application of recognised techniques to identify the functions of a product or service and provide those functions at the lowest total cost.

Value Engineering should not be treated as a mere cost reduction technique or cheapening of the product. It is more comprehensive and the improvement in value is attained without any sacrifice in quality, reliability, maintainability, availability, aesthetics, etc. It was traditionally applied in the area of hardware projects, such as product design, though these concepts are equally applicable in software projects, in

13.13 SELF-ASSESSMENT EXERCISES

1 Should maintenance be regarded just as a repair function?
2 What do you understand by the term 'tero-technology'? Is the term and concept easily acceptable?
3 If the trends of computerisation of processes continue to grow, what would be its impact on the maintenance function?
4 What are the objectives of maintenance management?
5 Can you think of some examples from your experience that either conform to or are at variance from the 'bath tub curve' of failure rate phenomena.
6 What are the different types of maintenance systems? Could you give some illustrative example for each alternative system? You may take the example of a car, scooter or any other asset of your choice for elaborating your answer explicitly.
7 What is 'priority index' and how would you obtain it?
8 What precautions should you keep in mind while attempting to apply work study techniques to maintenance engineering?
9 What is 'criticality analysis'? Explain how the Pareto Principle finds its application for effective maintenance planning and control.
10 Discuss the need for devising some maintenance performance indices.
11 What is the utility of maintenance performance indices? Discuss a few of them.

13.14 FURTHER READINGS

Ar'c, S., *Maintenance Management*, NPC: New Delhi.

Aggarwal, S.C. 1968. *Maintenance Management*, Prabhu Book Service: New Delhi.

Chase R.B. and Aquilano, N.J. 1977. *Production and Operations Management: A life cycle approach*, Revised edition, Richard D. Irvin Inc: Chicago.

Chandra, D. 1976. *Design out Maintenance and Instrument Aids*, Universal Book Corpn.; Bombay.

Corder, A.S. 1977. *Maintenance Management Techniques*, McGraw Hill: New York.

Gradon, F. 1973. *Maintenance Engineering*, Applied Science Publishers Ltd.: London.

Kelly, A. 1984. *Maintenance Planning and Control*, Butterworths Company Ltd.: London.

Mohanty, R.P. 1984. *Works Management*, AIMA-Vikas Management Series: New Delhi.

White, E.N. 1979. *Maintenance Planning, Control and Documentation*, Second Edition, Gower Press: London.

BLOCK 5 VALUE ENGINEERING AND QUALITY ASSURANCE

This block of two units deals with major aspects of Value Engineering and Quality Assurance. Unit 14 on Value Engineering first develops Value Engineering (VE) in historical perspective and differentiates between value and cost. An attempt is made to develop appreciation of the role of VE in cost reduction and performance improvement. VE job plan and some of the techniques of VE are then discussed. Some practical case studies are discussed to examine the improvements in product value through VE techniques. Finally behavioural and organisational issues involved in organising VE functions are elaborated upon.

Unit 15 on Quality Assurance develops appreciation for the role of quality control, quality assurance and quality assessment. The unit then discusses how to design a sampling plan, draw up operating characteristics curve for a given sampling plan, compute Average Outgoing Quality limit, assess process variability and whether the process is in control or not.

14.4 VALUE ENGINEERING JOB PLA

Value Engineering Process

As mentioned earlier, the major advantage of the approach is that it is a systematic and organised approach that examines all aspects of a problem employing a questioning attitude. Thus a formal approach has to be adopted to go through the VE programme. This formal procedural model of VE process is called VE Job Plan. In the beginning, when Miles proposed VE Job Plan, it was just a modified form of the steps involved in work study. Subsequently, it has been modified and a number of approaches have emerged which are essentially similar. These job plans have various steps and phases with their associated VE techniques at each phase. In one of the job plans the seven steps involved are: (1) preparation, (2) problem selection, (3) information, (4) evaluation, (5) creation, (6) selection and presentation, and (7) implementation and follow up.

In this unit we shall briefly outline the salient features of three different approaches to conduct a VE programme. These are:

a) Job Plan due to Mudge

b) DARSIRI method

c) FAST (Function Analysis System Technique)

Since the Job Plan due to Mudge is a very well recognised approach, we will deal with it in this section. The seven phases of Job Plan are:

i) General phase

ii) Information phase

iii) Function phase

iv) Creation phase

v) Evaluation phase

vi) Investigation phase

vii) Recommendation phase.

Each of these phases comprises or is supported by one or more techniques. There are work-sheets for each phase. The practice of Job Plan and the application of VE techniques should be made on properly selected project. Thus selection of VE project is important. Those products should be chosen for the study which are significant in terms of cost reduction potential. In step-by-step application of the Job Plan the project unfolds from the information phase right up to recommendation phase.

The general phase plays vital role throughout and provides a good base for other phases to succeed.

Brief description of each phase together with associated VE techniques are given in the following sub-sections.

General Phase

Throughout the application of the entire Job Plan the techniques of this phase must be diligently applied to create the right environment for Value Engineering job plan to be effective. There are five techniques associated with this phase:

a) **Use good human relations:** It will be seen that considerable personal contact is necessary throughout the Project. The use of good human relations means assistance in place of resistance.

b) **Inspire team work:** This is one of the easiest to talk about, yet one of the hardest to accomplish. It calls for subordinating personal prominence or ego in the interest of the group as a whole.

c) **Work on specifics:** We should avoid generalities and work on specifics. Concrete data and information on specific problems must be secured. Only opinions and hearsay can be expected when talking in generalities.

d) **Overcome roadblocks:** In any organisation a group of dissenters can be found. These individuals knowingly or unknowingly, will use every means at their command to resist change. It is important to be able to recognise roadblocks and then take steps to overcome them. Mudge has in fact compiled an impressive list of 'killer phrases' which people use to kill an idea. It is very crucial to avoid such mental roadblocks.

e) **Apply Good Business Judgment:** Business decisions and judgments must be based on facts. Poor business decisions and poor judgment become prevalent when personal opinions and feelings take control. To apply good business judgment one must be resourceful, able to think and should be able to pursue new knowledge.

With the general phase as the base of foundation of the job plan, we can enter the second phase—information phase. The techniques included in the second phase, though seemingly simple, incorporate some of the most difficult portions of the approach.

Information Phase

The objective of this phase is to gain an understanding of the project being studied and to obtain all essential facts relating to the project as also to estimate the potential value improvement. This phase comprises of three techniques:

a) **Secure facts:** Information gathered must be authentic; it is one of the most arduous tasks. The type of information required will be:

   i) Technical specifications —dimensions, grades, tolerances, quality, appearance.
   ii) Environmental specifications—Seventy, test conditions.
   iii) Engineering drawings.
   iv) Production sample—actual or model of it.
   v) Production data—operations, speeds, rates, output and stock levels.
   vi) Cost data—material, labour, overhead-costs.
   vii) Work specifications—work place layout, standard times.
   viii) Features preferred by Customers.
   ix) Development, testing and service records.
   x) Quantities involved.
   xi) Scrap rates.

b) **Determine costs:** In order to direct towards those areas promising the greatest return on time and efforts in VE, the complete and accurate costs must be secured.

c) **Fix Costs on Specifications and Requirements:** By establishing a relationship between the costs and the specifications and requirements, a means is presented by which the latter two can be quantitatively evaluated. Extreme care should be taken during this phase to be sure that true facts are gathered, accurate costs are secured, and these costs are truly related to the specifications and requirements.

Once the techniques of the information phase have been used to secure pertinent data, the function phase of the Job Plan can be used.

Function Phase

The objectives of this phase are to define the functions that a product actually performs and is required to perform as well as to relate these functions to the cost and worth of providing them.

The two techniques of this phase are a major part of the functional approach. When combined with the other techniques of the Job Plan it produces a systematic approach which is different and more productive than any other product improvement or cost reduction approach.

The two techniques of this phase are:

a) **Define function:** This is one of the most crucial stages in Value Engineering. The method of functional analysis requires functions to be described with only two words, a verb and a noun. By so restricting the functional specifications, clear descriptions of the functions are possible. Concise function descriptions reduce the possibility of a detailed semantic elaboration. They force a rational approach by eliminating superfluous frills. The rules of function description are:

   i) Determine user's need for a product or service.
   ii) Use only one verb and one noun. The verb should answer the question "What does it do?" The noun should answer "What does it do"? Where possible, noun should be measurable and verb should be action oriented.

capabilities than most of his customers. We may decide to buy an item from the vendor instead of making it within if it is a cheaper and better proposal. Suppliers should be asked for cost-reducing and quality improving ideas. The degree of VE assistance by vendors also varies directly with the types of rewards, such as giving more business to cooperating vendors. Specialists can also contribute by suggesting a better material substitute, for example, by virtue of vast and up-to-date knowledge they may have in their chosen area of specialisation. In VE philosophy the consultation with others is a strength rather than a sign of weakness.

c) **Use Specialty Products, Processes and Procedures:** These in many cases provide a lower-cost way of accomplishing the function; but before being adopted these should be evaluated to ensure lower costs in relation to standard products, processes and procedures.

Recommendation Phase

This is the final phase of the Job Plan in which the finally selected value alternative is recommended for acceptance and implementation. It is vital in the sense that the entire project of conducting VE would succeed only if the recommendation is accepted. Many a time the acceptance of the suggested alternative depends upon the way it is presented to the management. The two techniques associated with this phase are:

a) **Present Facts:** Facts usually speak for themselves.
b) **Motivate Positive Action:** The presentation of accurate, specific and detailed facts and costs will motivate positive action. This technique requires the follow-up to make sure that the action is taken for idea implementation.

The presentation of facts can be either verbal or written in standard format or in combined form. The combined strategy is the best. The final recommendation need not contain all the data but should contain sufficient information to enable decision makers to find the course of action to be taken.

Example 5: We take the same example as 'Door Assembly' of a refrigerator which was given for functional analysis phase. After successfully carrying out VE Job Plan, the improved design of the 'Door Assembly' was suggested. Figure 2 shows the existing design and the proposed design. Table 5 shows the comparison of costs of the existing design and the proposed design. It shows a saving potential of Rs. 37,15,200 per year without jeopardising the functions to be accomplished by such an assembly.

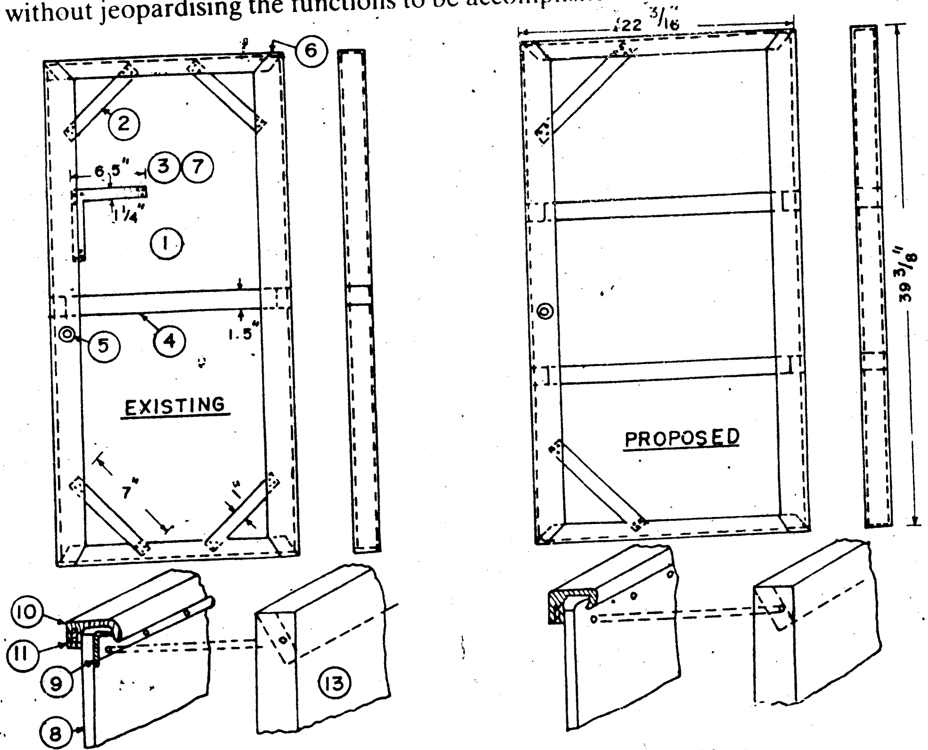


Figure II: Existing and Proposed Door Assembly

Table 5
Summary of savings through VE for the door assembly

Item	Cost per unit (Rs.)		Savings (Rs)		
	Existing	Proposed	Per unit	Per day	Per year
Door Assembly	207.14	194.24	12.90	10.320	37,15,200

Other Variants of Job Plan

Some other variants of the Job Plan described above have also been reported. These are: DARSIRI method and FAST. The FAST is the most powerful of these and will be discussed in detail in the next section. DARSIRI is essentially similar to the Job Plan of Mudge described alone. The seven steps involved are—D (Data Collection), A (Analysis), R (Record of Ideas), S (Speculation), I (Investigation), R (Recommendation) and I (Implementation).

These are self-explanatory steps and hence need not be elaborated.

14.5 FAST DIAGRAM AS VALUE ENGINEERING TOOL

Basic Methodology of FAST Diagrams

FAST (Functional Analysis System Technique) was developed in 1965 by Charles W. Bytheway. It visually represents the relationships of functions performed by a product, service or system and identifies where the functions have the greatest impact on costs. It is useful in determining the function inter-relationship in analysing an entire system and gives a better understanding of the interaction of function and cost. FAST is like a network diagram. The steps involved in constructing the FAST diagram are as follows:

a) Prepare a list of all functions of the product using verb and noun technique of functional analysis.
b) Write each function on a small card. Select the card pertaining to Basic Function. Determine the position of the next higher and lower function by answering the following logical questions.
   How is this function accomplished?
   Why is this function performed?
   When is this function performed?

A critical function path may result from the logic sequence of the basic and secondary functions. It is composed of only those functions that must be performed to accomplish the functions. The FAST diagrams are usually bounded on both ends by the scope lines, which delineate the limits of responsibility of the study. For example, if one is value analysing an over-head projector, the FAST diagram will be expanded up to the point where current is conducted to the device. 'Generate electricity' is outside the scope of the study.

Illustrative Example

The technique of drawing FAST diagram as applied to Refrigerator Packaging is shown in Figure III. It shows the scope of the study and the entire logical relationship for its basic function 'Prevent Damage'. 'Prevent Damage' function is to support another function—'Facilitate Transportation' (beyond scope line) and is supported by 'Prevent Corrosion' and 'Prevent Impact'. Similarly, the entire network is completed.

The cost of each part is divided into different headings of functions in the ratio of its estimated contribution to perform this function. Thus total cost apportioned to perform that function is computed and entered in the FAST diagram outside the box

Table 2

Numerical evaluation chart for functions

PART No.

PART NAME

Part No.	Part name
1	OUTER PLAN
2	GUSSET
3	HANDLE REINFORCEMENT
4	CENTRE STIFFENER
5	LOCK ASSY.
6	SLEEVE DOOR HINGE
7	HANDLE
8	LINER
9	GASKET RET. STRIP
10	GASKET
11	MAGNETIC STR.
12	DECORATIVE STRIP
13	INSULATION GLASS WOOL

BASIC FUNCTION

	Basic function
A	PROVIDE SECURITY
B	PROVIDE STRENGTH
C	PROVIDE LOCATION
D	PROVIDE STIFFNESS
E	PROVIDE FASTENING
F	PROVIDE ROTATION
G	FACILITATE OPENING
H	ACCOMODATE ARTICLES
I	PROVIDE RETENTION
J	PROVIDE SEAL
K	PROVIDE FORCE
L	PROVIDE AESTHETICS
M	PROVIDE INSULATION

	A	B	C	D	E	F	G	H	I	J	K	L	M	WEIGHTS	ADJUSTED WEIGHTS	PERCENTAGE WEIGHTS	PERCENTAGE COST	VALUE INDEX = COST/WORTH	
A		A2	A3	A3	A3	A2	A3	A3	A3	A3	A3	A3	A1	32	33	18.5	22.3	1.2	POOR VALUE & HIGH COST
B			B2	D1	B2	F2	B1	H1	B2	J1	B3	B1	M2	11	12	6.7	3.9	0.6	
C				D2	C1	F3	C1	112	C1	J3	C2	L1	M2	4	5	2.1	4.8	1.7	POOR VALUE
D					D2	F2	D2	H1	D3	J1	D3	D2	N3	15	16	8.9	1.2	0.1	
E						F3	62	H2	E1	J3	E2	L1	M2	3	4	2.2	4.6	2.0	EXTERNAL VARIABLE
F							F3	F2	F2	F1	F3	F2	M2	23	24	13.4	1.9	0.4	
G								H2	62	J2	63	G1	M2	9	10	5.6	1.4	0.2	
H									H3	J1	H3	H2	M2	16	17	9.5	21.9	2.3	EXTERNAL VARIABLE
I										J3	I2	L2	L3	2	3	1.7	2.0	1.2	POOR VALUE
J											J3	J2	M3	19	20	11.2	9.5	0.8	
K												L1	M2	0	1	0.5	6.5	13	POOR VALUE
L													M3	5	6	3.4	3.0	0.9	
M														26	27	15.6	14	0.9	

Table 3

Function-cost matrix for a compass

Sr. No.	Component	Function	I (%)	C (%)	Value Index I/C
1	Pencil leg	Contain marker	16	25	0.6
2	Pencil lock	Apply leverage	5	4	1.3
3	Lock rivet	Create fulcrum	1	1	1.0
4	Handle	Access Assembly	0	9	0.0
5	Screw	Connect Components	12	7	1.7
6	Nut	Induce torque	7	3	2.3
7	Washer	Maintain Friction	1	4	0.3
8	Pinleg	Hold Pin	12	20	0.6
9	Pin	Anchor Axis	21	4	5.3
10	Pencil	Deposit graphite	25	23	1.1

Creation Phase

The objective of this phase is to create ideas for value alternatives to accomplish the functions defined in the previous phase. The first step is to try answering the question 'What else will do'? This phase requires creativity to be the focal point. Brainstorming is a very effective way of promoting creativity. In brainstorming 'free wheeling' is permitted. Two powerful techniques to promote creativity are:

a) **Establish positive thinking:** Here we divorce the judicial part of the mind from the creative part by insisting that we do not attempt to judge an idea simultaneously when it is being created.

b) **Develop creative ideas:** This is done by cultivating uninhibited thinking and developing a multitude of ideas and approaches for accomplishing the defined functions. The desired thing at this point is a large number of ideas, no matter whether they look ridiculous. A number of check-lists and idea-stimulators could be used for the purpose.

Evaluation Phase

The objective of this phase is to select for further analysis the most promising of the ideas generated during the creative phase and to subject the ideas to a preliminary screening to identify those which satisfy the following criteria:.

- Will it work?
- Is it less costly than the present design?
- Is it feasible to implement?

This phase of the Job Plan together with its supporting techniques must be undertaken with both care and diligence, for it is here that the judicial part of the mind is brought into active use. There are four techniques associated with this phase:

a) **Refine and combine ideas:** The ideas must be practicable and to make them so we may have to refine an idea or combine two or more than two ideas.

b) **Establish cost on all ideas:** As an idea or combination of ideas is being refined, an estimated cost should be calculated. What are the potential costs of implementing the idea and what are the resultant savings implied?

c) **Develop function alternatives:** This makes further use of the information developed in the evaluation of functional relationships to mould the individual functional solutions into total solutions.

d) **Evaluate by comparison:** When these rough total solutions and their related estimates of costs have been established they are compared to determine which one will provide the greatest value advantage.

The evaluation of value alternatives may have to be done on multiplicity of attributes—both tangible and intangible. The decision matrix approach can be a very effective way of multi-criteria evaluation. Here each criterion is assigned a relative importance and a normalised value score is allocated to each alternative on each attribute. The total weighted score is obtained for each alternative and the greatest score determines the preferred alternative.

Example 4: For the compass of Example 3 suppose the criteria for evaluation are: Ease of use, Ease of manufacturing, Safety, Quality and Attractiveness with the relative percentage weightage of 15, 30, 20, 25 and 10, respectively. Then the four value alternatives can be compared by using decision-matrix approach as shown in Table 4. As can be seen value alternative A_2 is the best as it gives the greatest total weighted score.

Table 4
Decision-Matrix to evaluate value alternatives for a compass

Sr. No.	Value Alternative	Attributes					Total Score
		Ease of use (15)	Ease of Manuf. (30)	Safety (20)	Quality (25)	Attracti-veness (10)	
1	A_1	100	30	50	70	100	61.50
2	A_2	80	100	100	50	50	79.50
3	A_3	30	50	70	100	70	61.50
4	A_4	50	60	80	50	60	57.00

Investigation Phase

The three techniques of this phase further refine the selected ideas into workable and acceptable solutions providing lower cost methods for performing the desired function. The three techniques are:

a) **Use Company and Industrial Standards:** Within a standard lies tried and proven solution to a problem. We should try to use standards to the extent possible.

b) **Consult Vendors and Specialists:** The vendor may prove to be invaluable source of help in VE programme because he knows more about his product and its potential

iii) Avoid passive or indirect verbs.
iv) Avoid goal-like words or phrases, such as improve, maximise, minimise, optimise, etc.
v) List a large number of two-word pairs and then select the best pair.

Example 1: Some functional definitions are:

Product	Function
a) Mirror	Reflect light
b) Brake	Arrest motion
c) Clutch	Transfer power
d) Election tube cover	Shield Tube
e) Cigarette lighter	Provide ignition.
f) Light bulb	Emit light
g) Screwdriver	Transfer torque
h) Coffee cup	Hold Liquid.

b) **Evaluate Function Relationship:** This technique attempts to determine relative importance of various functions. Through this technique a descending order of importance of the functions is established alongwith the relative value of their importance.

A paired comparison technique to determine the numerical value of various functions is very simple and effective to use. In this, pairs of functions are compared and it is sought to determine which is more important and whether the degree of variation is major, medium or minor. Suppose we are comparing A with B. Then A-3 will mean that A is more important than B and there is a major difference in their importance. B-1 would have meant that B is more important than A but there is a minor difference only. This way a total number of n (n−1)/2 pairs are compared and values entered in a cell if n-functions are to be compared. Then the score is obtained by adding all the numerals following a particular function. The function score divided by the total score gives relative importance of that function.
Function description should be derived for the product and all its components. The evaluation process also helps to find out whether it is a primary (basic) function or a secondary function. The basic function will have the highest score in the above-mentioned process of evaluation. The technique not only establishes the basic and secondary functions but also identifies those functions which are present because of specifications and requirements or present design approach. Generally, a product or component will have only one basic function and a number of secondary functions. If you have more than one basic function, it must be a mere restatement of the other.
Example 2: Here we illustrate the application of function phase on the item. 'Door Assembly' of a refrigerator. The two-word definition of each part or component of the door assembly is shown in Table 1 in the form of Functional Analysis Worksheet. The paired comparison of various functions is shown in Table 2. Figure I shows the graphical display of the relative importance of various functions which identify them as basic and secondary. You can also distinguish functions which are there due to present design approach as well as due to specifications and requirements. The basic function of the door assembly emerges as 'Provide Security' with the highest score. Having defined the functions, the next step is to establish the worth of each function. The objective is to determine the poor value functions and to obtain a reference point from which the cost of alternatives can be compared.

Function cost matrix is an effective technique of finding out the relative importance of a function and the percentage cost incurred in attaining that function. If the importance is low and cost is high then it reflects a poor value area.
Example 3: Table 3 shows a Function Cost matrix for a typical product (compass). It describes in two-words the function of a component. Its percentage importance (I) as obtained by paired comparison and percentage cost (C) obtained by allocating cost to attaining that function by that component. The Value index is given by I/C. A low value of I/C ratio shows a poor value area

Item: Door Assembly

Table 1
Functional analysis work sheet

Qty	Description	Function: Verb	Function: Noun	Part: Basic	Part: Sec	Assembly: Basic	Assembly: Sec
1	Outer Pan	Provide	Support		X		
		Provide	Security	X		X	
		Permit	Rotation		X		
		Provide	Appearance		X		
4	Gusset Plates	Provide	Strength	X			
1	Handle	Provide	Location	X			
	Reinforcement	Provide	Stiffness		X		
1	Centre Stiffner	Provide	Stiffness	X			
1	Lock Assembly	Provide	Fastening	X			
2	Sleeve door	Provide	Location		X		
	Hinge	Provide	Rotation	X			
		Support	Weight		X		
1	Handle	Facilitate	Grip		X		
		Facilitate	Opening	X			
1	Liner	Accommodate	Articles	X			
		Prevent	Leak		X		
		Provide	Insulation		X		
		Support	Insulation		X		
4	Retainer	Apply	Force	X			
	Strip (Gasket)	Provide	Location		X		
1	Gasket	Provide	Seal	X			
4	Magnetic Strip	Provide	Force	X			
1	Decorative Strip	Provide	Aesthetics	X			
—	Insulating Glass	Prevent	Conduction		X		
	Wool	Provide	Insulation	X			

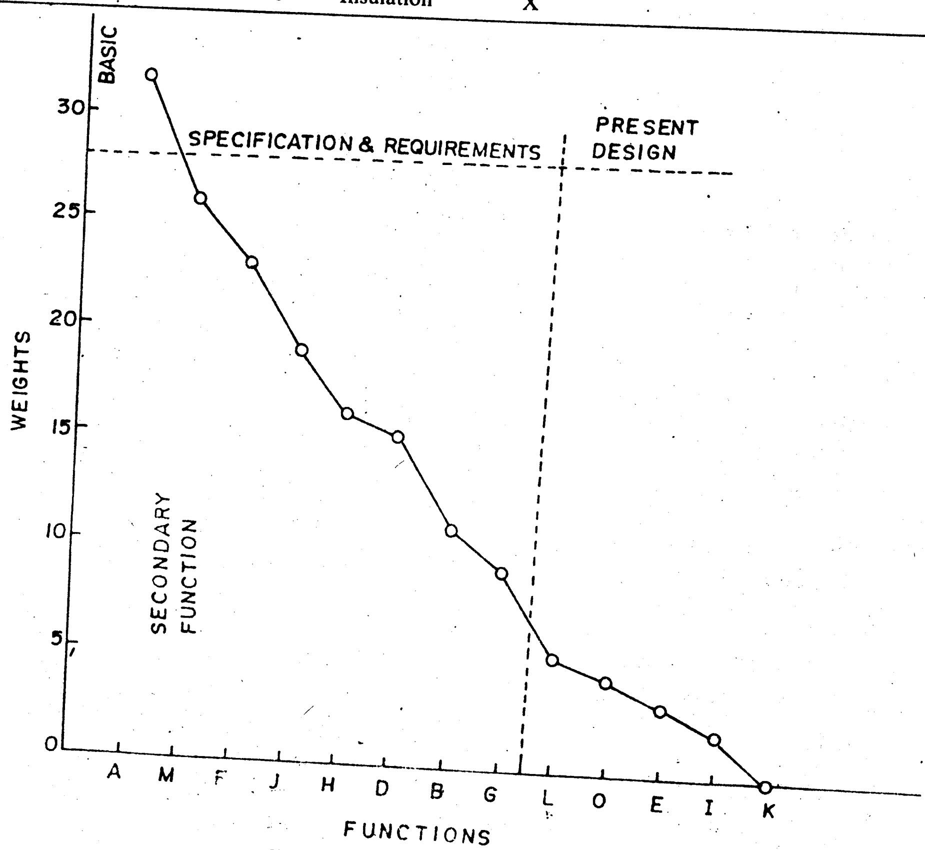


Figure I: Weight Factor vs. Function

describing the function. In Figure III the highest functional cost is Rs. 17 to accomplish the function 'Product Corners' in the Packaging. It thus identifies the high cost functions where potential for savings exist. In the proposed packaging, the total cost could be reduced to Rs. 77.96 per unit as compared to Rs. 87.84 per unit in the existing design, thus giving a saving potential of Rs. 69, 78,240 per annum.

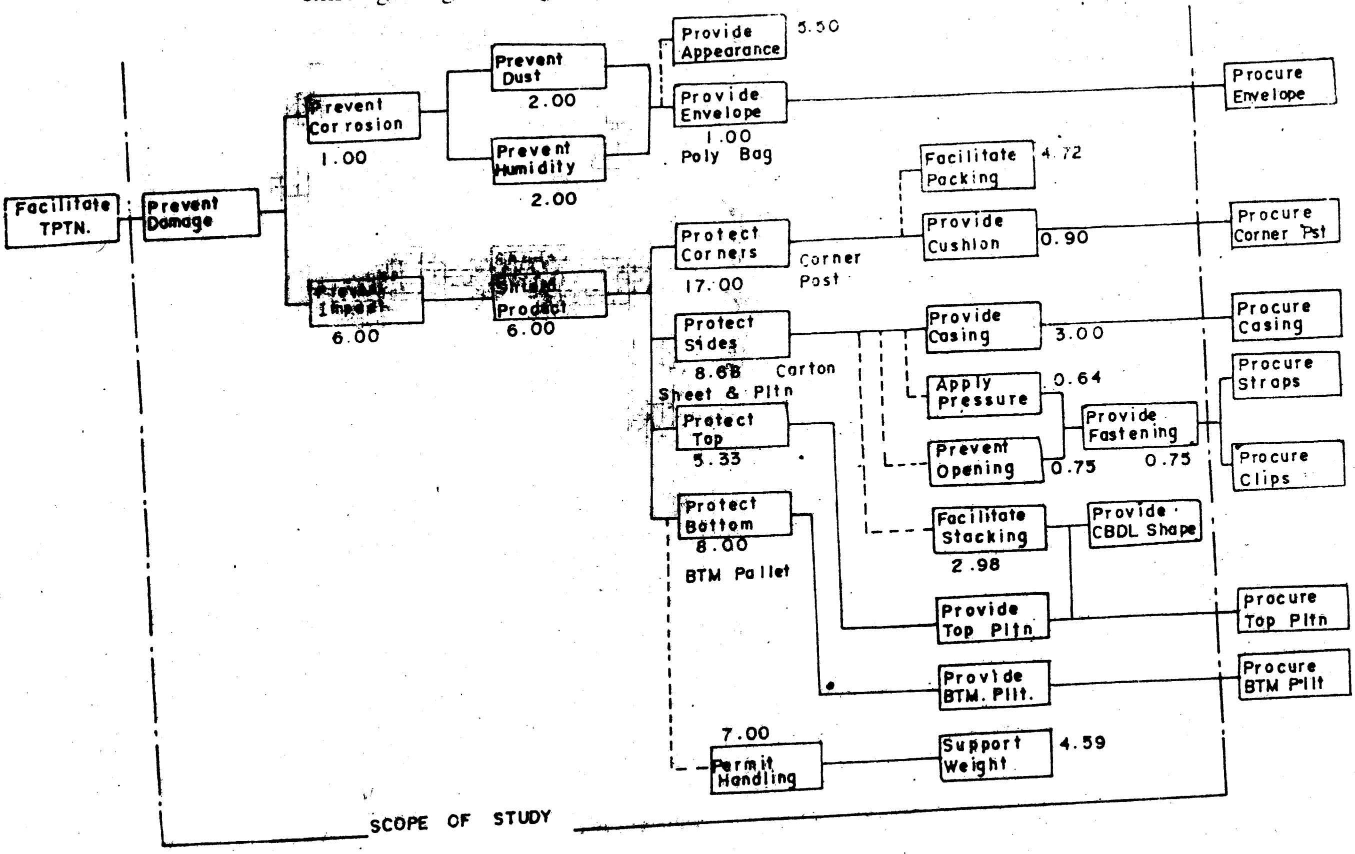


Figure III: Fast Diagram Refrigerator Packaging (Existing)

14.6 SOME CASE STUDIES IN VALUE ENGINEERING

Value engineering has been very extensively applied in product design, systems and procedures and a very large number of case studies have been reported in books and journals on Value Engineering. In many of these case studies large amounts of savings have been reported. In Indian industries value engineering applications have been reported from TISCO, Escorts, TELCO, Kelvinator, Railways and other units in public and private sectors. It is also known to have been applied in Indian Army and Navy.

Some very simple case illustrations are as follows:

i) **Problem:** Make design changes to reduce the construction cost in a large garage for a trucking firm.

Function: Protect Trucks

General Explanations and Solutions: Company management had drawn plans to construct a large garage complex for its fleet of trucks. The value Analysis pointed out that trucks were on road on an average of 20 out of 24 hours. What was really needed was a large parking area and a small maintenance building.

ii) **Problem:** Reduce the number of guards by combining entrances to classified areas.

Function: Monitor doors

General Explanations and Solutions: It was difficult to reduce the number of doors to the classified areas. However, it was found that each guard could monitor and control two entrance doors by using CCTV and electric door locks.

iii) **Problem:** Reduce the manufacturing cost of gasoline tanks for the landing aircrafts.

Function: Hold gasoline

General Explanations and Solutions: Initial design was inherently very costly. It was discovered that standard 55 gallon steel drums could be easily modified, coated and used.

iv) **Problems:** Reduce the manufacturing cost of oil dipstick

Function: Measure Oil

General Explanations and Solutions: It was discovered that standard dipstick used in large numbers could be more economically purchased from outside vendors instead of making

14.7 BEHAVIOURAL AND ORGANISATIONAL ASPECTS OF VALUE ENGINEERING

Basic foundation of VE is structured around the effective use of people in teams. If team work is not properly harnessed it may not achieve major cost reductions. Some problems and roadblocks that are commonly encountered in the VE process are:

i) Individuals involved in VE usually have other jobs and are already busy.

ii) Teams may be inherently conservative, non-coherent and may avoid decisions and waste time.

iii) Individual members of the team may have vested interests in resisting changes.

The success of VE study is enhanced if organisational and behavioural aspects are considered early in VE process. Hence the importance of the general phase of the VE Job Plan. Some important factors are:

a) **Organising for VE:** Organising of VE function itself is very important. There are many alternative ways of doing it and there are many question to be answered. Size, composition, level of participation, leadership are some of the relevant issues. VE may be organised as a team of multidisciplinary areas coordinated by a value engineer/industrial engineer. It may be an independent cell in staff level or it may be visualised as a philosophy-conditioning of mind so that every individual be trained to be value conscious so that it gets reflected in his decisions and attitudes towards problem solving. The right choice is contingent upon various situational parameters.

b) **Decision Making:** How are decisions to be made in a team? What are the external influences? What are the processes of approval? Are there some relevant issues that must be debated in the early stage of VE process?

14.8 BENEFITS OF VALUE ENGINEERING AND CONCLUDING REMARKS

Value Engineering helps in improving efficiency as well as effectiveness of products, systems and procedures. In general, VE,

i) enables people to pinpoint areas that need attention and improvement.

ii) provides a method of generating ideas and alternatives for possible solution to a problem.

iii) provides a means of evaluating alternatives including intangible factors.

iv) provides a vehicle for dialogue.

v) documents the rationale behind decisions.

vi) materially improves the value of goods and services.

In conclusion, it must be re-emphasised that VE/VA is an extremely powerful methodology for cost reduction and value improvement and is becoming more and more popular. It is applicable to all areas: hardware, products, services, systems or procedures, and in all functional processes: purchasing, designing, producing, packaging physical handling and distribution.

14.9 SUMMARY

Value Engineering/Value Analysis is a systematic and organised effort to identify the functions of a product, system or procedure and to attain that function with minimum cost without jeopardising quality, aesthetics, appearance etc. The Systematic procedure is known as VE Job Plan. Its phases include General Information, Function, Creation, Evaluation, Investigation and Recommendation. Each phase has a set of techniques associated with it. FAST diagram is another powerful technique for VE. Other important techniques are functional analysis, function-cost matrix, paired comparison and decision matrix. Value Engineering requires a good team spirit and an effective organisation. Benefits of VE in cost reduction and value improvement are tremendous. It is equally applicable to hardware and software projects.

14.10 KEY WORDS

Brainstorming: The process of generating creative ideas in a group by permitting free and uninhibited discussions among the team members.

Decision Matrix: A technique of evaluating finite number of alternatives against a multiplicity of factors.

Esteem Value: The properties, features or attractiveness which create a desire to possess the article.

FAST: Function Analysis System Technique; it looks like a network representation of various basic and secondary functions showing their inter-relationships.

Function: The term used to mean the purpose or use of a product.

Function Analysis: A technique to describe function of a product or system using two words—a verb and a noun.

Function Cost Matrix: A tool for identifying poor value areas by showing percentage importance of a function in a product and percentage cost spent in accomplishing that function.

Job Plan: A systematic procedure consisting of seven phases to carry out a Value Engineering Project.

Mental Roadblocks: Conditions of mind due to beliefs, resistance, fear etc. which retard creativity and idea generation.

Primary (Basic) Function: It is the basic or specific purpose for which the component or assembly was designed.

Paired-Comparison: A technique of determining relative importance of functions in Value Engineering by comparing two functions at a time.

Secondary Function: A function which does not directly contribute to the basic function or is only needed to support the achievement of a primary function playing enabling role.

Scope-lines: Used in FAST diagram to delineate the scope of responsibility of VE study.

Unnecessary cost: Also termed as hidden or invisible cost which does not improve the quality, features required by customer or the product utility but only increase the cost for example, materials handling cost.

Use value: The properties which accomplish a use, work or service. The use value is equal to the value of the functions performed.

Value: A composite of product quality and cost considerations expressed as a ratio of quality to cost.

Value Engineering (Value Analysis): A systematic organised approach to determine the function of a product and system and find least cost ways of achieving it.

Value Index: Ratio of relative importance of a function to its relative cost.

Vendor: Supplier of materials, products or services who can play an effective role in cost reduction and value improvement.

Worth: Relative importance of a function.

14.11 SELF-ASSESSMENT QUESTIONS/EXERCISES

1 Identify five products in your day-to-day life and determine reasons for poor Value in them.

2 Applying the Function Analysis approach write down the basic functions of the following objects in two words:
   i) Umbrella
   ii) Ash Tray
   iii) Paper Weight
   iv) Wrist Watch
   v) House.

3 Write true or false against the following statements:
   i) Value engineering aims at reducing the cost by compromising on the desired quality.
   ii) Basic functions can be many in a product.
   iii) It is good for creativity if an idea is evaluated immediately after generating it.
   iv) Value Engineering is equally applicable to products, systems, procedures, services.
   v) L.D. Miles developed the FAST.

4 Choose the most appropriate answer from the following:
   a) Value Analysis concepts were developed by:
      i) Arther E. Mudge
      ii) F.W. Taylor
      iii) G.B. Dantzig
      iv) Henry Gantt
      v) Frank Gilbreth.
   b) The basic function of a telephone is to:
      i) transmit message
      ii) provide status
      iii) provide safety
      iv) permit dialogue
      v) allow discussion.
   c) The tie clip as product is:
      i) primarily use value-oriented
      ii) primarily esteem value-oriented
      iii) substitutable by a paper clip.
      iv) not amenable to Value Engineering concepts
      v) too trivial for applying Value Engineering.

5 Suppose the following five attributes are identified to evaluate a value alternative initial cost; functional performance; reliability and maintainability; product appearance; and, dependence on supplier. Use paired comparison approach to determine the relative importance of these attributes.

6 Identify the basic and secondary functions of a typewriter and arrange them in a descending order of importance.

7 Write an essay on how to organise value engineering function in an electronic industry.

8 Why are suppliers sometimes helpful in value analysis programmes? How can they help? Does it violate your concept of good business ethics to involve them in your problems?

9 Critically examine the following statement: "Value Engineering is more of a human relations, team building and motivation programme than anything else".

10 Study the following situation and attempt to answer the questions raised.

Thomas is a purchasing manager of a company making do-it-yourself power tools. The president of the company entrusted him the task of cost reduction through value analysis.

Thomas organised a display of all bought out parts and sub-assemblies and the fancy Drill-A-Thon, made of castings, stampings and termings to draw the most attention. It had been designed and turned over to a supplier before purchasing became a separate profit centre under the president. In response to his queries to improve the assembly he got the following responses from three visiting salesmen.
The first company said that they would really gain price advantage if plastic instead of metal was accepted. The second company offered to make the product with fewer parts while the third company suggested that the best way was to assemble it within and they would supply parts at rockbottom prices.

Vice President of the Deen Dayal Industries Pvt. Ltd. who are the present suppliers rang up Thomas to express his concern in offering the products his company had been supplying for long to others and wondered whether these newcomers could make a better offer. He expressed a desire to be given a chance to reduce cost by trying value analysis. The chief design engineer also ridiculed the idea of going for plastic in place of metals and saw in it a conspiracy to cheapen their merchandise.

Thomas thus faces a conflict of view points. The president has given an ultimatum to reduce cost by at least 5 per cent, and his company's design experts are uneasy about outside interference. Would-be-suppliers are anxious in re-designing Drill-A-Thon to fit their own shops Now:

i) How can Thomas start a sound value analysis programme?
ii) How should he handle the reactions of his present supplier?
iii) In what way can he use the offered help of the would-be-suppliers who can be genuinely helpful?

14.12 FURTHER READINGS

Demarle, D.J. and L.M. Shillito, 1982. Value Engineering, Chapter 7-3 in G. Salvendy (ed)., *'Handbook of Industrial Engineering'*, John Wiley: New York.

Dobler, D.W, Lee, Lamar Jr. and D.N. Burt, 1984. *Purchasing and Materials Management: Text and cases*, McGraw-Hill Book Co.: New York.

Greve, J.W. and F.W. Wilson, (eds.) 1967. *Value Engineering in Manufacturing*, Prentice-Hall: Englewood-Cliffs.

Miles, L.D. 1961. *Techniques of Value Analysis and Engineering*, McGraw-Hill: New York.

Mudge, Arther E. 1971, *Value Engineering: A Systematic Approach*, McGraw-Hill: New York.

Reuter, V.G. 1985. Becoming Competitive with Value Engineering/Value Analysis *"Journal of Systems Management"*. (October 1985, 24-31).

Saxena, G.C. 1985. *Application of Value Analysis Techniques in a Refrigerator Industry*, unpublished M.Tech. Thesis in Ind. Engg., I.I.T.: Delhi. March.

UNIT 15 QUALITY ASSURANCE

Objectives

After successful completion of this unit, you should be able to:

- appreciate the role of quality control, quality assurance and quality assessment
- design a single sampling plan
- draw an operating characteristic curve for a given single sampling plan
- compute the AOQL
- assess process variability
- draw up an $\bar{X}$ and R Chart
- decide whether a process is in control or not.

Structure

15.1 INTRODUCTION

You all must have come across the word **quality** in different contexts. All of us look for good quality in goods and services. We all realise the fact that the major achievement of industrial revolution has been the ability to mass produce a variety of goods of uniform quality, the classic example being the automobile. You will agree that the characteristic which sets apart Japanese goods as a superior class, is precisely their quality. In this unit we will describe the assessment, control and management of the quality function in an industrial organisation. We will develop a simple working definition of quality and then outline the assurance aspects of quality management. Statistical techniques have contributed substantially to the success of modern quality control. Two of the important statistical techniques, viz., Acceptance Sampling and Control Charts will be developed in detail. Finally we will outline the role of computers in the area of quality control.

While this unit will outline methods and techniques which are useful in quality control and quality management, a successful quality improvement will depend on the skill and efficiency of the manager in using these techniques.

15.2 CONCEPT OF QUALITY

Even though we all talk of quality, it is not easily defined. Before we give a definition, it will be a good idea to give your own definition.

Activity A

In the space provided, write down your definition of quality, in your own words, also. Also write down how quality can be measured.

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....

One of the accepted definitions of quality is **fitness for use**. An equally good definition is **conformance to requirements**. Note that in both the definitions quality is defined relative to use, rather than as a general characteristic that may be intangible. By this simple, yet practical definition, if a product or service lives up to expectations, it is of high quality. On the other hand, extra fine finish or using materials that are far stronger than required does NOT add quality to an item unless it somehow causes the item to conform to its requirements better. To appreciate the definition of quality, try the following activity.

Activity B

Judge the quality of the set of notes you are reading based on these definitions.

....

....

....

You will notice that the same item may be perceived to be of quite different quality based on individual perception of end users. You should always keep this point in mind.

15.3 COST OF QUALITY

The term cost of quality is often a misnomer. Cost of quality is a measure of the cost to the firm for a lack of quality. It is very difficult to measure and often cannot be found in account books. One has to carefully back calculate, as most of the cost elements are hidden.

Quality costs are distributed throughout the organisation. Most organisations include only the cost of quality control departments whereas the cost of inspection, and measurement carried out in production departments are often ignored. More importantly the cost of bad workmanship; wastages, rework, etc. are often not included in quality costs. Careful examination of quality costs should account for Prevention, Assessment, Control Costs and costs due to lack of control.

"Quality is free, but it is not a gift". This statement sums up the opinion that effective permanent quality improvement is difficult to achieve. but more than pays for itself in increased productivity.

15.4 QUALITY MANAGEMENT

Quality assessment is an investigation of the level of quality being achieved. **Quality control** on the other hand, begins with assessment, and includes action taken to eliminate unacceptable quality. The typical quality control programme is based on periodic inspection, followed by feedback of the results and changes or adjustments whenever necessary. **Quality assurance** includes quality control, but it also refers to emphasis on quality in the design of products, processes and jobs and in personnel selection and training. **Total quality control** refers to the managerial commitment to quality so as to include the quality aspect in every functional area of work, production, marketing, finance and personnel. It also includes behavioural science based techniques like Quality Circles, Zero Defect Programmes. Naturally, the management of quality is an extensive area of study.

Quality assurance as an idea is quite old, but a systematic inclusion of quality assurance in organisations is a twentieth century phenomenon. Statistical methods of quality control were first proposed by Shewart in 1924, in the United States. Intensive training courses in statistical control popularised by the American and Japanese industry contributed to much of the success of quality control programme. Recently the concept of **Quality Circles** has been a runaway success in Japanese industries. A quality circle is a group of employees whose assignment is to identify problems, formulate solutions, and present their results to management with Suggestions for implementation. It is getting increasingly popular with employees and management in India also.

15.5 QUALITY ORGANISATION

A common mistake is to view quality as the responsibility of the department that produces the goods or services. Lack of conformance, however, can be a problem of design or even advertising. Consider the manufacture of automobile transmissions. If the gears are improperly designed, the transmission will fail despite the best quality of the manufactured gears. **That Quality is Everyone's Business** must be understood by everyone in the organisation.

Also, quality begins at the product concept stage and extends throughout the development, production, delivery and use of an item. Causes of poor quality can occur anywhere in the organisation, from top management to the shop floor worker, in accounting, production, sales, service or any other functional area of management (including the quality control function itself!). Some quality problems have routes outside the organisation, such as defective supplies from a vendor or incorrect specifications from a customer.

To achieve success, a major commitment to quality must be made by top management, and it must be visible to all the employees. Major quality problems often cross departmental lines, so barriers to system-wise actions must be removed. Quality improvement must be established as a positive effort rather than blaming the assignment. In general, training is the key to the success of quality control. Keeping these principles in mind, several alternatives exist for organising the quality control function.

Activity C

Ascertain from your organisation how the quality control function is set up. It may be a good idea to draw up an organisation chart.

....

....

....

15.6 ACCEPTANCE SAMPLING

One of the powerful statistical techniques of quality control is Acceptance Sampling. This technique is generally used in those situations where items are inspected in batches, generally known as **lots.** For example, you may receive a shipment of 10,000 electric bulbs and you may have to decide whether to accept the shipment or return it back to the supplier. The acceptability will depend on the acceptable quality of the lot, which in turn depends on the use and the price you are willing to pay for this quality. Suppose you decide to accept if the average fraction defective is less than 5 per cent. Then to ascertain the actual quality you may decide to inspect each and every bulb. Such a strategy of **100 per cent inspection**, however, may often be expensive and impractical. In such cases a more intelligent way is to use the concept of **Sampling Inspection.**

Activity D

Think of a common situation where 100 per cent inspection is

a) Impractical

b) Impossible

....

....

The idea of sampling inspection is to inspect only a small portion of the lot and **infer** the quality of the lot, based on the quality of the sample. Acceptance is based on the inference made from the sample and hence the technique is known as Acceptance Sampling. Typically a lot is specified by its size (N) and the fraction (f) of defectives that are expected to be present (at the most) in the lot. The principles of statistics are used in the inference process.

Interestingly the concept of acceptance sampling is no different from the strategy adopted by a typical housewife who decides whether or not a pot-ful of rice is cooked by inspecting just a spoonful of grains.

Two things must be kept in mind. In order that sampling inspection might work, the sample must be **representative** of the lot. Typically this is ensured by choosing the sample at random so that every portion of the lot has equal representation in the sample. Such a sampling is known as **Random Sampling.** Second, a sample is only representative and not identical (in characteristic) with the lot. In the inference process, therefore, a few good lots will be rejected and a few bad lots will be accepted. We can control such **sampling errors**, but they cannot be eliminated. In fact in the design of **sampling plans** we will ensure that the errors are kept below certain acceptable levels.

Sampling Plans

We will first consider a **single sampling plan** in which accept/reject decisions are based on the results of a single sample of *n* items from the lot of *n* items. Each of the *n* sample items is inspected and categorised as either **acceptable** or **defective.** Such a plan is known as **Sampling by Attributes** (we will not discuss **Sampling by Variables** in this unit. The interested reader may refer to the references cited at the end). If the number of defective items in the sample exceeds a pre-specified cut off level, *c*, the entire batch is rejected. (Depending on costs, a rejected lot may be scrapped, 100 per cent inspected or returned back to the manufacturer). Since a finding of *c* or fewer defective items in the sample implies accepting the batch, *c* is often referred to as the **acceptance level.** A Sampling Plan is specified by the values of *n* and *c*.

The sampling plan is supposed to separate good lots from bad lots. As mentioned earlier there are bound to be sampling errors. We will now study the probabilities of such error graphically, using an **Operating Characteristic Curve.**

The Operating Characteristic Curve

t is useful to have a simple picture that allows us to compare sampling plans as to how hey will react to different lots with **unknown, varying** fraction defective. Such a comparison is provided by the **operating characteristic curve** (OCC) which displays he probability of accepting a lot with any fraction defective.

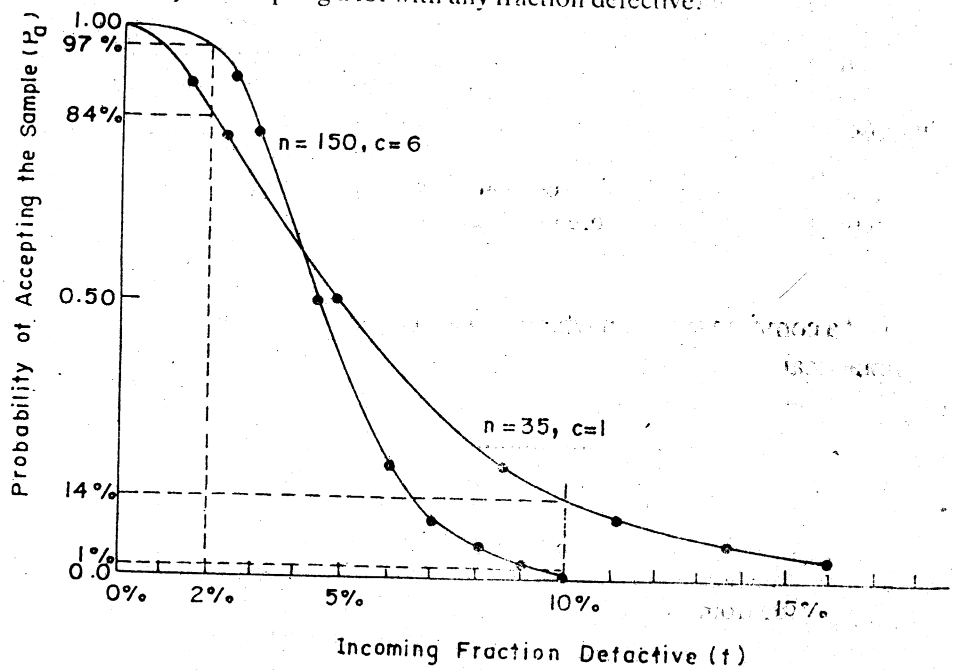

Figure I: Operating Characteristics Curve

Figure I shows OCC for two single sampling plans A and B with n = 35, c = 1 and n = 150, c = 6, respectively. For example, suppose that a lot with F = 10 per cent defectives is considered to be a bad lot and a lot with f = 2 per cent defectives is considered to be a good lot. From Figure I, it is clear that sampling plan A would stand a 14 per cent chance of accepting a bad lot. The same unfortunate error can occur with the sampling plan B, with larger sample size also, but the probability of error is much smaller. In fact it is only 1 per cent. The sampling plan B is also better at not rejecting good lots (f = 2 per cent). Sampling plan A has 16 per cent chance of rejecting a good lot whereas sampling plan B has only 3 per cent chance of rejecting a good lot.

It is not surprising that a larger sample does a better job of discriminating between good and bad lots. It has more information. However, the price for increased accuracy is higher inspection costs. The design of a sampling plan has to optimally **trade off** cost with discrimination.

The values of the ordinates of the Operating Characteristic Curve are determined from the Poisson Distribution. The actual details can be found in the advanced texts listed in the reference.

At this moment, pause for a while and check for yourself whether you have understood OCC. Do the following activity.

Activity E

a) How will the OCC change shape as

i) n is increased, keeping c constant.

ii) c is increased, keeping n constant.

b) What will be the limiting shape of the OCC.

c) Can you interpret your answers to (a) and (b).

....

....

Design of Single Sampling Plan

You have to design a sampling plan (n, c) that has an OCC that meets certain pre-specified requirements. Generally the design is based on the following criteria that are related to the probability of making either of the following errors: accepting bad lot (β) and rejecting a good lot (α). The criteria are established subjectively and ultimately should reflect the cost of accepting a bad lot or rejecting a good lot. Needless to say before α and β values can be specified, one has to decide what is a good lot and what is bad lot. Invariably this is done by specifying the lower/upper limits of fraction defective (f), as illustrated below:

AQL (Acceptable Quality Level) the fraction defective (f) that the user considers acceptable. Thus if a batch were known to have a fraction defective equal to AQL, it should not be rejected.

LTPD (Lot Tolerance Per cent Defective) the fraction defective that defines a bad lot or one that should be rejected. Of course AQL must be less than LTPD.

Producers Risk (α) the largest allowable probability of rejecting a good lot (due to statistical error). Note that a good lot has fraction defective less than or equal to AQL (generally 5 per cent).

Consumers Risk (β) the largest allowable probability of accepting a bad lot (due to statistical error). Note that a bad lot as fraction defective greater than or equal to LTPD (generally 10 per cent).

Example 1
Consider a manufacturing situation with the following values:

$$AQL = 0.02, \quad \alpha = 0.05$$
$$LTPD = 0.10, \quad \beta = 0.01$$

From Figure I you can verify that sampling plan A ($n = 35$, $c = 1$) has a probability of acceptance of 84 per cent for a fraction defective of 0.02 (AQL). In other words this plan has a 16 per cent chance of rejecting a good lot. Similarly, it has a probability of 0.14 of rejecting a bad lot with $f = 0.10$ (LTPD). Since both the values are higher than the allowed values of 0.05 and 0.01, respectively, this sampling plan is not acceptable. Only larger values of n can yield better discriminating power.

The sampling plan B($n = 150$, $c = 6$) has the probability of accepting a good lot by 97 per cent and probability of rejecting a bad lot by 1 per cent. In other words it has a α value of 0.03 and β value of 0.01. This discriminating power is even more than what is needed. The plan is acceptable but it may be possible to get the required discrimination with smaller sample size and in turn with a lower inspection cost.

One way to decide the optimal **sampling** plan is to search through several sampling plans with n values between 35 and 150 and select the one that matches α and β values more closely. An easier way is to use **Thorndike Chart** (Table 1). This chart can be used for

a) Plotting OCC, and

b) Designing a Sampling Plan.

We will illustrate the design of sampling plan using this chart. Before we move to this topic, ensure that Plan A does not meet the requirement and Plan B meets more than the requirements, by following the arguments given earlier.

To design the sampling plan follow the instruction at the bottom of the chart. Note that we have to read off $\beta = 0.01$ and $(1-\alpha) = 0.95$ rows only. We first need to find a c value for which $\mu_\beta/\mu_\alpha \leq$ LTPD/AQL. For this problem LTPD/AQL $= 0.10/0.02 = 5$. Starting with c=0, we read off $\mu_\beta=4.6052$ and $\mu_\alpha=0.0513$ and so $\mu_\beta/\mu_\alpha \leq 5$ is not satisfied. Continuing with C=1, 2, 3, 4, 5 we find that for C=6, $\mu_\beta/\mu_\alpha=14.5706/3.2853 \leq 5$. Hence we choose c=6.

To get the value of n, the limits are $n_\beta=\mu_\beta$/LTPDL and $n_\alpha=\mu\alpha$/AQL. Reading off the table we get.

$$n_\beta = 14.5706/0.10 = 146$$
$$n_\alpha = 3.2853/0.02 = 165$$

Table 1

Thorndike Chart for Single Sampling Plans

Acceptance Probability	P_a	Acceptance Number C: 0	1	2	3	4	5	6	7	8	9	10
		$\mu = nf =$ expected number defective in the sample										
β rows, entries denoted μ_β	0.010	4.6052	6.6383	8.4059	10.0450	11.6046	13.1085	14.5706	16,0000	17.4027	18.7831	20.1447
	0.025	3.6889	5.5716	7.2247	8.7672	10.2416	11.6683	13.0595	14.4227	15.7632	17.0848	18.3904
	0.050	2.9957	4.7439	6.2958	7.7537	9.1535	10.5130	11.8424	13.1481	14.4346	15.7052	16.9622
	0.100	2.3026	3.8897	5.3223	6.6808	7.9936	9.2747	10.5321	11.7709	12.9947	14.2060	15.4066
	0.200	1.6094	2.9943	4.2790	5.5150	6.7210	7.9060	9.0754	10.2325	11.3798	12.5188	13.6507
	0.500	0.6931	1.6783	2.6741	3.6721	4.6709	5.6702	6.6696	7.6692	8.6690	9.6687	10.6685
	0.800	0.2231	0.8244	1.5350	2.2968	3.0895	3.9037	4.7337	5.5761	6.4285	7.2892	8.1570
(1—α) rows, entries denoted μ_α	0.900	0.1054	0.5318	1.1021	1.7448	2.4326	3.1519	3.8948	4.6561	5.4325	6.2213	7.0208
	0.950	0.0513	0.3554	0.8177	1.3663	1.9701	2.6130	3.2853	3.9808	4.6952	5.4254	6.1690
	0.975	0.0253	0.2422	0.6187	1.0899	1.6235	2.2019	2.8144	3.4538	4.1154	4.7954	5.4912
	0.990	0.0101	0.1486	0.4360	0.8233	1.2791	1.7853	2.3302	2.9061	3.5075	4.1302	4.7712

1 To plot an OC curve for a given sample plan (n,c): (a) Find the column for your c value. (b) Divide each number in that column by n. The results are the f values for the horizontal axis. (c) The P_a values, for the vertical axis, are in the far left column.

2 To find a single sampling plan:

a) Find c for which $\mu_\beta/\mu_\alpha \leq$ LTPD/AQL.

b) Then choose any n between $n_\beta = \mu_\beta$/LTPD and $n_\alpha = \mu_\alpha$/AQL.

3 To find the acceptance probability for a given n,c, and f: (a) Multiply (n) (f). (b) In the appropriate c column, find values above and below nf. (c) In the P_a column read upper and lower limits for P_a in two rows from step (b) (interpolate, if you wish).

Hence sampling plans with size in the range of 146 to 165 will satisfy the requirement. The exact values of α and β for any sampling plan can be determined using Thorndike Chart again. The exercise at the end of the unit will give you an opportunity to design many other sampling plans and decide the exact values of Consumer's Risk and Producer's Risk.

Average Outgoing Quality

The inspection process rejects lots with high fraction defectives. After rejection either you may stop, or you may continue the inspection of all the items in the rejected lot and all defective items are replaced with good items. Such a policy is known as **Rectifying Inspection.**

In rectifying inspection, all outgoing lots consists of N items either accepted ones or rejected ones. Suppose a lot has incoming fraction defective f. If it is accepted (N – n) items remain uninspected. We, therefore, expect f (N – n) defectives in the accepted lots (assuming that the defectives found in the sample are replaced with good ones). In contrast, if it is rejected and hence (100 per cent rectified and inspected) there are no defectives. Thus if P_a is the probability that the sampling plan will accept the lot,

$$\text{Outgoing fraction defective} = \frac{(P_a)(f)(N-n) + (1-P_a)(0)}{N}$$

$$= (P_a)(f)\left(\frac{N-n}{N}\right) \simeq (P_a)(f)$$

A plot of outgoing fraction defective against incoming fraction defective (f) is generally called the **Average Outgoing Quality** (AOQ) curve. Figure II shows the curve for sampling plan B (n = 150, C = 6) of the earlier example. This curve has a surprising property that, as f increases, there comes a point at which the outgoing fraction defective actually begins to improve. The reason being that the sampling plan rejects most bad lots and they are rectified through 100 per cent inspection.

The most critical incoming fraction defective f gives the worst outgoing quality. On the average, the value of that critical f is not important but the corresponding outgoing fraction defective generally known as **average outgoing quality limit** (AOQL) is extremely useful. No matter what the incoming fraction defective is, the long-run average outgoing fraction defective will not be worse than AOQL.

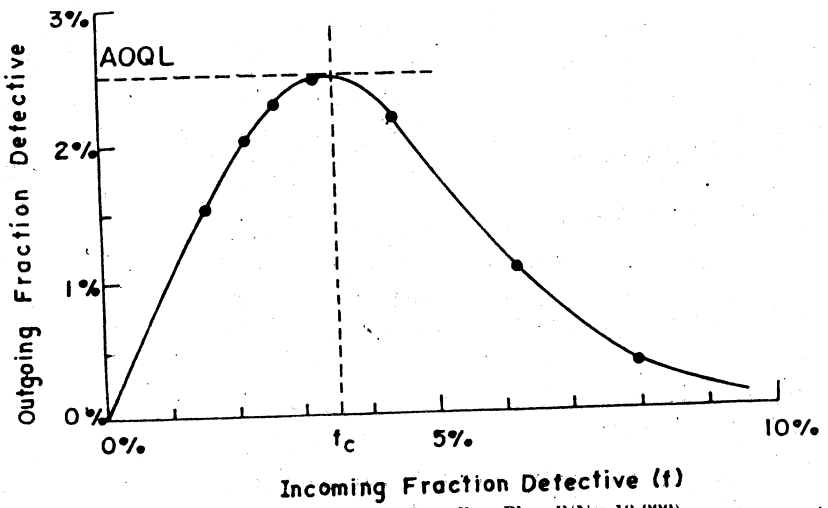

Figure II: AOQ Curve for Sampling Plan B(N = 10,000)

You do not have to determine AOQL by plotting the AOQ. One can use the following AOQL factor table. To get the AOQL simply use the formula,

$$\text{AOQL} = (\text{AOQL factor})\left(\frac{1}{n} - \frac{1}{N}\right)$$

Table 2
AOQL Factor

Acceptance Number (C)	AOQL factor (Y)
0	0.3679
1	0.8400
2	1.3711
3	1.9424
4	2.5435
5	3.1682
6	3.8120
7	4.4720
8	5.1457
9	5.8314
10	6.5277

Convince yourself that you understand the mechanism of determining AOQL by doing the following exercise.

Activity F

a) Using OCC for sampling plan B draw the AOQ curve over the range of 0-10 p cent fraction defective and determine AOQL.

b) Verify your answer to (a) using AOQL factor in Table 2 and the formula.

Many managers prefer to use the AOQL as a criterion for designing a sampling plan rather than trying to decide on values of AQL, LTPD, α and β. Dodge and Romig (1959) present tables that are designed for this purpose. In fact these tables meet the requirement of a specified AOQL and minimise the expected number of items inspected per lot.

The OCC approach and AOQL based approach are but two of the many other approaches that can be used to design a sampling plan. Choice among them is a match of personal experience, the exact situation and the objectives of the organisation. Regardless of the approach, all sampling plans have both an OC curve and an AOQ curve, so the principles discussed in this unit can be used to evaluate any sampling plan.

Double and Multiple Sampling

Extensions of the single sampling plans to double and multiple sampling plans are also available. In a double sampling plan, after the first n_1 samples have been inspected there are three choices depending on the number of defectives found:

1 reject the lot
2 accept the lot, and
3 draw a second sample of n_2 items.

If choice (3) is made the final accept/reject decision is made on combined sample of $n_1 + n_2$ items. A multiple sampling plan operates in the same way, but with more than two samples. Double and multiple sampling plans reduce inspection costs because many accept/reject decisions are made based on the first sample which is smaller than that of the single sampling plan. However, single sampling plan is more common and easy to use. Details of multiple sampling plan are found in references.

15.7 PROCESS CONTROL

Variability

All products and services have a certain amount of natural variability because of variations in the input as well as imperfections in the process. For example, different quality of raw materials could have been used and different quantities of chemicals could have been used in the process. This **process variability** may be measured by the process standard deviation σ, which indicates how much the products will vary even if the process is in control.

Products have to meet **specified tolerances** imposed by their intended use. Accordingly the natural variability must be substantially smaller than the specified tolerance. This is explained in Figure III in which the central line is the desired average of the process and the dashed lines are the '3-Sigma limits' representing the natural process variability.

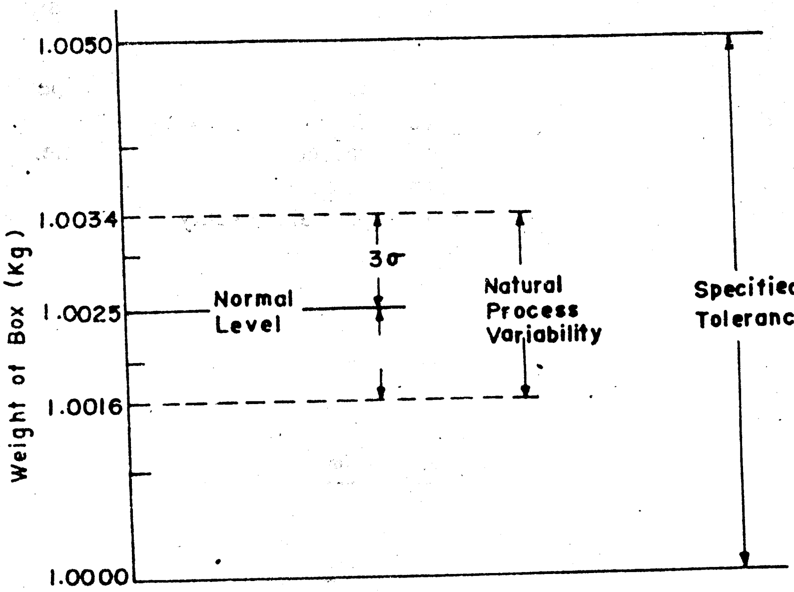

Figure III: Process Variability

It can be shown that variations of more than 3σ from the process average are very unlikely. In fact it is about 0.25 per cent if the process follows the normal distribution and definitely less than 5% for most processes. The solid lines represent the tolerances specified by the intended use of the product.

Within the specified tolerances, a certain amount of process variability is to be expected. However, it is the goal of the **statistical process control** to determine when the process variability is getting out of hand, so that corrective action can be taken, preferably before the required tolerances are violated. This is generally achieved by a **Control Chart**

Control Chart

In order to provide rapid feedback to an ongoing production process, methods somewhat different from acceptance sampling are appropriate. Samples are taken as soon as they are available, rather than waiting for the completion of a lot. This affords the opportunity to detect unplanned changes in the process, shortly after they occur and take a quick action, such as adjusting the machine.

The most common device used for this purpose is Shewart Control Chart introduced in 1931. The **control chart** is a visual display of the result of an inspection process incorporating carefully derived limits to indicate unusual behaviour. A control chart can be based on categorical information or actual measurement. Accordingly, they are called **control chart for variables** and **control chart for attributes.** Since control chart for variables are more commonly used and more powerful, we will describe them first.

The control chart is based on the idea that the average of a sample of several items wil tend to cancel out the normal process variability, so that undesirable changes in the process will be more visible. We will illustrate the idea through an example.

$\bar{X}$ and R Charts

Consider XYZ Company that uses an automatic machine to fill 1kg. boxes of sugar. The tolerances are specified as 1.000 kg. on the lower side (legal requirement) and 1.005 kg. on the high side (no point wasting sugar). Since the spread is only 0.005 they selected a machine that has a natural process variability of $=0.0003$. The three sigma limits of the machine therefore are $3(.0003) = .0009$ kg. above and below the mean. The spread is .0018 which is narrower than the specified tolerance of .005. They adjust the machine to fill boxes with an average 1.0025 kg. half way between the tolerance limits.

An $\bar{X}$ Chart (Average Control Chart) was set-up to detect when the machine goes out of control. In order to reduce the natural process variability, samples of $n = 5$ boxes were weighed, and the average weight per box, $\bar{X}$, was recorded for each sample. Figure IV shows the control chart used for this machine and the four points plotted on the chart represent the $\bar{X}$ values from four samples (a total of twenty 1 kg. boxes). We shall examine the details of the chart.

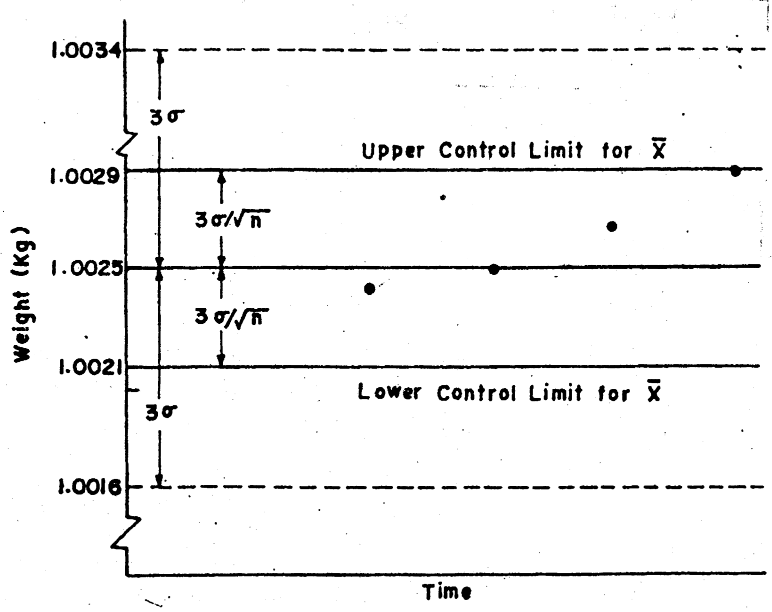

Figure IV: $\bar{X}$ Chart

There is an apparent trend in $\bar{X}$. The samples seem to be getting progressively heavier. However, appearances notwithstanding, the trend in the Figure IV may be $\bar{X}$ due to random fluctuations. It is for this reason that we must incorporate the concept of **statistical significance** in our discussion. The standard deviation of the sample average is expressed through the formula,

$$\sigma_{\bar{X}} = \sigma/\sqrt{n}$$

Therefore, the averages of $n = 5$ boxes of sugar should have a standard deviation of $\sigma_{\bar{X}} = 0.0003/\sqrt{5} = 0.000134$ kg. The control limits in Figure IV represent 3 sigma limits and are therefore $(3)(0.000134) = 0.0004$ above and below the intended average of 1.0025. If a sample average falls outside these control limits the deviation from the process average is **statistically significant.**

The fourth sample X is on the control limit and therefore there is a strong statistical evidence that more sugar is put into the boxes than what was intended and the machine needs adjustment.

The R Chart (Range Control Chart) is also used to control the processes. The range of a sample is the largest value minus the smallest. An R chart is appropriate if process sometimes goes out of control in such a way that there is inconsistency in the values but no shift in the mean value of the process. For example, a worker who is basically good might produce an inconsistent set of sizes (of some manufactured product) when he is fatigued. The R chart used to plot the data of XYZ Company appears in Figure IV.

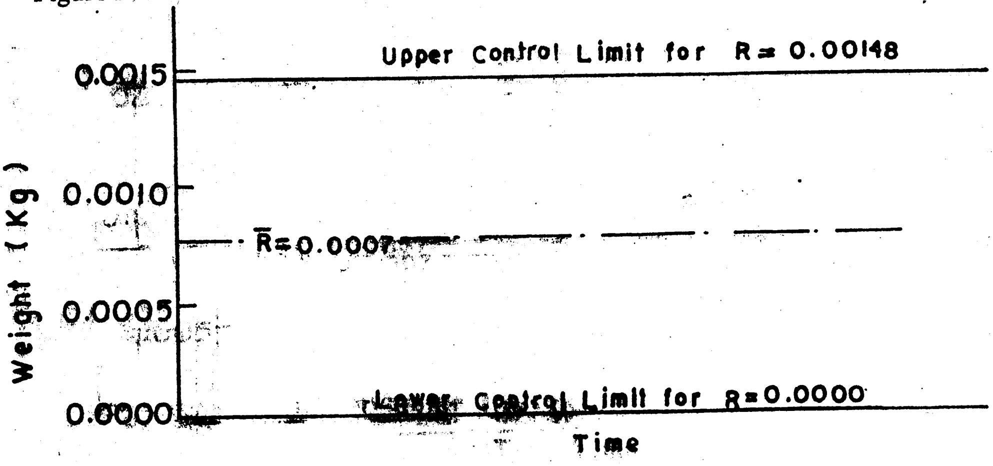

Figure IV: R Chart

The control limits for R chart are determined differently. There is no need for lower control limit which is generally (for $n \leq 6$ it is zero) zero. Table 3 is used to set the upper control limit for an R chart and factor D_2 from the table is multiplied by the process standard deviation, σ. In the case of XYZ Company data, $D_2=4.918$ (for a sample size of 5) and hence upper control limit=(0.0003) (4.918)=0.00148. As can be seen in Figure IV no statistically significant shifts are present.

Table 3
R Chart Factor

Sample Size	D_2
2	3.686
3	4.358
4	4.698
5	4.918
6	5.078
7	5.203
8	5.307
9	5.394
10	5.469

Activity G
Verify the control chart for the example given in Figure IV. The data regarding the samples as in Table 4.

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Table 4
Weights of Twenty 1-kg. Boxes

Box	Sample 1	Sample 2	Sample 3	Sample 4
1	1.00218	1.00266	1.00266	1.00306
2	1.00298	1.00242	1.00290	1.00266
3	1.00210	1.00258	1.00223	1.00234
4	1.00226	1.00250	1.00250	1.00322
5	1.00258	1.00234	1.00301	1.00322
Average	1.00242	1.00250	1.00266	1.00290
Range	0.00088	0.00032	0.00078	0.00088

Determining the **sample size** is an important decision. It is common to use n = 4 or n = 5 in order to obtain low cost feedback. Large samples such as n = 15 or 20 are necessary if the process standard deviation is large. To a large extent this will depend on the rate of production, convenience and other considerations as well. Similarly, it is important to decide the **frequency** of sampling. It should be in general proportional to the average frequency of out-of-control conditions. It is a fairly complex decision to make if one were to look for some optimality. Generally, it is decided by convenience.

Other Control Charts

There are several other control charts, including the p-chart which is used to control the process when the measurement is by attributes. In other words the decision is only to decide whether or not the sample item is acceptable. No measurement is taken. For example in using the GO/NO GO gauges one gets only such a measurement.

The p-chart is based on the fraction defective, p, in a sample of n items. If p_0 represents the normal process defective (i.e. when the process is in control) then the 3 sigma control limits are,

This is based on the fact that the number of defectives has the binomial probability. The control chart is used just like an $\bar{X}$ chart, except that the fraction defective p is calculated rather than $\bar{X}$ for each sample of n items and a lower control limit is often omitted.

$$p_0 \pm 3\sqrt{\frac{p_0(1-p_0)}{n}}$$

This is based on the fact that the number of defectives has the binomial probability. The control chart is used just like an $\bar{X}$ chart, except that the fraction defective p is calculated rather than X for each sample of n items and a lower control limit is often omitted.

Sample sizes are typically larger for p-charts then for $\bar{X}$-charts. Since the information content of a yes/no measurement is much smaller than the actual variable measurement, it can only be expected. In fact, the required sample size can be computed approximately from the following formula.

$$n = \left[\frac{1.645\sqrt{p_1(1-p_1)} + 3 \quad p_0(1-p_0)}{p_1 - p_0}\right]^2$$

In this formula p_0 is the normal process fraction defective, p_1 is the specified fraction defective that is unacceptable. (p_0 like AQL and p_1 is like LTPD in acceptance sampling).

For example, consider ABC Company that makes ready-made shirts. It has been found that 4 per cent of the shirts are defective when the process is under control. ABC Company wants to be able to detect a shirt to 12 per cent defective on the basis of one sample of n items. The formula for n suggests a sample size of n = 197. The upper control limits will be

$$p_0 + 3\sqrt{p_0(1-p_0)/n} = 8.19 \text{ per cent}$$

15.8 USE OF COMPUTERS IN QUALITY CONTROL

Now-a-days with most of the computers including personal computers well written quality control packages are available. In some special cases these computers can be linked directly to take the sample measurements and control the process **on-line**. These packages are likely to take much of the chores associated with the lengthy calculations and make the application of quality control techniques far more easy and yet effective.

15.9 SUMMARY

Quality is fitness for use. Using this definition leads to many opportunities to improve both quality and productivity simultaneously. Many quality problems have causes that cross departmental boundaries. So a good quality management system must make the entire organisation responsible for quality. Statistical methods are important tools for quality control. They separate random variations from real assignable causes of deviations from normal. Acceptance sampling helps in deciding the quality of a large batch (lot) from an inspection of small sample. The operating characteristic curve precisely gives the risks associated with any sampling plan. The design of a sampling plan can be based on Operating Characteristic Curve as well as Average Outgoing Quality. Control charts display the results of inspecting a continuous process. This provides convenient and rapid feedback suggesting when feedback, overhaul or adjustment, may be needed. The design of control chart is based on sound statistical principle regarding the behaviour of sample mean.

The statistical methods described in this unit are used widely in manufacturing and service industry. They are also the basis for many of the commonly used, yet more complex, schemes described in the references.

15.10 KEY WORDS

Consumer's Risk: Probability of accepting a bad lot.

Producer's Risk: Probability of rejecting a good lot.

OCC: Operating Characteristic Curve.

AQL: Acceptable Quality Level.

LTPD: Lot Tolerance Per cent Defective.

AOQ: Average Outgoing Quality.

AOQL: Average Outgoing Quality Limit.

Control Limits: Limits if exceeded imply that the process is out of control.

15.11 SELF-ASSESSMENT QUESTIONS/EXERCISES

1 What is the fundamental difference between the use of acceptance sampling plans and process control charts?

2 Why are averages of samples used in control charts rather than individual readings?

3 Comment on the following:
   a) It is important to inspect the inspector.
   b) As a quality improvement programme is established, cost of quality increases.

4 In the example in the text, the sampling plan A with $n = 35$ and $c = 1$ has $\alpha = 0.16$ and $\beta = 0.14$, both too large to be acceptable.
   a) What would happen to α and β if c were increased but n remained at 35?
   b) Why do we need to increase both n and c to lower both α and β?
   c) If a batch contains 8% defective items, what is the probability that it would be rejected by the plan $n = 40$ and $c = 1$.
   d) Find a sampling plan for $AQL = 0.008$, $LTPD = 0.01$, $\alpha = 5\%$, $\beta = 10$ per cent.

5 A manufacturing company produces a small product in lots of 10,000. They want to be 90 per cent sure of accepting the lot with fraction defective of 0.01 and 95 per cent sure of rejecting a lot with a fraction defective of 0.08. They do not know anything about sampling plan design. They intuitively decide that they will take a sample size of 100 and accept if not more than 4 defective items are found.

The reasoning is that it amounts to 4/100 = 0.04 fraction defective which is roughly the mid point of their acceptable and rejectable quality.

a) Does their plan achieve their goals?

b) Suggest a better plan.

c) What are the AOQL values for these pians?

6 One of the important functions of a hospital laboratory is the perform blood samples. The quality of this process is tested periodically be selecting five blood specimens and dividing each specimen into two equal parts. Approximately 30 minutes after the first batch of five has been processed, its twin are submitted and the results are compared. The following data are taken at four different times in an 8 hours shift.

Batch 1	Batch 2	Batch 3	Batch 4
1.2	0.6	0.6	2.1
1.8	0.3	1.5	0.6
1.5	0.3	1.0	0.6
0.9	0.0	1.0	2.7
0.3	0.6	0.9	2.7

a) Calculate the 3 sigma control limits for the process. Assume normal process average to be 0.9 and the process standard deviation is 0.5.

b) What control limit will be used for range chart?

c) Is the process in control?

7 Using the data of Problem 6 calculate the mean and standard deviation of each of the batch data. Use the average of the means and the average of the standard deviation as the estimate of the process average and nrocess standard deviation (instead of 0.9 and 0.5, respectively).

Rework problems 6(b) and 6(c).

15.12 FURTHER READINGS

Duncan, A.J., 1974. *Quality Control and Industrial Statistics*, III Ed. Irwin (Indian Reprint-Taraporewala): Bombay.

Dodge, H.F. and H.G. Romig, 1959. *Sampling Inspection Tables:* Single and Double Sampling, John Wiley: London.

Feigenbaum, A.V., 1983. *Total Quality Control*, III Ed. McGraw Hill: Delhi.

Ingle, S and N. Ingle, 1983. *Quality Circles in Service Industries*, Prentice Hall: Englewood-Cliffs.

Juran, J.M. and F.M. Gryna, 1980. *Quality Planning and Analysis*, McGraw Hill (Indian Reprint-TMH): Delhi.

McClain, J.O., and L.J. Thomas, 1985. *Operations Management*, II Ed. Prentice Hall: Englewood-Cliffs.

Shore, B.. 1973. *Operations Managements*, McGraw Hill (Indian Reprint-TMH): Delhi

BLOCK 6 MATERIALS MANAGEMENT

Effective Materials Management involves maximising materials productivity. This requires well coordinated and integrated approach towards various problems involving decision-making with respect to materials. Unit 16 discusses various purchase systems and procedures. Problems related to reducing inventories in the context of reducing uncertainties in demand and supply, reducing excessive material varieties are discussed in Unit 17. Issues of proper planning of store layout, issuing policies, avoidance of pilferage and losses are discussed in Unit 18. Unit 19 discusses various standardisation, codification, and variety reduction methodologies for improving materials productivity. Finally, Unit 20 discusses how to minimise waste if it cannot be totally eliminated.

UNIT 16 PURCHASE SYSTEM AND PROCEDURE

Objectives

After completion of this unit, you should be able to:

- appreciate the need of professionalism in purchase
- define the scope and objectives of the purchasing department of an organisation
- prepare the appropriate formats of input forms to the purchase departments for an efficient processing
- identify the demand characteristics of materials and their specifications, management policies, legalities, etc. to identify the suitable purchase procedures
- decide on selection of suppliers, timing, price, quality and quantity
- decide on the forms, records and reports relevant to purchasing
- evaluate purchase department
- evolve the procedures for vendor evaluation
- design the organisational structure for the purchase activity in an organisation
- introduce computerisation of purchasing activities.

Structure

16.1 INTRODUCTION: ROLE OF PURCHASING FUNCTION

From our daily life we know that every one of us depends on commodities and services supplied by other individuals or organisations. Similarly, every organisation, big or small, to varying extents, depends on materials and services from other organisations. These materials and services are obtained through exchange of money. This process of exchange is known as purchasing. In the present context, we shall concentrate on the purchase of materials. Materials constitute an important ingredient of inputs to the activities of several types of organisations. Industries require raw materials, components and equipments for their production, service organisations require supplies, spare parts are required for maintenance operations, and so on.

Furthermore, in most of the organisations, the value of materials as compared to other inputs to the system is high. In an industry, on an average about 40 to 60 per cent of the total money is spent on materials and related services. Similar estimates about the large sums of money involved can be made for public works departments, electricity boards, developmental agencies, corporations etc.

With the increasing complexities in materials' characteristics and their usage vis-a-vis increasing competition, the purchasing function has emerged as a specialised organisational activity. In many organisations, it is regarded as a supportive functions. However, in order to attain the maximum contribution to the efficiency and effectiveness of an organisation, the purchasing should be treated as one of the functional areas.

Objectives

Purchasing principles are usually epitomised as buying materials of right quality, in the right quantity, at the right time, at the right price, from a right source and also at the right place. The main objectives are:

1 To make the user departments of the organisation from time to time aware of the range of the quality of materials available in the market and to maintain the right quality of purchased materials based on standards, technical specifications and suitability as determined by the user departments.

2 To procure at the lowest possible cost consistent with quality and service requirements.

3 To ensure the minimum possible investment in service operations related to purchased materials, such as transportation, inspection, storing, record keeping etc.

4 To maintain continuity of the supply to ensure that scheduled activities are not interrupted.

5 To integrate the requirements of all departments of the organisation in order to take the advantage of economy of scale wherever possible and to also avoid duplications of purchases resulting in wastes and obsolescence.

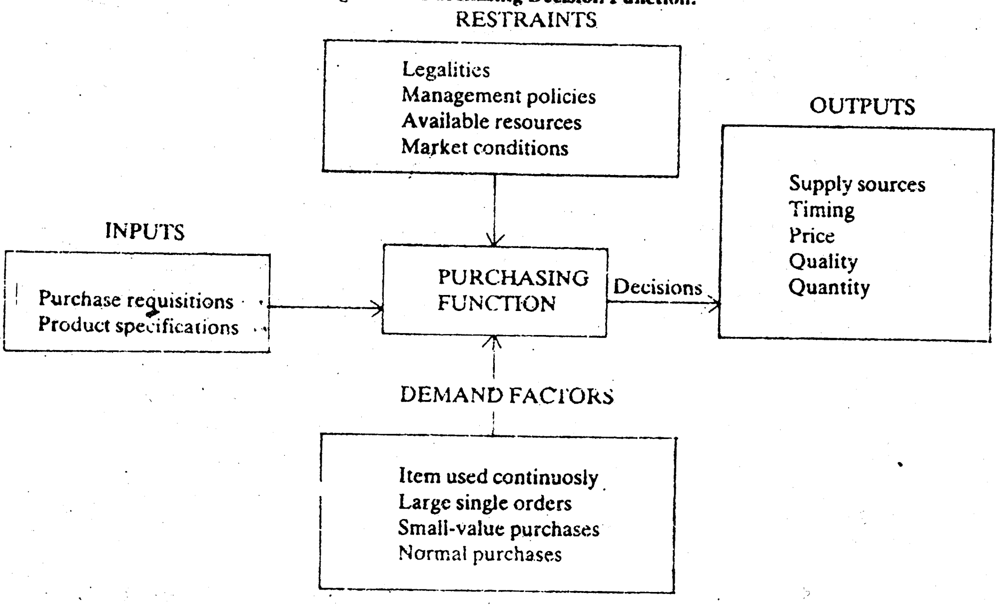
6 To create goodwill for the organisation through healthy buyer-supplier relationship.

Purchasing Functions

In order to meet the above objectives of the purchasing functions, the requisite inputs and possible restraints and factors must be identified. The purchasing function is responsible for a host of decisions. Figure I depicts the purchasing function.

In addition to the outputs shown in Figure I, responsibilities of the purchasing department include other related activities:
(1) Vendor Rating and Development, (2) Make or Buy, (3) Value Analysis, (4) Surplus Disposal. (5) Control and Audit. Maintenance and Development of Procedures, Forms, Records and Reports.
We shall discuss the relevent points with reference to Figure I in subsequent sections.

Figure I: Purchasing Decision Function.



Activity A

Prepare the list of all household items under the following headings: groceries, clothes, Kitchenette, electronic and electrical appliances, and furniture. Then classify the items under: (I) used continuously, (ii) large single items, (iii) small value items.

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Review your actions and decisions for these items to meet the following objectives:

'a) To procure at lowest possible cost to ensure overall minimum investment, and

b) To maintain continuity of the supply to ensure that scheduled activities are not interrupted.

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16.2 INPUTS

The preparation of inputs constitute pre-purchasing activities and decide to a great extent the success of the purchasing system. The inputs to purchasing come in the form of requisition or indent from various departments and units of the organisation. The success of purchasing department depends upon the quality of these inputs and also upon the ability of the purchasing department personnel to analyse the inputs to the fullest extent. The most important inputs are: purchase requisitions and their accompanying product specifications.

Purchase Requisitions or Purchase Indents

A purchase requisition is the primary and authorisation document describing the needed items. Most organisations have a standard requisition form for the use of all its departments. The format, however, may change from organisation to organisation. The three most common types of the requisition forms are

a) standard purchase requisition,

b) travelling purchase requisition, and

c) bills of materials.

a) Standard Purchase Requisition Form: This form is standard for a given organisation. Different organisations may use different formats. A standard purchase requisition form is used for non-recurring requirements of items and normally contains the following information:

1 Requisition number (for identification, may use blocked codes including a short code for the department, name of the requisitioner, year, serial no. etc.).
2 Date of the requisition.
3 Name of the department/section.
4 Account to be charged (an appropriate head may be ticked out of standard account heads).
5 Description and quantity of items.
6 Purpose of the items.
7 Date when items are needed.
8 Approximate unit price and the total cost.
9 Suggested suppliers' names and addresses.
10 Signatures of the requisitioner, head of the department, approving authority (as appropriate).

A sample format of standard requisition form is shown in Figure II. Space may also be provided for the purchasing department to record:

1 Purchase order no.
2 Shipping instructions
3 Delivery date and quantity delivered.

Figure II: Specimen of Standard Materials Requisition Form

STANDARD MATERIALS REQUISITION FORM

Date .... **No...........**
Department/Section ....
Account to be charged:

Sl. No.	Description of Items	Quantity	Purpose	Approx. unit price	Approx. Total cost
			TOTAL COST		

Suggested Suppliers

(1) Name .... **(2)** .... **(3)** ....
Address ....

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(Requisitioner) **(Head of the Department)** **(Approving Authority)**

Activity B

Suggest some suitable place and procedure to indicate (a) price discounts, (b) urgency of need on the standard materials requisition form shown if Figure II.

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b) Travelling Purchase Requisition: This type of form is used by stores for recurring requirements for materials and standard parts. The requisition form is in the format of a card for a single item containing the information about the item (name and brief description, brief or coded names of the user department, annual usage rate, re-order point, order quantity) potential suppliers, records of receipts and issues, and so forth. The card can be used for many requisitions. When the stock level drops to or below the re-order point, the card is sent to the purchasing department for placing the order with the supplier. Sometimes a separate requisition form which is a brief version of standard form, is also used when it is not convenient to send the card. To identify that the item is requisitioned, a coloured signal clip is attached with the card until the order is received. The entire transaction can be handled with minimum delay and without much of clerical paper work.

A sample format of the travelling purchase requisition card is shown in Figure III.

Figure III: Specimen of Travelling Requisition Form

Travelling Requisition Form

Material description:
Part number:
Annual usage:
Suppliers:

A ______
B ______
C ______

Order Quantity:
Re-order Level:
User Departments:

Requisitioned			Received		REMARKS
Date	Quantity on hand	Quantity requested	Date	Quantity	

c) Bill of Materials: This is a list of all items for a finished product and is prepared at the time of engineering drawing of the product. The bill of materials and the production schedule are sent to the purchasing department which computes the total requirements of each part for each period of the production. This eliminates the necessity of typing numerous requisitions for usually a large number of items.

Specifications

Specifications of an item intended to be purchased provide detailed description of the characteristics and features of the item. These must be provided by the requisitioning department by taking, if necessary, assistance from the purchasing department which has acquired specialisation in the related matter. The major objectives of the specifications are: (1) to let the purchasing department understand exactly the features required in the item, (2) to let the supplier know exactly what the buyer wants, and
(3) to permit the easier, quicker and accurate verification of items upon receipt.

Following are the common types of specifications used to describe and grade the items:

a) Market Grade: Market grades are used in case of items bought and sold in a market place. Grading is done by comparison with a standard generally and widely accepted. Trade associations, commodity exchanges and government agencies establish and regulate such grades. Market grades are limited to natural products such as wheat, cotton, rice, lumber, etc. The suitability and success of this system, however, depend on the accuracy of grading and ability to ascertain the difference by inspection.

b) Commercial Standards: These standards are used for the items above commodity level because of their widespread use. When a material or item is standardised with complete quality description and established by customs, and accepted by the government, its agencies and industry in general, the material or item is said to be commercially standardised. Standard specifications have been prepared for many items by the Bureau of Indian Standards. Commercial standards have proved to be of great assistance in interchangeability for the user, and simplification of design, purchase procedure, inventory control, and cost reduction. These play vital role in mass production.

c) Trade or Brand Names: Trade or brand names are used by some manufacturers to establish the identity of various models produced and to protect them from other substitute. Branded products are simplest to buy, procedurally. Specifying an item by brand name limits the scope of competition and indicates a reliance upon the integrity and reputation of the supplier to provide consistent quality. This system of specification can be very economical for low-cost lot purchases.

d) Material Specifications: These specifications define the physical or chemical properties desired in an item. Items such as metals (aluminium, steel, copper, etc.), drugs, oils and paints are examples of products with material specifications.

e) Performance Specifications: Rather than describing an item physically or chemically, performance specifications describe the requirements about the performance characteristics. The seller is free to choose the materials, methods of processing and other details. These specifications are commonly used in case of equipments, machines, tools etc. This method, however, requires proper selection of supplier. The items supplied are tested to see that stated performance features are met. Purchase of computer system is a good example of this technique.

f) Samples: In case of special items of non-repetitive nature or where quality requirement is not rigid or when the quantity of items is so low that it does not justify the formulation of specifications, specifications are established by specimens or samples. The supplier is supposed to match the sample. Difficulty arises if the samples are subject to change, physically or chemically. In case of mechanical parts for replacement where the identification marks are not easily read, this method of specifications by sample may be the only possible way of purchasing the item.

g) Blueprints: A blueprint or engineering drawing is recommended for accompanying a purchase requisition when close tolerance or a high degree of mechanical perfection is required. Blueprints are used for mechanical parts, and for construction and other projects.

h) Combined Specifications: Many products cannot be adequately described by a single type of specification. In such cases, a combination of two or more specifications may be used. Quite a few products for industrial uses are so complex that a combination becomes a practical necessity.

Activity C

For the domestic items listed in Activity A, indicate the popular way(s) of specifications against each one of them.

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16.3 RESTRAINTS AND FACTORS

Restraints limit the alternatives available to purchasing department for its decisions. Similarly, the type of purchasing procedure adopted will depend on the factors related to the demand for the item. In this section, we shall discuss some of these restraints and the demand factors.

Purchasing decisions are restrained by legal considerations, management policies, resource availability, market conditions and so forth.

Legal Consideration

The purchasing department commits a good deal of finance when a purchase order is placed. It is, therefore, necessary to have sufficient understanding about the legal aspects of purchase. The Indian Sale of Goods Act, 1930 and the Indian Contract Act of 1872 cover some of important legal aspects. The important relevant laws are (1) Law of Agency, (2) Law of Contract, (3) Law pertaining to Sale of Goods, including Patent Laws, Warrantees, Trade marks, etc., and (4) Arbitration. Professional legal advice related to these laws is a must for major contracts involving large sums of money or extending over a long period of time like imports. Indian Chamber of Commerce and International Chamber of Commerce have codified general business terminology to minimise the friction between buyer and seller. In addition to the legal precautions, emphasis should be on mutual trust and confidence.

Management Policies (Centralised vs. Decentralised Purchases)

Management may choose between centralised and decentralised organisation or a mixture of these two for purchases. Centralised purchasing has economic advantage due to specialisation and input standardisation and thus, is an attractive strategy for multi-plant and multi-location activities using related items. In addition it offers:

1 Development of specialised purchasing skills.
2 Consolidation of order quantities which can result in quantity and cash discounts.
3 Better control over inventory investment.
4 Less overlapping and duplication of effort.
5 Uniform quality and less variety of materials.

Centralised purchasing however, tends to be slow, rigid, and rule-bound, and may turn out to be very costly for low-value purchases. Also, if item required by various departments are unrelated and less frequently demanded, the advantages of centralisation may be lessened. In such cases, management may decide to decentralise the purchase.

Resource Limitations

Finance is the major resource which can seriously influence the purchasing activities. The corporate finance is shared by all the departments of the organisation and purchase department must operate within the allocated budget. This may lead sometimes to purchasing decisions somewhat less optimal than what it would have been had the purchase department been able to get the finance as and when desired. Thus sometimes the advantages of quantity discounts might have to be foregone in favour of overall financial planning of the organisation. Other resources such as manpower, storage space, and handling equipments also place limitations on purchasing decisions.

Market Conditions

The market conditions relate to short-term market situations which are influenced by supply and demand as well as overall national economy. Thus during shortage, the reliability of supply may be considerably more important than the price. The purchasing strategies should, therefore, change to cope up with these situations, and ability to anticipate these conditions measures, to a good extent, professionalism acquired by purchase personnel.

Demand Factors

Based on the demand pattern, the items can be grouped into four basic categories:

1 **Items Used Continuously:** Items that are continuously used with a fairly predictable demand can be handled under blanket purchase orders (also known as open-end purchase orders). A contract is negotiated with supplier(s) for a fixed period of time (six months or one year) with quantities, delivery dates, discounts etc. The price may be fixed, or kept open in which case the market price at the time of delivery will be applicable. Blanket orders conserve the time and effort of the purchasing department.

2 **Large Single Orders:** The situation of large single orders usually occurs in case of special machinery or other special goods, such as computers, vehicles, buildings etc Considerable planning and evaluation are involved. The suppliers submit their bids with all relevant details and purchases are negotiated by comparison and evaluation of the bids.

3 **Small-value Purchases:** The low-cost infrequently used items are purchased usually by the concerned departments using petty cash or by identifying some small local supplier. For the value involved, it is not worth going through the complete cycle of purchase process.

4 **Normal Purcha..s:** Items other than mentioned above fall in this category and are handled by the normal procedure, i.e., following the complete cycle of the purchase process discussed above.

Activity D

For each group of items discussed above suggest suitable input forms as discussed in Section 16.2

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16.4 PURCHASING DECISIONS

With the purchase requisitions and specifications as inputs from the departments and sections of the organisations, the restraints from the external environment and the factors about the demand pattern, the purchasing department has to make several decisions. Some are purely operational while some relate to policy formulation having far-reaching impact on the long-term success of the organisation. In this section we shall discuss the operational decisions. Policy related decisions will be covered in later sections.

From purchase requisitions, the purchasing department generates purchase orders which is a legal document. Purchase order forms vary in their format and their routing through the organisation. A purchase order should contain at least the following:

1 Purchase order number (for identification).
2 Date of issue.
3 Name and address of supplier receiving the order.
4 Quantity and description of item(s).
5 Required delivery date.
6 Shipping instructions.
7 Price and payment terms.
8 Other conditions governing the order.

A sample of the purchase order is shown in Figure IV.

Figure IV: Specimen of Purchase Order

PURCHASE ORDER

No....... Date..........

To

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....

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REF: Quotation No................................ Dated ....

S. No.	Description	Quantity required	Unit	Rate Rs. P.	Amount Rs. P.
				Total Value	

Payment Terms:

Delivery Terms:

Terms related to Sales Tax:

Other Information:

Purchase Officer

Copy to: All concerned departments

We shall now discuss some of the decision function leading to preparation of the purchase order.

Supplier Selection

Information on external sources of supply can be obtained from numerous references: (a) industrial advertisements of the supplier appearing in newspapers and periodicals, (b) supplier catalogues, (c) supplier salesmen, (d) trade journals, (e) yellow pages of telephone directory, (f) trade directories prepared by government agencies and trade associations, (g) list of suppliers approved by the government agencies, (h) enquiries through advertisements or individual communications, and (i) records of the organisations past purchases.

After compiling the information about suppliers for the needed item, relative proficiency of each potential supplier must be assessed on the basis of comparative quotations of price, quality, quantity, delivery, and other services. Other relevant variables are the supplier's management capability, technical ability, production capacity, depth of service, and financial stability. The purchase order is then issued to the most promising supplier. The information about other suppliers can be stored for future references.

Timing of Purchases

An organisation is primarily interested in an adequate supply of material at the best price consistent with quality requirements. Timing is not a critical concern when the purchases are made in price stable market but it becomes critical in unstable price market situation. Following approaches may be adopted while trying to time the purchases in response to market conditions:

a) Speculative Buying: It involves purchasing in excess of foreseeable requirements in order to make profit (or imputed profit) from rising prices. Opportunities arise for such a purchase when price falls temporarily and the organisation has sufficient working capital to finance such speculative purchases.

b) Forward Buying: It involves purchasing in economical quantities exceeding current requirements, but not beyond actual, foreseeable requirements. This approach is often used when prices are stable over time. It is adopted to obtain a favourable price, to get quantity discounts, to secure items when they are available, and to protect against prospective shortages. It, however, assumes the risk of increased inventory holding cost which ties up working capital.

c) Hand-to-mouth Buying: This practice is resorted to satisfy only immediate current requirements and may be uneconomical. This may be suitable in case of high-value items. It is not recommended for normal operations.

There are inherent risks in all these approaches in the environment of fluctuating market and price instability. Two techniques may be used to reduce the financial risk.

a) Time-budgeting Purchases: Using time-budgeting purchases, an organisation can frequently purchase an item over a long periodic cyclic fluctuation at an average price very close to average market price. This is accomplished by purchasing small quantities over short operating periods of equal length.

b) Hedging: The organisation purchases the required quantity on the spot or open market and at the same time sells the same quantity in the future market contracting to deliver at a future date in order to mitigate the risk associated with fluctuating prices. This approach, however, can be used in case of those items for which organised commodity markets or exchanges exist.

Price Determination

Price per unit of an item comprises the unit purchase price, transportation cost, handling cost, inspection, insurance and the administrative variable cost. The right price simply means the lowest possible total price for the organisation.

The typical approaches for price determination are published price lists, competitive bidding, and negotiation. Price lists published by the suppliers give initial indication of the price. In competitive bidding, the requests for bids are sent to several suppliers. Usually the lowest bidder gets the order. Normal practice requires at least three competitive quotations wherever possible. Generally competitive bidding is most applicable to standardised products that are widely used and are produced to stock. Bids are normally secured when the size of an order exceeds some minimum amount.

Negotiation is the approach resorted to when time is too short, the number of bidders is too small, value of purchase is high, willingness to compete is lacking, or the specifications are too vague. In such circumstances, the buyer contacts the potential supplier and negotiates for the fair price and prompt delivery. An advance planning and analysis are expected to bring satisfactory results out of negotiation.

While determining the price, shipping terms should also be clarified. The shipping terms established (1) who will pay the freight charges, (2) when does the buyer take the legal title to the goods, and (3) who will prosecute loss and damage claims against carriers. There are numerous terms of shipment, but the most common ones are:

a) F.O.B. (Free on Board) Buyer's Plant: The buyer takes the title to the goods when the goods are delivered at his plant and supplier pays all transportation charges and processes all claims against the carrier for damages or loss of goods.

b) F.O.B. Seller's Plant: The buyer takes the title when goods are loaded onto the carrier and he pays all transportation charges as well as negotiates all freight damage claims with the carrier.

c) F.O.B. Seller's Plant—Freight Allowed: Legal responsibilities same as in F.O.B. seller's plant, but the supplier pays the freight charges.

d) C.I.F. Contracts: The price includes cost of materials, insurance and freight.

e) F.A.S. (Free Alongside Ship): Used in shipping by sea where supplier is responsible for getting goods to the ship, and the buyer takes title as well as all responsibilities thereafter.

Further, purchase contracts can be of fixed price (quite common), cost plus contract (no definite limit to costs) or blanket order (for six months or one year) type.

Discounts: An important aspect of price determination involves discounts that can be secured. Following types of discounts are common:

1. **Trade Discount:** To protect certain distribution channel when it is economical to buy from the distributor than the manufacturer.
2. **Quantity Discount:** For purchasing worth beyond certain amount of money.
3. **Seasonal Discount:** For purchasing in off-season.
4. **Cash Discount:** For prompt and full payment.

Quality and Quantity

The process of determining right quality in purchasing implies striking a balance between technical specifications and economic considerations. The right quality has no absolute meaning but is specified in relation to a purpose. As mentioned above most of the technical specifications are decided by the requisitioning department. The purchasing department should be instrumental in making the quality decisions by making, to the requisitionig departments, available various market grades, trade names, commercial standards etc. and corresponding prices and sources of supply to enable them to specify quality of items. Once the quality standards are specified, the purchasing department makes arrangement in collaboration with the requisitioning department for the inspection of the items after delivery. Sometimes, inspection is performed by an organisational representative in the vendor's plant. On-site inspection can save time and money while minimising operational delays from the inferior quality. For normal items supplied in lots, inspection for acceptance is carried out by sampling.

Procedures should be established for handling inferior quality. Should the shipment be returned to the supplier and contract cancelled? Should the buyer rework the item to an acceptable quality and bill the supplier? Should only rejected items be returned for replacement and acceptable items retained? Such issues must be resolved in advance to maintain a long-term relationship.

After determining the quality, the next important step is to determine how much quantity to buy and when. For items continuously used, the purchasing department can collect the projected demands from various departments and then can incorporate these details into the blanket purchase order. For large single orders, there is not much to decide about the quantity. Small-value purchases are made as and when need arises. For normal purchases usually two quantities govern the ordering decision: reorder-point an order quantity. When the stock goes to or below reorder-point an order for quantity equal to order quantity is placed.

Reorder-point = Safety stock + average demand during the lead-time

$$\text{Order quantity} = \frac{\sqrt{2AD}}{h}$$

where,

A = fixed cost of ordering (Rs./order)
D = average annual demand (unit/year)
h = holding cost (Rs./unit/year)

Safety stock depends on the variation of demand and can be taken as 3 times the standard deviation.

In case of production components, the determination of right quantity can be linked with the concept of Materials Requirement Planning (MRP).

Activity E
Analyse the formula for quantity determination when items are not demanded throughout the year at are demanded in a seasonal manner.

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16.5 PURCHASING ORGANISATION

Purchasing department is usually under the General Manager at par with other functional departments such as engineering, finance, accounts, manufacturing, marketing etc. Some times it is kept along with other related departments like stores, inventory and materials control, under materials manager who in turn is under General Manager. Choice of an organisational structure depends on the volume of work and value of the purchase. A good structure encourages the assignment of specific responsibilities, specific authorities and smooth chains of command of delegation. It should lead to the development of policies that permit routine decisions to be made by subordinates.

Within purchase department, the structure may be worked out using following approaches:

a) **Organisation by Function:** It is based on the principle that job should be organised so as to promote maximum possible specialisation of skills. Total purchasing job is broken up on the basis of specialisation, such as (1) processing of purchase requisitions, (2) floating enquiries, (3) selection of suppliers, (4) preparation of purchase orders, (5) receipt inspection and storing, (6) liaison with accounts section, (7) records maintenance etc. Each job, or a group of jobs, is assigned to individual or group of individuals who specialise in that work. This approach has obvious advantages but suffers from the disadvantage of people getting bored doing the same kind of jobs for a long time, and sometimes it leads to bureaucratisation.

b) **Organisation by Product:** The items purchased are classified into groups and each group is assigned to a team of personnel who specialise in purchase of that particular type of the materials. For example, a team may be specialist in buying raw materials, while other in components and sub-assemblies, and so forth.

c) **Organisation by Location:** This is applicable for the organisations which are large and have several plants. Each plant may have a purchasing department under the overall supervision of the central purchasing department.

d) **Organisation by Stage of Manufacturing:** In case of manufacturing, sometimes it is advisable to organise the purchase activities according to the stage of manufacturing, e.g. raw materials, parts, sub-assemblies etc.

Activity F

Discuss the suitability of centralized and decentralized purchasing systems in view of the purchasing organization discussed in Section 16.5

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16.6 PROCEDURES, FORMS, RECORDS AND REPORTS

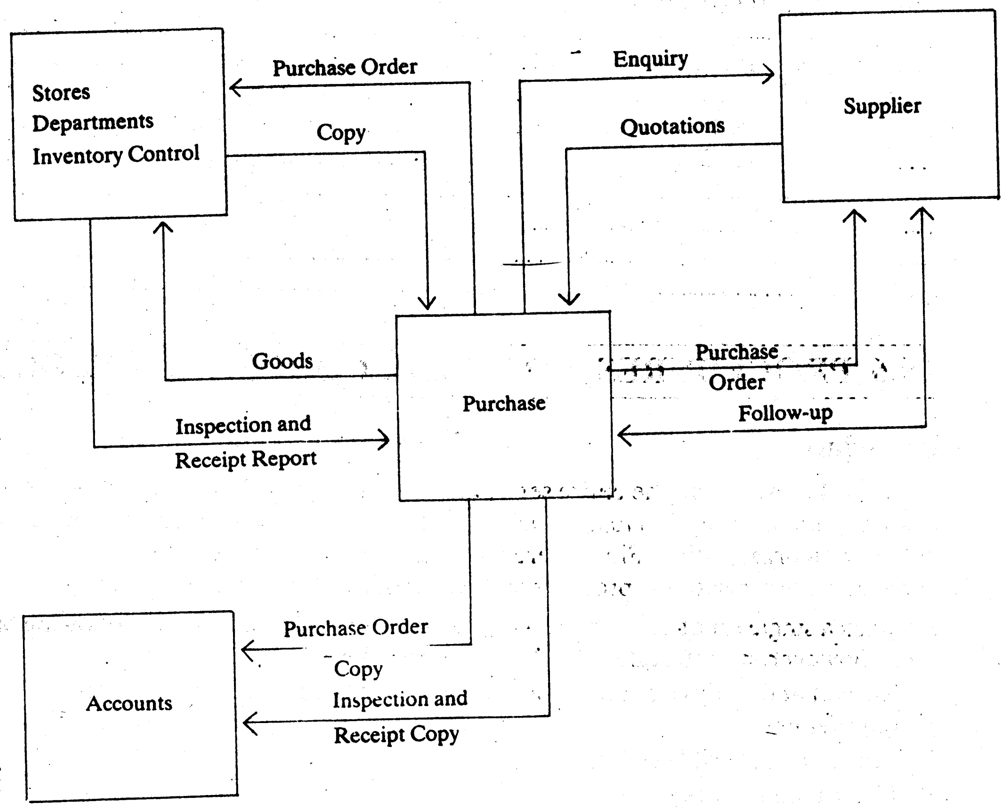
Procedure

By procedure we mean the entire set of steps in which a purchase transaction is carried through from its inception to its conclusion. These steps together form the purchase policy of an organisation. Since there are wide variations among industries, companies, organisations, products and personnel, it would not be feasible to establish a single set of procedures which would apply to all cases. The following basic steps, however, must be taken in one way or another:

1 Receipt and analysis of requisition to assess the need and description of requirement.
2 Selection of possible sources of supply.
3 Determining the time, price, quality and quantity.
4 Placing the order.
5 Following up and expediting of the order.
6 Checking the invoice and receiving the order.
7 Processing discrepancies and rejections after inspection.
8 Communicating with accounts' section for payment.
9 Closing completed records.
10 Maintenance of records and files.

A schematic purchase procedure involving some of these steps is shown in Figure V.

Figure. V: A Schematic Diagram of Purchase Procedure



Purchase Forms

Forms are very important tools for purchasing department to standardise the communication with internal departments of the organisation and external agencies such as supplier, local government bodies, etc. The number of forms required depends on the size of the organisation, the purchasing system employed in the organisation, and the accounting and internal control methods in effect. Normally there should not be too many forms as they create confusion and red tapeism. Certian links of communication can be sent copies of some forms (as shown in Figure V) instead of individual forms. The forms should incorporate the principles of good design to facilitate data entry and data retrieval, to minimise the possibility of errors, and finally, to be just economically sufficient in size and number of entries required.

Purchase forms for the following functions are usually employed (some of which have already been exhibited).

1 Purchase requisition
2 Request for quotation
3 Purchase order
4 Follow-up
5 Receiving and Inspection.

In addition, some other forms are also used by some large organisations. Among such forms are: acknowledgement for quotation received, change of order notice, purchase contract, sample test report etc.

Purchase Records

Since purchasing is a repetitive process, accurate records are a necessity for efficient operation. These records provide a history of what has been done in the past (supplier, price, discounts, quality delivery etc.) and provide a wealth of information upon which to base future decisions. Maintaining a good-record system will increase operating costs but expectedly it should bring some handsome savings in the long run.

Most purchasing departments maintain the following basic records:

1 **Purchase Order Log:** It contains a numerical brief record of all purchase orders issued. It contains purchase order number, supplier's name, brief description of purchase, total value of the order etc. The log makes it possible to summarise several administrative data.
2 **Open Order File:** Contains the status of all outstanding orders. It contains purchase requisition, purchase order, follow-up data.
3 **Close Order File:** Contains a historical data of all completed purchases.
4 **Vendor Record:** Contains the names and addresses of suppliers, materials that a supplier can supply, delivery and quality records.
5 **Commodity Record:** Such record is maintained on each major material or service that is purchased repetitively. It shows the list of suppliers, annual usage rate, price, orders placed, orders received and disbursements to the departments.
6 **Contract File:** Contains the purchase records of items under a term contract. It is specially important when the contract is an open one, against which orders may be placed.

Purchase Reports

Since the purchasing department handles a sizeable proportion of corporate finance, it is desirable to have some summary reports periodically (quarterly, half-yearly or annually) available to the management. Some of the important reports are:

1 Total value of purchase.
2 Allocation of purchase value against major items.
3 Allocation of purchase value against each requisitioning department.
4 Budget for purchase for the next year.
5 Proposals for revisions of budget in current year.

In addition, the purchasing department brings out the report for its own use. They are:

1 Vendor Performance Report
2 Pattern of Consumption of materials.
3 Pattern of market prices.

Activity G
Design a suitable form for preparing the annual budget for the purchasing department.

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16.7 EVALUATION OF DEPARTMENTAL PROCEDURES AND VENDORS

Evaluation of the purchasing department is essential for the economic health of the organisation. At the same time, a good proportion of the efforts in purchasing activities are not immediately visible and so the evaluation becomes rather difficult. In any case, a consistent effort towards this aspect must be kept on with the following objectives of evaluation:

1 Performance improvement of the department.
2 Aid to Organisation.
3 Easy coordination amongst departments.

Establishing evaluation criteria is also very difficult. Following criteria can be combined for an overall picture of purchasing performance:

1 Cost-Purchase Comparison (annual cost of purchasing department divided by the total value of purchases).
2 Cost per Order (total purchasing department cost divided by the number of orders).
3 Return on Investment (net savings per rupee spent on purchasing).
4 Quality Criteria (measured by number of rejects).
5 Quantity Criteria (measured by downtime).
6 Price Criteria (comparison with other organisation or standard price indexes).

The evaluation standards can be based on past performance, budgeted performance, or performance of departments in other organisation to judge what is being done as compared to what should have been done.

16.8 VENDOR EVALUATION AND RATING

It is not always easy to identify good suppliers. Records maintained or procured from some other sources about the vendors help in their evaluation and rating. Usually a combination of price, quality, quantity, delivery time, service etc. giving relevant weightages to these factors is used to rate the vendors. In addition, a checklist can be used to facilitate rating from department standpoints. Some of the points are mentioned below:

Reliability

1 Is the supplier reputable, stable and financially strong?
2 Are the supplier's integrity and ability above doubt?
3 Is the supplier going along with product improvement?
4 Is the supplier's competitive strength as to price, quality, etc. proved by past experience?

Technical Capabilities

1 Can the supplier provide assistance as to application engineering?
2 Can the supplier provide assistance as to analytical engineering?
3 Can the supplier provide design assistance?
4 Can the supplier handle special needs and contribute to improve product efficiency/basic processes?

Convenience

1 Can the supplier help reducing acquisition costs through personal visits, telephone calls, incoming inspections, rejection of defects, spoilage, etc?
2 Can he offer other related products?
3 Is he qualified to help in solving difficult problems?
4 Does the supplier package his product conveniently?

Availability

1 Does the supplier assure delivery in time?
2 Are his stocks locally available, and or at short notice?
3 Is the supplier's location advantageous?
4 Can he plan his supply to minimise inventory?
5 Can he be depended on for a steady flow of materials?

After-sales Service

1 Does the supplier have a service organisation?
2 Is an emergency service available?
3 Are parts available, when needed

Sales Assistance

1 Can the supplier help building mutual markets?
2 Will he recommend our products?
3 Does the use of supplier's product enhance appearance of our products?

Vendor Evaluation

Recognising that there is a need for having good vendor, it is essential that supplies are obtained from vendors after an evaluation of his capabilities. The buyer, who has to do the evaluation, is faced with two different situations:

1 Evaluating the performance before the vendor has delivered anything.
2 Evaluating the performance of vendor after the deliveries have been made.

The latter one is normally called Vendor Monitoring and the former Vendor Evaluation.

In case of Vendor Evaluation the buyer lacks the direct evidence on the results achieved by the vendor and must get his information in other ways. This includes (1) general reputation of vendor, (2) data from other buyers, (3) vendor surveys.

Vendor Rating

Product quality submitted by vendors has always been evaluated and used as a factor in making purchasing decisions. Recently, the evaluation has been formalised by the use of vendor rating formulas which provide a quantitative measure of vendor quality. These ratings are primarily meant to provide an overall quality rating of a vendor for use in reviewing, comparing, and selecting vendors. Vendor rating is not a tool for making decisions on submitted lots.

To create a single numerical quality score is difficult because there are several inputs, each involving its own unit of measure:

1 The lot quality, expressed as lots rejected versus lots inspected.
2 The parts qualities, expressed as per cent defective.
3 The characteristic qualities, expressed in numerous natural units, e.g., rupees per square cm., per cent active ingredient, MTBF, etc.
4 The economic consequences of bad quality, expressed in rupees.

The National Association of Purchasing Agents, New York, has published three alternative vendor rating plans:

1 **Categorical Plan:** This is a non-quantitative system in which buyers hold a monthly meeting to discuss vendors and rate each as plus, minus, or neutral.

2 **Weighted-point Plan:** Each vendor is scored on various factors like quality, price, service etc. These factors are weighted and a composite rating is then calculated for each vendor. The details of this performance evaluation scheme are as follows:

i) **Quality Rating:** Quality Rating for a consignment

$$R_Q = \frac{Q_1 + Q_2 X_1 + Q_3 X_2}{Q} \times 100$$

where,

Q = Quantity supplied
Q_1 = Quantity accepted
Q_2 = Quantity accepted with concession
Q_3 = Quantity accepted with rectification
Q_4 = Quantity rejected

and

$$Q = Q_1 + Q_2 + Q_3 + Q_4$$

X_1 and X_2 are weightage factors each less than 1.

ii) **Price Rating:** Price rating for a consignment:

$$R_P = \frac{P_L \times 100}{P}$$

where, P_L = Lowest price quoted
P = Price agreed by supplier

iii) **Delivery Rating:** Delivery rating for a consignment:

$$R_D = \frac{\text{Promised delivery time (days)} \times 100}{\text{Actual delivery time (days) of the full consignment}}$$

Rating in excess of 100 shall be equated to 100.

iv) **Quantity Rating:** Quantity Rating for a consignment:

$$R_{Qty} = \frac{\text{(Qty. supplied within stipulated delivery time)}}{\text{Quantity promised}} \times 100$$

$$= \frac{Q}{Q_P} \times 100$$

v) **Service Rating:** Service Rating, RS, is to be assigned by Purchase Department as per the following table for each consignment.

Sl. No.	Service Factor	Max. Score
1	Cooperativeness and readiness to help in emergencies	a_1
2	Readiness to replace rejected material	a_2
3	Providing support documents in time	a_3
4	Promptness in reply	a_4
5	Acceptance of terms without complaints	a_5

where $a_1 + a_2 + a_3 + a_4 + a_5 = 100$

vi) **Composite Vendor Performance Rating:**

$$VPR = f_1R_Q + f_2R_P + f_3R_D + f_4R_{Qty} + f_5R_S$$
$$\text{where, } f_1 + f_2 + f_3 + f_4 + f_5 = 1$$

Fixing of Weightage Factors: In order to implement this scheme, it is necessary to fix the weightage factors X_1, X_2, a_1, a_2, a_3, a_4, a_5, f_1, f_2, f_3, f_4 and f_5 as suited to the organisation.

. **Cost-ratio Plan:** This plan compares vendors on the total rupee cost for a specific purchase. Total cost includes price quotation, quality costs, delivery costs, and service costs. The final rating is in rupees of net value cost. The net value cost is the product of the adjusted unit price and the number of units. The adjusted unit price incorporates three cost ratios.

i) The quality-cost ratio reflects the relative cost of quality.

ii) The delivery cost ratio reflects the relative cost of placing and receiving an order. It also includes a promises-kept penalty based on a ranking of past performance of vendors.

iii) The service cost-ratio reflects the technical, managerial, and field service competence of the vendor.

All three of these plans recognise quality in the rating of vendors but the rating is not restricted to product quality.

Vendor Relations

The ultimate objective in vendor quality assurance is the production of materials which so adequately conform to the buyers, requirements that there is no need for extensive acceptance or corrective procedures by the buyer. The activities needed to achieve this objective include:

1 Communication of essential and helpful information, design, specifications, standards, practices etc.
2 Communication of engineering changes, changes in specifications etc.
3 Developing methods for detecting deviations from standards promptly.
4 Helping the vendor in resolving quality problems. In case of vendors like sub-contractors and ancillaries, rendering necessary technical assistance as well.
5 Providing for use of vendor quality data in lieu of incoming inspection.
6 Using multiple vendors for major procurements of items.
7 Developing methods for identifying the qualified vendors, and for eliminating those who are unable to meet the quality requirements.
8 Reviewing the performance of the vendor through vendor rating or other plans and following up on the chronically poor vendors.

The guiding principle in vendor relations is the spirit of what is best for the partnership. The supplier must be made to realise that it is not sufficient to accept the returns willingly or to negotiate the disposition of materials not delivered to the specifications. The supplier should view such instances objectively and work constructively with the buyer to correct the conditions that brought about the delivery of unsatisfactory material or service.

16.9 COMPUTERISED PURCHASING SYSTEM

The attractive characteristics of computers such as high speed, huge storage, quick retrieval accuracy, versality and diligence on the one hand and increasing complexities in purchasing on the other make an excellent match for computerisation of purchasing system. The declining cost of computer system is an additive factor. Although there are no complex arithmetic computations involved in purchasing, the requirements of quick processing of requisition, follow up, payment etc. find a computer of immense help. In this section, we shall discuss broad outline of computerisation of the system (not the computer technology).

Let us visualise that the computer has the following files:

1 Inventory file for each item.
2 List of the suppliers (alongwith their performance history).
3 Budget allocation for each department.
4 Master purchase file condensing the previous purchases (item-wise, department-wise, supplier-wise, price, quality etc.)

In addition, the computer has facilities to print and (may do so on a preprinted stationary) the quotation request, purchase order, follow up, inspection report etc.

When a requisition is received, the relevant data are entered through the appropriate programme. Now a days, the screen and template designs are proving much more convenient and fool proof. The computer checks the inventory status of the items and if in-stock items are issued and inventory record is updated. If not in the stock, a programme finds the classification of the item, that is , whether it is a continuously used item or a special item. From the suppliers list, it finds the suppliers who can supply the items and prints quotation requests. If it is a special item, then human intervention will of course be needed to float the enquiries. The programme also checks the budget of the department and account head to which the sum is to be debited. The data from quotations are entered and the computer displays the comparative statement. It will select the supplier and print the purchase order. Upon receipt, it will update the inventory of the item. In addition, computers are very useful for monitoring the status of the purchase order to assist in follow-up actions.

So we see that computer performs all the actions displayed in Figure V and generates the reports as desired above. In addition it is very useful in processing exceptional reports, such as budget is over, orders not supplied in time, payments not made in time etc.

It may be mentioned that most of the computers, specially small and mini-computers, offer a host of utilities which are very useful for computerisation of tasks like purchase.

Computerisation of purchase (such as receiving, issuing, instruction, stores, inventory, handling etc.) can easily bring the desired coordination among other functions of materials management as well as among other departments of the organisation such as production, design, engineering, finance and accounting, marketing etc. through suitable design of database and information systems.

16.10 PURCHASING IN GOVERNMENT ORGANISATIONS

With the aim of providing the best possible servic to the society out of the limited resources and following its policy of mixed economy, the Government of India has itself entered into manufacturing and other types of commercial and trading activities. To gain the advantages of centralised purchase al Governmental purchase operations are controlled by a central agency, the Directorate General of Supplies and Disposal (DGS & D), New Delhi headed by its Director General (Supplies and Disposal) under the Ministry of Supply, Government o India. The DGS & D is responsible for all purchase of materials of all kinds and funcons as a purchasing and inspection agency on behalf of:

1 All Ministries, attache's and subordinate oices of Government of India.
2 All State Governments and their departmets.
3 All local bodies, such as, Municipal Corpo:tions, District Boards, etc.
4 All Quasi-public Institutions, Statutory Coorations and Public Sector industrial undertakings may also avail of the servicesf the DGS & D.

It also makes purchases from foreign countrithrough its subsidiaries like the Indian Supply Mission in London and Washington. also purchases from East European and South-Eastern countries on trade agreennts and has a full-fledged Inspection Directorate in Japan.

Organisation Set-up of DGS & D

The role of the DGS & D is very wide and, f smooth and efficient functioning, it is divided into following wings:

a) Supply
b) Inspection
c) Progress
d) Disposal.

The organisation has regional offices locat at Calcutta, Bombay, Kanpur and Madras. Besides, there is a regional office Bombay exclusively for textiles. The regional offices are empowered to purcha a large number of items provided the individual demand for them does not excl Rs. 6 lakhs. All items financed through foreign loans are purchased by the HQ irpective of thier nature and value.

In addition to the activities carried thre its wings, the DGS & D performs following functions and has directorated offices all over the country.

1 Public Relations and Publications.
2 Standardisation and Quality Control
3 Development of Indigenous Sources Supplies.
4 Purchases from Cottage and Small S Industries.
5 Registration of Suppliers.
6 Termination, Suspension and Blacking of Suppliers.
7 Rate and Running Contracts.
8 Payment Procedure.
9 Indent Processing.

16.11 SUMMARY

Purchasing, in ordinary sense, is the :urement of materials, components, machines, equipments, supplies etc.)ayment. In the present environment of frequently varying price conditions ncreasing material variety and competition, the purchasing function needs profeialism to reduce the total investment in purchase while making the required materials of right quality available on time. The purpose of this unit is to present and discuss various aspects of purchasing to achieve this professionalism. Major topics discussed include: scope and objectives of purchasing, inputs, environmental and management factors influencing the purchasing decisions, purchasing decisions, procedures, forms, records and reports, procedure evaluation, vendor evaluation, and organisation for purchasing. The presentation and discussions are aimed at an efficient information flow amenable for computerisation.

An efficiently designed purchase system, with appropriate procedure, forms, and information flow, can generate the reoarts with required contents intended for specified destinations at various level of management in the organisation. Such a system would enable the organisationto carry out efficient overall financial and materials planning and monitoring. The system, in effect, would enable the purchase department itself to plan and monitor its own activities to achieve the objectives of an integrated purchasing system.

16.12 KEY WORDS

Average Down Buying: Policy of purchasig items at a moment when the market dips sharply in the course of gradual price chage.

Bill of Materials: A list of all items incorprated into a finished product produced by the organisation. It is prepared on the bas of engineering drawing.

Bill of Lading: A document signed by theııpping agency acknowledging the receipt of certain specified goods for carriage andmbodying an undertaking that goods will be delivered to the consignee.

Blanket (or Open-end) Purchase Order: Aurchase order in the form of a contract for continuously used items for a fixed period sually a year) with delivery dates and quantities. The prices may be negotiated fothe whole period or kept open in which case the prevailing market price applies.

Cash Discounts: Price concessions offeredr prompt and full payment of bills.

Commercial Invoice: Statement showing thletails of items and their prices. It is a preliminary document sent by supplier to ber and is used by the buyer to check the goods received.

Competitive Bidding: Several vendors respding to supply certain items and final selection of the successful bidder is made one basis of price, quality and other consideration.

DGS and D (Directorate General of Supplies & Disposal): The central purchasing organisation of Government of India for publuying.

Forward Buying: Policy of purchasing items iconomical quantities exceeding current requirements, but not beyond actual fseeable requirements.

Hand-to-mouth Buying: Policy of purchasing ils only to meet immediate shortterm requirements.

Hedging: Practice of entering simultaneously itwo transactions of a like amount—a cash transaction and a futures transon. The cash transaction involves the current exchange of the buyer's cash for the sical goods and the futures transaction involves the buyer's sale of a futurestract on the item with promised delivery at a specified date in future.

Letter of Credit: An arrangement by which the gation to pay an exporter is undertaken by a bank.

Negotiation: Purchaser approaches the suppliersprice determination. It is used when the number of bidders is small, value of puse is too high and time is too short for competitive bidding or willingness to biacking.

Product Specifications: Detailed description of tharacteristics and features of an item. Some common types are: blue-prints markedes, commercial standards material specifications, performance specificatior.

Quantity Discount: Price concessions given to a buyer for purchasing larger quantities or for larger values of money.

Reciprocal Buying (or Reciprocity): Practice of giving preference in buying in those suppliers who are customers of the buying organisation.

Seasonal Discount: Price concessions offered for purchases made in the off-season.

Speculative Buying: Policy of purchasing items in excess of foreseeable requirements in order to make a profit from rising prices.

Standard Purchase Requisition: A requisition form used by internal departments of an organisation to raise the indents for non-recurring materials. The completed form is submitted to the purchase department.

Trade Discount: Price concessions given to a buyer on the basis of his classification—Wholesaler, retailer etc.

Travelling Purchase Requisition: A requisition card maintained continuously for each item and used to procure recurrently needed materials and parts. It originates from stores or inventory control section.

16.13 SELF-ASSESSMENT EXERCISES

I Review Questions

1 What are the common objectives of the purchasing function?

2 What are the common forms used to authorise a purchase and what are the governing factors to decide the suitability of these forms?

3 What are the major purposes of product specification and what are the common methods of product specifications?

4 What are the activities in the purchasing function which require high consideration for legal aspects?

5 What are demand factors and how do they influence the purchase decisions?

6 What are the common approaches for price determination?

7 What are different types of discounts offered by the suppliers?

8 What are the approaches for price determination.

9 What are the common shipping criteria?

10 When and how are the various purchasing approaches beneficial to decide the timing of purchases?

11 What are the various purchase forms and records usually employed by a purchasing department?

12 What are the basic types of purchase contracts and when should they be used?

13 What are the criteria commonly employed for the evaluation of purchasing system?

14 How are vendors evaluated?

15 Sketch the information flow between purchasing and various other departments of an organisation and list the responsibilities of each to meet the objectives of an integrated purchasing system.

II Design Exercises

1 Design a suitable form to be used for preparing the comparative statements to enable the purchasing manager to take the decision about the best supplier.

2 Design an inspection report form to enable the purchasing department to release various instalments of the payment and to enter the appropriate data in the supplier's file.

III Problems

1 An item is demanded at the rate of 20,800 units per year and the lead time is 2 weeks. The unit price is Rs. 50 and the holding cost is Rs. 10 per unit per year (i.e. 20 per cent of the unit price). It costs Rs. 20 for each lot of procurement. The standard deviation of the demand over the lead time is 10. Calculate the order quantity, reorder point and safety stock and prepare the purchase plan and the budget for the whole year.

Consider a problem of comparing suppliers by weight point plan. A total of 100 points are allocated among those factors considered important by an organisation. The supplier with the largest number of weight points is the most desirable. The following weights are used to compare the suppliers: quality (40 points), price (35 points), and service (25 points). Based on the data given below, rank the four suppliers:

Supplier	Shipment received	Shipments accepted	Unit price	Fraction of commitments fulfilled
A	500	480	10.00	0.94
B	600	560	9.60	0.90
C	80	78	1.20	1.00
D	200	192	8.90	0.98

16.14 FURTHER READINGS

Ammer, D.S., 1982. *Materials Management and Purchasing*, Richard Irwin, Ind. Rept. edn., D.B. Taraporevala: Bombay.

Datta, A.K., 1986. *Integrated Materials Management—A Functional Approach*, Prentice-Hall of India: New Delhi.

Gopalakrishnan, P. and Sundaresan, M., 1981. *Materials Management — An Integrated Approach*, Prentice-Hall of India: New Delhi.

Tersine, R.J. and Campbell, J.H., 1977. *Modern Materials Management*, North Holland: New York.

Westing, J.H., Fine, I.V., and Zenz, G.J., 1979. *Purchasing Management*, John Wiley, Ind. Rept. edn., Wiley Eastern Limited: New Delhi.

UNIT 17 INVENTORY MANAGEMENT

Objectives

Upon completion of this unit, you should be able to:

- understand the meaning of inventory and identify inventory related cost parameters
- learn about various types of inventory policies
- appreciate the role of selective inventory management
- know the exchange curve concept for aggregate inventory planning
- get a feel of some mathematical models of inventory analysis
- perform sensitivity analysis on a type of model
- compute safety stocks
- understand the problems of slow moving items
- appreciate the role of computers in inventory control
- have a brief idea about recent developments in inventory management.

Structures

17.1 INTRODUCTION TO INVENTORY SYSTEMS

Concept of Inventory

'Inventory' may be defined as 'usable but idle resource'. If resource is some physical and tangible object such as materials, then it is generally termed as stock. Thus stock or inventory are synonymous terms though inventory has wider implications.

Broadly speaking, the problem of inventory management is one of maintaining, for a given financial investment, an adequate supply of something to meet an expected demand pattern. This could be raw materials work in progress finished products or the spares and other indirect materials.

Inventory can be one of the indicators of the management effectiveness on the materials management front. Inventory turnover ratio (annual demand/average inventory) is an index of business performance. A soundly managed organisation will have higher inventory turnover ratio and vice-versa.

Inventory management deals with the determination of optimal policies and procedures for procurement of commodities. Since it is quite difficult to imagine a real work situation in which the required material will be made available at the point of use instantaneously, hence maintaining, inventories becomes almost necessary. Thus inventories could be visualised as 'necessary evil'.

Inventory Related Cost

An inventory system may be defined as one in which the following costs are significant:

a) cost of carrying inventories (holding cost)
b) cost of incurring shortages (stockout cost)
c) cost of replenishing inventories (ordering cost)

a) Cost of carrying inventory : This is expressed in Rs./item held in stock/unit time. This is the opportunity cost of blocking material in the non-productive form as inventories. Some of the cost elements that comprise carrying cost are—cost of blocking capital (interest rate); cost of insurances; storage cost; cost due to obsolescence, pilferage, deterioration etc. It is generally expressed as a fraction of value of the goods stocked per year. For example, if the fraction of carrying charge is 20% per year and a material worth Rs. 1,000 is kept in inventory for one year, the unit carrying cost will be Rs. 200/item/year. It is obvious that for items that are perishable in nature, the attributed carrying cost will be higher.

b) Cost of incurring shortages: It is the opportunity cost of not having an item in stock when one is demanded. It may be due to lost sales or backlogging. In the backlogging (or back ordering) case the order is not lost but is backlogged, to be cleared as soon as the item is available on stock. In lost sales case the order is lost. In both cases there are tangible and intangible costs of not meeting the demand on time. It may include lost demand; penalty cost; emergency replenishment; loss of good-will etc. This is generally expressed as Rs./item short/unit time.

c) Cost of replenishing inventory: This is the amount of money and efforts expended in procurement or acquisition of stock. It is generally called ordering cost. This cost is usually assumed to be independent of the quantity ordered, because the fixed cost component is generally more significant than the variable component. Thus it is expressed as Rs./order.

These three types of costs are the most commonly incorporated in inventory analysis, though there may be other costs parameters relevant in such an analysis such as inflation, price discounts etc.

Importance of Inventory Management

Scientific inventory management is an extremely important problem area in the materials management function. Materials account for more than half the total cost of any business and organisations maintain huge amount of stocks much of this could be reduced by following scientific principles. Inventory management is highly amenable to control. In the Indian industries there is a substantial potential for cost reduction due to inventory control. Inventory being a symptom of poor performance we could reduce inventories by proper design of procurement policies by reduction in the uncertainty of lead times by variety reduction and in many other ways.

17.2 FUNCTIONS OF INVENTORY

As mentioned earlier, inventory is a necessary evil. Necessary, because it aims at absorbing the uncertainties of demand and supply by 'decoupling' the demand and supply sub-systems. Thus an organisation may be carrying inventory for the following reasons:

a) Demand and lead time uncertainties necessitate building of safety stock (buffer stocks) so as to enable various sub-systems to operate somewhat in a decoupled manner. It is obvious that the larger the uncertainty of demand and supply; the larger will have to be the amount of buffer stock to be carried for a prescribed service level.

b) Time lag in deliveries also necessitates building of inventories. If the replenishment lead times are positive then stocks are needed for system operation.

c) Cycle stocks may be maintained to get the economics of scale so that total system cost due to ordering, carrying inventory and backlogging are minimised. Technological requirements of batch processing also build up cycle stocks.

d) Stocks may build up as pipeline inventory or work-in-process inventory due to finiteness of production and transportation rates. This includes materials actually being worked on or moving between work centres or being in transit to distribution centres and customers.

e) When the demand is seasonal, it may become economical to build inventory during periods of low demand to ease the strain of peak period demand.

f) Inventory may also be built up for other reasons such as: quantity discounts being offered by suppliers, discount sales, anticipated increase in material price, possibility of future non-availability etc.

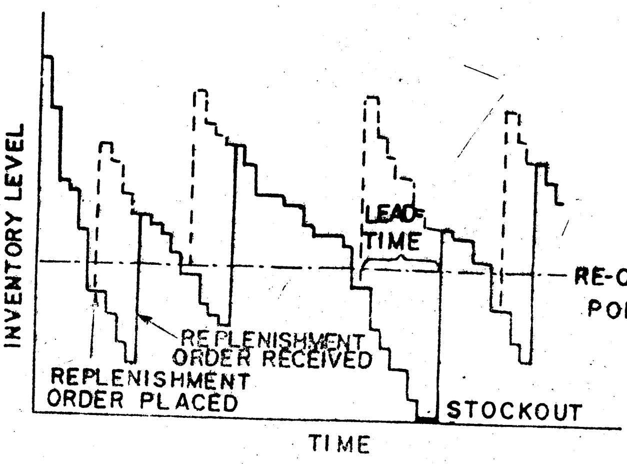
Different functional managers of an organisation may view the inventory from different viewpoints leading to conflicting objectives. This calls for an integrated systems approach to planning of inventories so that these conflicting objectives can be scrutinised to enable the system to operate at minimum total inventory related costs—both explicit such as purchase price, as well as implicit such as carrying, shortage, transportation and inspection costs. Concepts and techniques useful in analysis these problems to arrive at sound policy decisions are the focal point of presentation in this unit.

17.3 CLASSIFICATION OF INVENTORY SYSTEMS

Lot Size Reorder Point Policy

Under this operating policy the inventory status is continuously reviewed and as soon as the inventory level falls to a prescribed value called 'Reorder Point'. A fresh replenishment order of fixed quantity called Economic Order Quantity (EOQ) is initiated. Thus the order size is constant and is economically determined. This is one of the very classical type of inventory policies and a lot of mathematical analysis has appeared on this type of policy. Figure I shows the typical stock balance under this type of inventory policy. The solid line in this figure represents the actual inventory held in practical situation with a finite lead time, the lead time being defined as the time delay between the placing of a replenishment order and its subsequent receipt. The broken line indicates the inventory that would be held in the ideal situation if no lead time existed. Lot size and reorder point are the two decision variables involved in the design of the policy.

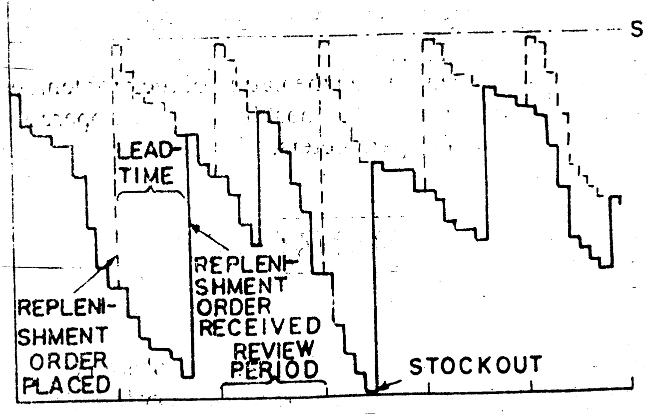
Figure I: Typical Inventory Balances for EOQ—Reorder Point Policy.



Fixed Order Interval Scheduling Policy

Under this policy the time between the consecutive replenishment orders is constant. There is a maximum stock level(s) prescribed and the inventory status is reviewed periodically with a fixed interval (T). At each review an order of size Q is placed which takes the stock on hand plus an order equal to the maximum stock level. Thus order quantity could vary from period to period. This policy ensures that when the level of stock on hand is high at review, a smaller size replenishment order is placed. Figure II shows the typical stock balances under this fixed reorder cycle policy. S, the maximum stock level and T the review period are the decision variables under this policy.

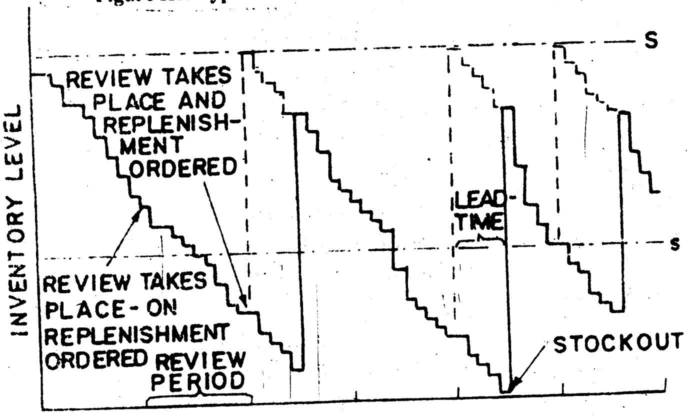
Figure II: Fixed Reorder Cycle Policy.



Optional Replenishment Policy

This is very popularly known as the (s, S) policy. Figure III shows the typical stock balance under this policy. The status of stock is periodically reviewed and maximum stock level (S) and minimum stock level (s) are prescribed.

Figure III: Typical Inventory Balances in (s, S) Policy.



If at the time of review, the stock on hand is less than or equal to s, an order of size Q is placed so that stock on hand plus on order equals the maximum stock level S. If stock on hand at review is higher than s, no order is placed and the situation is reviewed at the time of next review period. S, s and T (review period) are the decision variables in the design of such inventory policy.

Other Types of Inventory Systems

There may be other policies which may be special cases of the policies mentioned above or may be a combination of these policies. As a special case of (s, S) policy we may have (S-1, S) policy or one-for-one order policy when the maximum stock level may be upto S and whenever there is demand for one unit, a replenishment of one unit is ordered. Such a policy may be quite useful for slow moving expensive items.

We may use a combination of lot-size reorder point policy and fixed interval order scheduling policy. Yet another variation of inventory policy could be multiple reorder point policy where more than one reorder point may be established.

Other types of inventory systems may be static inventory systems when a single purchase decision is to be made which should be adequate during the entire project duration. Such decisions are not repetitive in nature. Other initial provisioning decisions may be with respect to repairable assemblies such as engines, gearboxes etc. in a bus which may have to be overhauled and for which we have to find adequate number of spare engines to be provided initially.

The right choice of an inventory policy depends upon the nature of the problem; usage value of an item and other situational parameters. We must first select an operating policy before determining optimal values of its parameters.

17.4 SELECTIVE INVENTORY MANAGEMENT

Role of Selective Inventory Control

One of the major operating difficulty in the scientific inventory control is an extremely large variety of items stocked by various organisations. These may vary from 10,000 to 100,000 different types of stocked items and it is neither feasible nor desirable to apply rigorous scientific principles of inventory control in all these items. Such an indiscriminate approach may make cost of inventory control more than its benefits and therefore may prove to be counter-productive. Therefore, inventory control has to be exercised selectively. Depending upon the value, criticality and usage frequency of an item we may have to decide on an appropriate type of inventory policy. The selective inventory management thus plays a crucial role so that we can put our limited control efforts more judiciously to the more significant group of items. In selective management we group items in few discrete categories depending upon value; criticality and usage frequency. Such analyses are popularly known as ABC, VED and FSN Analysis respectively. This type of grouping may well form the starting point in introducing scientific inventory management in an organisation.

ABC Analysis

This is based on a very universal Pareto's Law that in any large number we have 'significant few' and 'insignificant many'. For example, only 20% of the items may accounting for the 80% of the total material cost annually. These are the significant few which require utmost attention.

Figure IV: ABC Analysis

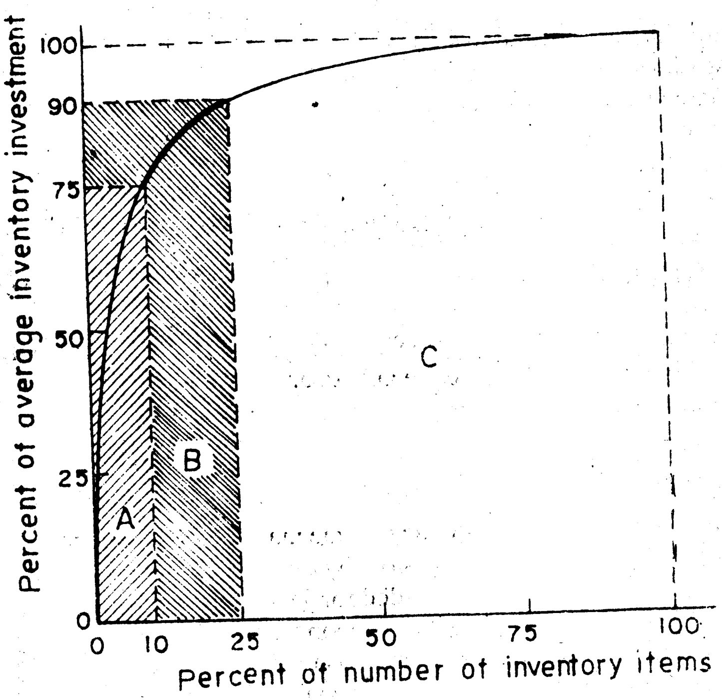


Figure IV shows a typical ABC analysis showing percentage of number of inventory items and percentage of average inventory investment (annual usage value). Annual usage value is the demand multiplied by unit price thus giving monetary worth of annual consumption. It can be seen from this figure that 10% items are claiming 72% of the annual usage value and thus constitute the 'significant few'. These are called A-class items. Another 15% items account for another 15% annual usage value are called B-class items. A vast majority of 75% items account for only 10% expenditure on material consumption and constitute 'insignificant many' and are called C-class items. To prepare an ABC type curve we may follow the following simple procedure:

i) Arrange items in the descending order of the annual usage value.
   Annual usage value = Annual demand × Unit price.
ii) Identify cut off points on the curve when there is a perceptible sudden change of slope or alternatively find cut off points at top 10% next 20% or so but do not interpret these too literally— rather as a general indicator.

A very simple empirical way to classify items may be adopted as follows:

$$\text{Average annual usage value } \bar{X} = \frac{\text{Total material cost per year}}{\text{Total number of items}}$$

A-Class items $\geq 6\bar{X}$
C-Class items $\leq 0.5\bar{X}$
In between we have B-class items.

Once the items are grouped into A, B and C category, we can adopt different degree of seriousness in our inventory control efforts. A class items require almost continuous and rigorous control. Whereas B-class items may have relaxed control and C-class items may be procured using simple rules of thumb, as usual.

VED Analysis

This analysis attempts to classify items into three categories depending upon the consequences of material stockout when demanded. As stated earlier, the cost of shortage may vary depending upon the seriousness of such a situation. Accordingly the items are classified into V(Vital), E(Essential) and D(Desirable) categories. Vital items are the most critical having extremely high opportunity cost of shortage and must be available in stock when demanded. Essential items are quite critical with substantial cost associated with shortage and should be available in stock by and large. Desirable group of items do not have very serious consequences if not available when demanded but can be stocked items.

Obviously the % risk of shortage with the 'vital' group of items has to be quite small— thus calling for a high level of service. With 'Essential' category we can take a relatively higher risk of shortage and for 'Desirable' category even higher. Since even a C-class item may be vital or an A-class item may be 'Desirable' we should carry out a two-way classification of items grouping them in 9 distinct groups as A-V, A-E, A-D, B-V, B-E, B-D, C-V, C-E and C-D. Then we are able to argue on the aimed at service-level for each of these nine categories and plan for inventories accordingly.

FSN Analysis

Not all items are required with the same frequency. Some materials are quite regularly required, yet some others are required very occasionally and some materials may have become obsolete and might not have been demanded for years together. FSN analysis groups them into three categories as Fast-moving, Slow-moving and Non-moving (dead stock) respectively. Inventory policies and models for the three categories have to be different. Most inventory models in literature are valid for the fast-moving items exhibiting a regular movement (consumption) pattern. Many spare parts come under the slow moving category which have to be managed on a different basis. For non-moving dead stock, we have to determine optimal stock disposal rules rather than inventory provisioning rules. Categorisation of materials into these three types on value, criticality and usage enables us to adopt the right type of inventory policy to suit a particular situation. In this unit, we shall mainly be developing some decision models more appropriate for A-class and fast-moving items. Later on a brief discussion on the inventory management of slow-moving items will be given.

Activity A

i) Collect consumption data for 100 different items for an organization and classify these into and ABC framework following the procedure described.

ii) List these items in two-way classification ABC and VED and identity the number of items belonging to each of these 9 distinct groups

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17.5 EXCHANGE CURVE AND AGGREGATE INVENTORY PLANNING

Concept of Exchange curve

Exchange curve (or optimal policy curve) is an effective technique to look at the inventories at an aggregate level in the organisation. It is a plot between the total number of orders (TO) per year and the total investment in inventories (TI) per year. The rationale is that for an optimal inventory policy the trade-off between total inventory and total procurement effort as indicated by the total number of replenishment orders per year must be made such that if total number of order are prescribed, we minimise total investment in inventories. Alternatively, if the total investment in inventories (TI) is prescribed then a rational inventory policy must aim at minimising (TO). Optimal inventory policy must exchange (TI) for (TO) in such a manner that

$$(TI) \cdot (TO) = K = \text{constant}$$

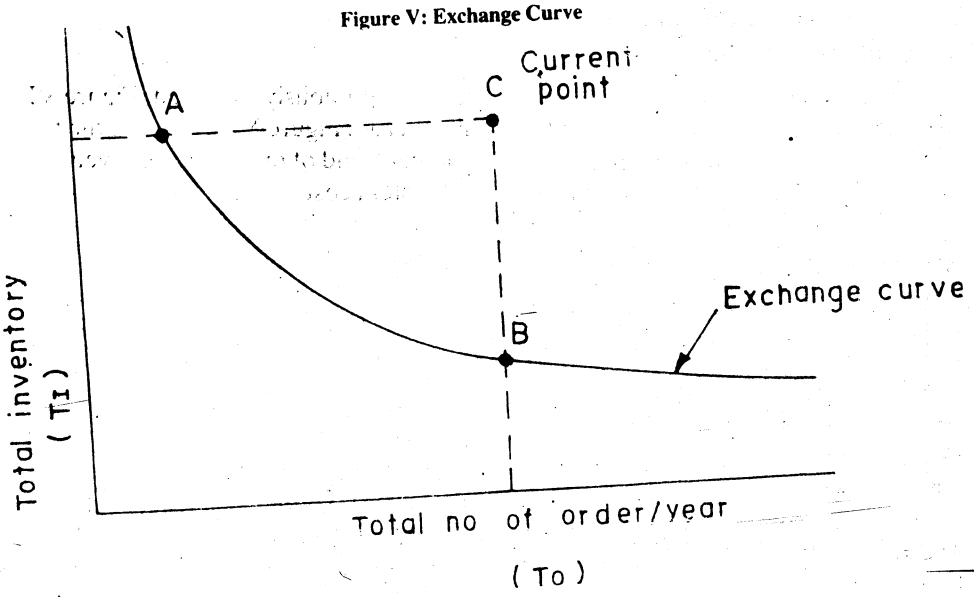
Value of constant K is given by

$$K = \frac{1}{2}\left[\sum_{i=1}^{N}\sqrt{D_iV_i}\right]^2$$

where D_i = Annual requirement of ith item,
V_i = Unit price for ith item, i = 1....N

Thus a plot between (TI) and (TO) is a rectangular hyperbola and is called as 'Exchange curve' or 'optimal policy' curve, Figure V shows a typical exchange curve for a situation where the ordering cost is not explicitly known. It shows that any point on the exchange curve is an optimal trade-off between investment in inventories and total number of orders.

Figure V: Exchange Curve



Uses of Exchange Curve

Exchange curve is an effective instrument for aggregate inventory analysis to quickly determine the rationality (or otherwise) of our existing stock provisioning policies. We first plot the exchange curve by computing the value of K for a chosen group of items. Then we determine the total number of orders (TO) and total investment in inventories (TI) under current practice.

If the current practice is at point C (in Figure V) above the exchange curve then it shows that our present procurement policies are not rational. If we want to rationalise these then there are two possible paths—AC or BC; so that we reduce inventory to B for the same ordering effort or reduce number of orders to A for the same inventory. Thus an exchange curve is a useful device at macro-level.

17.6 DETERMINISTIC INVENTORY MODELS

Classical EOQ Model

In this section we discuss some elementary inventory models with deterministic demand and lead time situations. The purpose is to provide an illustration of the mathematical analysis of inventory systems. The most classical of the inventory models was first proposed by Harris in 1915 and further developed by Wilson in 1928. It is very popularly known as EOQ (Economic Order Quantity) model or 'Wilson's Lot Size formula'.

When dealing with stocked items, the two important decisions to be made are—how much to order and when to order. EOQ attempts to provide answer to former while the Reorder point (RoP) provides the answer to the latter.

The following assumptions are made in the standard Wilson lot size formula to obtain EOQ:

a) Demand is continuous at a constant rate
b) The process continues infinitely.
c) No constraints are imposed on quantities ordered, storage capacity, budget etc.
d) Replenishment is instantaneous (the entire order quantity is received all at one time as soon as the order is released).
e) All costs are time-invariant.
f) No shortages are allowed.
g) Quantity discounts are not available.

The inventory status under EOQ-RoP policy is continuously reviewed. Figure VI (a) shows the behaviour of such a simple system whereas Figure VI (b) shows the total system cost behaviour highlighting the conflicting trend of ordering and inventory carrying costs. EOQ aims at minimising total system cost.

Figure VI (a): Inventory Behaviour under Classical EOQ Model.

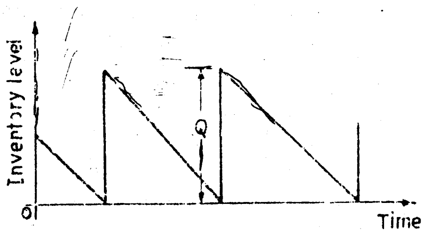
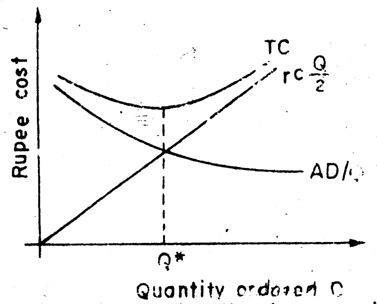


Figure VI (b): Total Cost Curve under EOQ Model.



Let us use the following notation in developing the classical EOQ model:

D = Demand rate; unit per year.
A = Ordering cost; Rs./order.
C = Unit cost, Rs. per unit of item.
r = Inventory carrying charge per year.
H = Annual cost of carrying inventory/unit item = r.c.
TC = Total annual cost of operating the system Rs./year (objective function).
Q = Order quantity, Number of units per lot (decision variable).

Since demand is at uniform rate average inventory is Q/2 throughout the year and the total number of orders are (D/Q) per year. Thus total annual cost of operating the systems consisting of carrying cost and ordering cost can be written as:

$$TC = A\left(\frac{D}{Q}\right) + \frac{H.Q}{2}$$

This gives $Q^* = EOQ = \sqrt{\frac{2AD}{H}}$

Minimum cost = $TC^* = \sqrt{2AHD}$

Due to convex nature of total cost curve, it is obvious that Q^* (EOQ) gives the global minimum total cost. It can also be seen that EOQ is obtained at the point of intersection of ordering cost and carrying cost in Figure VI (b).

Some interesting insight may be obtained using this classical system:

i) If ordering cost is of high tendency, the optimal policy is to have high EOQ thus raising average inventory level.

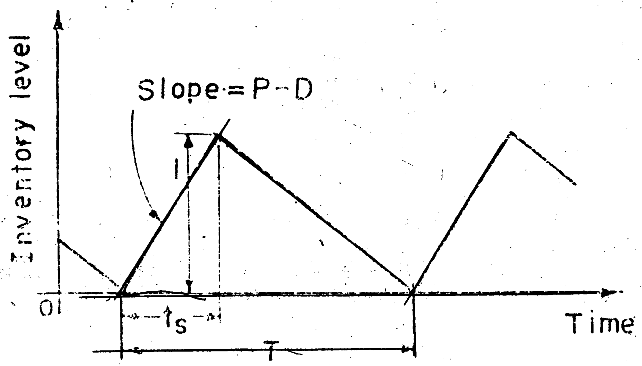
ii) If r or c are high leading to high value of H, the tendency will be to go for smaller lot sizes.

r may vary from 0.15–0.30 and will depend on the nature of item, A the ordering cost should be marginal ordering cost while H should be based on total purchased cost of the items.

Finite Replenishment Rates

We will now relax the assumption (d) of the classical EOQ model and permit finite replenishment rate (staggered deliveries). When the rate of procurement is P in units/year and the demand rate is D, in units/year, the build up of inventory is at a rate (P-D) due to simultaneous consumption. It is obvious that P>D for inventory to build up. Figure VII shows the inventory behaviour with finite supply rate. The stock builds

Figure VII: Inventory Behaviour under Finite Replenishment rate.



up to a maximum level I during supply period t_s, after which stock depletion takes place at rate D. It can be seen that

$I = t_s(P-D)$; $t_s = Q/P$

Thus $TC = A(D/Q) + H\,Q/2\,(1-D/P)$

For minimum TC we get, $Q^* = \sqrt{\dfrac{2AD}{H\,(1-D/P)}}$

and $TC^* = \sqrt{2ADH(1-D/P)}$

Some interesting observations can be made about the behaviour of such systems. These are:

i) Q^* under finite replenishment rates are higher than Q^* under classical EOQ model for the same values of other parameters.

ii) Total system cost under optimal Q^* is lower than corresponding total system cost and EOQ model.
Thus staggering the supplies always reduces inventory level and total operating system cost provided other cost parameters remain the same.

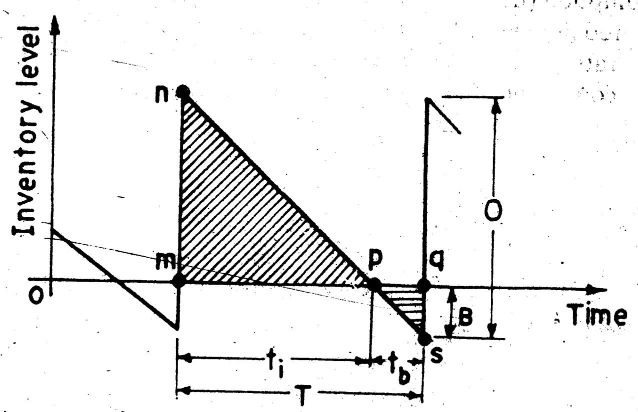
iii) As $P \to \infty$, Q^* and TC^* obtained are same as in standard Wilson's formula of instantaneous replenishment.

iv) At $P = D$, $Q^* \to \infty$; $TC \to 0$. Thus if we can have a fully devoted reliable supplier, then placing a single supply order of large size but matching supply rate with the demand rate is the optimal decision. Under such a system, no stocks are built, no replenishments are made, no shortages are incurred. This would seem to be an ideal system towards zero-inventory provided we know our requirements for sure and we have a dependable source to supply us at the rate to match the requirement. This brings out the role of dependable source of supply as an important asset to materials management function.

Planned Backlogging

Let us now consider the effect of relaxing assumption (f) of classical Wilson's model by permitting backlogging (shortages or back ordering) at a unit shortage cost of S in Rs./unit short/year. In such a case negative inventory shows the backlogging position. The order quantity Q is partly used to clear the backlogging level B and (Q–B) is the maximum stock level. Figure VIII shows the inventory behaviour under planned

Figure VIII: Inventory Behaviour with Planned backlagging.



backlogging. Inventory is maintained for duration t_i and demands remain backlogged for duration t_b. Total cycle time of each replenishment cycle is

$$T = t_i + t_b = Q/D$$

$$t_i = \frac{Q-B}{D}, \quad t_b = B/D$$

It can be seen that, average inventory = $\frac{(Q-B)^2}{2Q}$ and average back order level = $B^2/2Q$

TC = Total annual system cost

$$= A(D/Q) + H\frac{(Q-B)^2}{2Q} + S.\frac{B^2}{2Q}$$

Optimal values of Q and B can be obtained for minimum value of TC as follows:

$$Q^* = \sqrt{\frac{2AD}{H}} \cdot \sqrt{\frac{H+S}{S}}$$

$$B^* = \sqrt{\frac{2AD}{S}} \cdot \sqrt{\frac{H}{H+S}}$$

$$TC^* = \sqrt{2ADH} \qquad \sqrt{\frac{S}{H+S}}$$

Maximum stock level = $Q^* - B^*$

$$= \sqrt{\frac{2\ AD}{H}} \qquad \sqrt{\frac{S}{H+S}}$$

Some useful observations could be made about the behaviour of inventory system with planned backlogging as follows:

a) Total system cost is lower with planned backlogging than the corresponding total system cost under classical Wilson's lot size formula. Thus for a deterministic system with finite backlogging cost, it is economi. al to plan for backlogging. It can be seen that at $S \rightarrow \infty$, the model reverts to classical EOQ model.

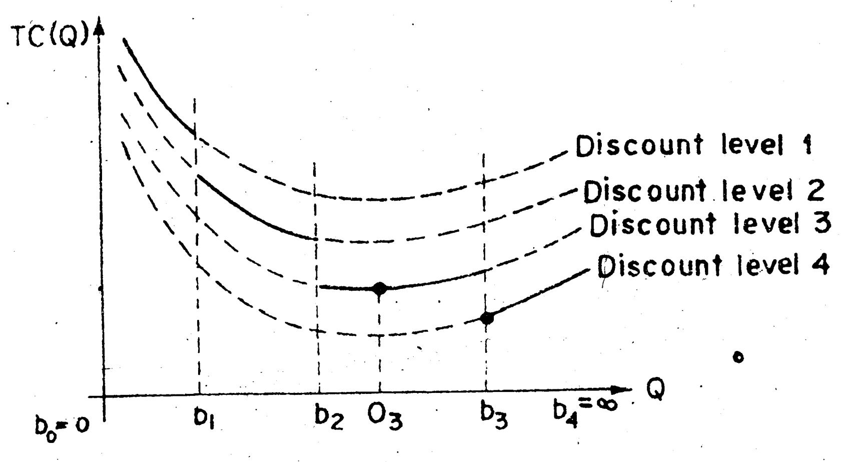
b) EOQ under backlogging is higher and maximum stock level is lower than the corresponding values under classical Wilson's lot size model.

c) If $S = O$ then $B^* = Q^* = \infty$. This means that with no charge for back orders one would keep piling up unfilled demand until the backlog gets infinitely large. Then one single order would be released to satisfy all accumulated demand. However, considering intangible cost of backordering such as loss of goodwill etc. it is debatable whether there are situations when the unit cost of shortages (S) is really zero.

Model with Quantity Discounts

Frequently, the vendors offer quantity discounts on bulk purchases to encourage users to place orders in large quantities. Quantity discounts may be all unit discounts or incremental quantity discounts. In all unit discounts entire order quantity is purchased at lower unit price if order size is higher than or equal to the stipulated conditions. In incremental case only quantity exceeding the threshold point is charged at lower unit cost. The immediate reaction may be to avail the discount and place bulk orders but if we see the total system cost, our decision may be otherwise. There may be a single or multiple quantity discounts. Figure IX shows total system costs under four discounts.

Fiigure IX: Total Cost Curves under Quantity Discounts.



The broken lines show the total cost curves without price break whereas solid lines show the actual total cost if price break takes place. The larger the number of price breaks, the more difficult it becomes to analyse the situation as more alternatives are to be evaluated. The important point to be made in such situations is that individual 'tuation is to be analysed to judge which of the options is suitable to avail discount and place bulk order to make it realisable, reject the offer and place small order at higher unit price or place order at the minimum possible quantity at which discount becomes valid. Any alternative is optimal if that minimises the total system cost. For example, it can be easily seen from Figure IX that for this case the minimum total system cost occurs at $Q^* = b_3$ is the minimum quantity at which discount level 4 is applicable.

Sensitivity Analysis

It may not be operationally very convenient to stick to EOQ if it is an odd figure. Then one may like to know the repercussions on total system cost if one deviated either way from Q^*. This is done through sensitivity analysis. If Q_a is actual order quantity, $Q_a = b.Q^*$ where b is sensitivity parameter. If $b = 0.8$ then actual Q_a is 20% less than Q^* and if $b = 1.2$ then Q_a is 20% less of higher than Q^*. Obviously the TC will increase over TC^* in either case. If we substitute Q_a as bQ^* in total cost expressions in the classical EOQ model, we can easily get the following relationship.

$$\frac{TC_a}{TC^*} = \frac{1+b^2}{2b} = p$$

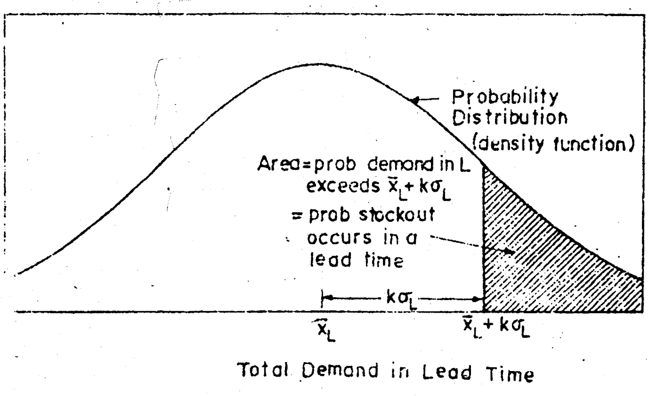
where TC_a is actual cost with order size being Q_a. It can be seen that at $b = 1, p = 1$. If b is allowed to vary within 0.9 to 1.10 then p will be within 1.005 indicating that $\pm$ 10% deviation in EOQ leads to less than half a per cent increase in TC. Thus TC is not very sensitive to EOQ and for operational convenience we should be able to vary EOQ within $\pm$ 10% of Q^* without adversely affecting total system cost.

17.7 PROBABILISTIC INVENTORY MODELS

Impact of Demand and Lead Time Uncertainties

In the inventory models described in previous section we assumed that there was no uncertainty associated with the demand and replenishment—lead times. However, in reality there is always some uncertainty associated with the demand pattern and lead times. It can be shown that as the uncertainty (variability) of demand and lead times increases, extra stock in the form of safety stock (buffer stock) is required to account for these uncertainties. In the deterministic system, reorder point is very easy to determine as it is the demand during the lead time. For example, if the demand is uniform at a rate of 100 units/month and lead time is 3 months, then in the deterministic system the reorder point is 300 units. However, if there is variability of demand and times, an extra buffer stock will be added to the expected demand during the lead times, to obtain the reorder point. Furthermore, despite higher reorder point due to extra safety stock to provide cushion for system variability, there will still be a probability of stock out. Figure X shows the mechanics of occurrence of shortage in a probabilistic inventory system. If $\bar{X}_L$ is the average demand during the lead time and

Figure X: Occurrence of stockout under probabilistic inventory situation



X_L – forecast demand over replenishment lead time

σ_L – standard deviation errors of a forecast over a lead time

Figure σ_L is the standard distribution of lead time demand and if reorder point is set at $\bar{X}_L + K\sigma_L$ for normally distributed demand, then the shaded area of Figure X gives the probability of stockout during the lead time. This value can be obtained from standard normal tables for various values of K.

Determination of Reorder Point

As stated earlier, the Reorder Point (R) in the probabilistic lot size inventory system is given by:

$$R = \text{Expected demand during lead time} + \text{Buffer (safety stock)}$$
$$= \bar{X}_L + K.\sigma_L$$

For obtaining X_L and σ_L from the distribution of demand and lead times a lead time demand distribution (LTDD) such as shown in Figure X can be obtained. The following expressions characterise the LTDD:

$$\bar{X}_L = \bar{D}.\bar{L}$$
$$\sigma^2_L = \sigma^2{}_L + \bar{D}^2\sigma^2{}_l$$

where
- $\bar{D}$ = Expected demand rate
- σd = Standard deviation of demand rate
- $\bar{L}$ = Expected lead time
- σ_L = Standard deviation of lead times

Therefore,

$$R = \bar{D}.\bar{L} + K\sqrt{\sigma a\ .\bar{L} + \bar{D}^2\sigma.1^2}$$

This expression quantitatively incorporates the effect of demand and lead time variability on R and buffer stock. It can be seen that as σd, $\sigma 1$ increase, signifying higher demand and lead time variability, the Reorder point and buffer stock increases. If lead time is constant at L, then $\sigma 1 = 0$ and $R = \bar{D}.L. + K.\sigma d\ \sqrt{L}$

Similarly if the demand is constant, $\sigma d = 0$, then

$$R = D.\bar{L} + K:\sigma 1.\ D$$

If both demand and lead times are constant, $\sigma d = 0$, $\sigma 1 = 0$, then

$$R = D.L. \text{ (Demand during lead time)}$$
$$\text{Buffer stock} = 0$$

Safety Stock and Service Levels

In the determination of safety stock, the factor K obtainable from normal distribution tables for normally distributed lead time demand, depends upon the risk of shortage we are prepared to accept. Higher value of K means less risk of shortage (or high service level) and vice-versa. For example if K = 1, then risk of shortage is 15.87 % or service level is (100–15.87 = 84.13%). At K = 2, the risk of shortage is 2.28% and at K = 3, the risk is 0.13 % only. Obviously, at K = 0, buffer stock is zero but risk of shortage is 50%. Thus we can choose K (hence buffer stock) for a prescribed risk of shortage during a lead time.

17.8 INVENTORY CONTROL OF SLOW MOVING ITEMS

Nature of Slow Moving Items

As stated earlier, slow moving materials are those which are not regularly demanded and their movement off the shelf is very occasional, say once in six months or so. Examples of slow moving materials can be — spare parts and some special purpose materials for projects required only for a certain kind of project activity Inventory models valid for fast moving models are not applicable for slow moving items due to lack of regular demand pattern. Generally slow moving items are quite expensive and therefore one has to first decide whether to keep them all in stock and if to keep them in stock then in what quantity further difficulty of slow moving parts is that initial over-buying decision could take years to remedy the situation due to rarely occurring demands.

Some Inventory Policies for Slow Moving Spares

We shall illustrate our approach to manage the inventory of slow moving items with spares inventory problem as a substantial percentage of spares come under the slow moving categories. Some of the strategies that could be possibly adopted for efficient inventory management of slow moving spares are as follows:

a) If spares are required only at pre-specified time such as at the time of major scheduled maintenance for replacement, then it is better not to stock them but to place procurement order sufficiently well in advance, keeping lead times in mind, so that these arrive just in time when these are needed.

b) If the part gives adequate warning of impending break down, then also the best policy is to place an order the moment we get the warning. Adequate warning refers to the case when the lead time required is less than the warning time. This shows that major improvements in slow moving inventory are possible by cutting down the lead times.

c) For inadequate warning spares we must keep the stock. Generally maximum stock level will be 1 or 2 and the (S-1, S) or one-for-one ordering policy is very useful. This means placing an order for one spare when one is consumed.

17.9 RECENT DEVELOPMENTS IN INVENTORY MANAGEMENT

Multi-echelon Inventory Systems

The inventory models described in the preceding sections pertained to situations where the stock is located at a single place. In practice the stock may be distributed over several locations. For example in a multi-project organisation, there may be a central store and a number of field stores or project stores. Such types of inventory systems are called 'Multi-echelons inventory Systems'. Since the inventory in all the locations belong to the same system, it is better to look at the inventory management for the system as a whole rather than treating each storage location independently. Recently a lot of attention has been given by the researchers to the analysis of such multi-echelon inventory systems. Important decisions concerning the design and operation of such systems are the number of echelons, number of storage points at each echelon (level), location of central store, optimal inventory policy to be followed by each storage location, stock redistribution policies etc. For very expensive slow moving item such as complex assemblies it may be desirable to locate the inventory at the central store rather than the project (field) store provided the item is standardised and is usable at each locations. Detailed mathematical analysis of multi-echelon inventory systems tends to be rather complex and is beyond the scope of this unit.

Materials Requirement Planning

Materials Requirement Planning (MRP) is an important concept and is increasingly becoming popular because of increasing role of computer based planning and control systems. MRP is useful for situations having products with inverted tree like structure so that the demand for parts and sub-assemblies is dependent upon the master production schedule of the end-product. The MRP concept provided a very basic and different way of looking at the management of produ[illegible]n inventories. MRP inputs are master production schedule; bill of materials and inventory status. MRP software package computes the parts requirement, and prepares production and procurement schedules. This indicates the increasing role of computers in inventory planning.

17.10 CONCLUDING REMARKS

Inventory management is an extremely important problem area in the management of materials. It is quite susceptible to control and a very large amount of scientific models are available in the literature to enable us to choose an optimal inventoy policy. Buying the optimal quantity can result only from a sound inventory control system which is achieved by judicious reconciliation of conflicting costs and departmental objectives. However, inventory is only an indicator of performance of materials management function and to cut down inventories we use not only scientific inventory management principles and models but also take long-term measures to reduce inventories through strategies such as variety reduction and standardisation, source development and vendor rating, lead-time reduction through improvements in the systems and procedures of procurement. It is obvious that scientific inventory management has to be practised selectively rather than indiscriminately to make it cost-effective. It is also important to have informational inputs like demand forecast, lead time estimate and other cost estimates to be realistic to make effective use of inventory models.

17.11 SUMMARY

This unit has attempted to highlight the role of inventory mangement in the successful operation of any production or service system. Functions of inventory and various inventory related costs parameters have been identified. Various operating inventory policies have been described. ABC/VED/FSN analysis concepts have been outlined to enable selective control on inventories and the role of exchange curve to quickly detect the irrationality of existing procurement practice has been highlighted. Some deterministic models to determine EOQ are presented and sensitivity of classical EOQ model is analysed. Impact of demand/lead time variability on reorder point and buffer stock has been explained. Problems of slow moving items inventory control has been identified and some guidelines have been given. Recent developments in inventory management have also been given.

17.12 KEY WORDS

ABC Analysis: Arranging items according to annual usage value in three categories A, B and C to identify significant few and insignificant many.

Annual Usage Value: Annual demand multiplied by unit price.

Backlogging: Process of accumulating unsatisfied demand till fresh replenishment of stock is made available.

Buffer Stock: Extra safety stock needed to absorb variation in demand and supply to provide cushion.

Carrying Cost: Cost associated with holding one unit in inventory for one time period (year).

Dead Stock: Material not demanded for a very long period due to obsolescence etc.

Exchange Curve: A curve indicating optimal trade off between total inventory and total number of orders (also called optimal policy curve.)

EOQ: Economic Order Quantity; the quantity for procurement which will result in minimum total system cost associated with carrying, ordering and backlogging.

FSN Analysis: Classification of items according to frequency of usage in Fast, Slow and Non-moving groups.

Inventory: Usable but idle resource having economic value.

Inventory Turnover Ratio: Annual demand divided by average inventory.

Lead Time: Time that elapses between placement of an order and actual receipt of materials.

MRP: Materials Requirement Planning; a system of order scheduling for dependent demand situation.

Multi-echelon Inventory System: A system of inventory control where the stock is located at different levels (echelons) at different locations.

Optional Replenishment Policy: An operating policy based on maximum and minimum stock levels with periodic review, popularly known as (s,S) policy.

Ordering Cost: Cost associated with placing a purchase order expressed as Rs./order.

Quantity Discount: A sales promotion strategy by vendor in which bulk purchases can be made at lower unit prices.

ROP: Reorder point; the stock level when the action for replenishment of stock be initiated by placing an order.

Service level: Percentage of times an item is available in stock when demanded.

Slow Moving Item: Items which are very occasionally demanded.

VED Analysis: Process of grouping items into Vital, Essential and Desirable categories depending upon the criticality of the items.

17.13 SELF-ASSESSMENT EXERCISES

1 An organisation is spending Rs. 20 crores annually in procuring a total of 50,000 different items. Using simple empirical decision rule to group items into A, B and C category, determine the cut off values of annual usage that will decide whether the item should be A, B or C class item.

2 Write true or false against the following statements:
   i) Perishable items should have higher value of inventory carrying charge than imperishables.
   ii) EOQ is smaller if backlogging is permitted under deterministic demand.
   iii) ±10% variation around EOQ is not very serious.
   iv) Finite replenishment rates enable more economical operation of an inventory system.
   v) Buffer stocks have no relationship with the amount of demand/lead time uncertainties.

3 In an inventory system the cost of placing an order is Rs. 100/order. The annual demand is 5000 units and the inventory carrying charge is 20% of the value per year. The item costs Rs. 75 each. Find EOQ and total system cost if shortages are not to be allowed.

4 If shortages are permitted and allowed to remain backlogged at a cost of Rs. 60 per unit short/year, determine the EOQ, maximum stock level, maximum backlog level and the total system cost under optimal condition for the data pertaining to problem number 3 above.

5 In an inventory system using classical EOQ model of Wilson, determine the range of variation of EOQ if 1% increase in cost over the minimum total cost is permissible. EOQ has been determined to be 400 units.

6 An item is demanded at the rate of 2000 units per year at a uniform rate. Ordering cost is Rs. 350 order. Inventory carrying cost is 24% of the unit price per year. The supplier has offered a unit price of Rs. 100/item but he is willing to reduce it to

Rs. 95/item if a purchase order of 1000 units or more is placed. Should you accept this offer?

7 An item is demanded at an average rate of 100 units/week with a standard deviation of 10 units. The lead time is normally distributed with a mean of 10 weeks and standard deviation of 2 weeks. If the lead time demand distribution is normal, find the reorder point and buffer stock if 2.28% risk of shortage can be accepted during a lead time.

8 "Inventory management for slow moving expensive items should focus more on lead time reduction than anything else". Critically examine the statement.

9 Who should be responsible for inventory control? Discuss this statement from a departmental as well as top management points of view.

10 Consider the following situation:

An inventory system has four items to be procured from different sources. Procurement action is based on each item to be considered individually and independently. The following data have been obtained for demand and unit prices for each item:

Item, i	Demand D_i (units/year)	Unit price V_i (Rs./unit)
1	7500	200
2	4000	90
3	500	500
4	100	80

The inventory control manager argues vehementally that there is no way to estimate ordering and carrying costs but he is prepared to accept that ordering cost to fraction of carrying charge is constant for each item. Currently he is following an ordering policy of using a 4-month supply of each item. He is under pressure to cut down inventory by 25% and is therefore about to adopt a policy of 3-month supply. Use exchange curve to show that he has better options available to him. What should he do?

.14 FURTHER READI...

...ebler, D.W., Lee. L., Jr. and Burt ... 1984. *Purchasing and Materials Management: Text and Cases*, McGr... ...ill Inc.: New York

...opalakrishan, P. and Sundaresan, M. ... *Materials Management: An Integrated Approach*, Prentice-Hall of India (P) ... New Delhi.

...x, A.C., and Candea, D., 1984. *Pr...tion and Inventory Management*, Prentice-Hall Inc.: Englewood-Cliffs

...ewis, C.D., 1970. *Scientific Inventory Control*, Butterworth: London.

...eterson, R. and Silver, E.A., 1981. *...ecision Systems for Inventory Management and Production Planning*, John Wi... ...ons: New York.

Plossl, G.W. and Wight O.W., 1979 ... *Production and Inventory Cont ol, Principles and Techniques*, Prentice-Hall of India Ltd.: New Delhi.

UNIT 18 STORES MANAGEMENT

Objectives

After completion of this unit, you should be able to:

- understand the role of stores in an organisation
- appreciate the problems and benefits of centralisation/decentralisation of stores
- become familiar with the systems and procedures for stores management
- get an idea of the types of stacking arrangements and layouts employed in stores and their impact on efficient retrieval
- become familiar with different kinds of equipment used in storing and handling of materials
- become aware of the latest developments in terms of automated storage and retrieval systems.

Structure

18.1 INTRODUCTION

ll the ctivities in any organisation cannot be carried out at one point of time, ge is an inevitable process. It increases the value of the material by simply ing it overtime; no transformation of any characteristics is desired. Thus stores in ompany has a vital role to play. All other activities involving materials are in o-day touch with the stores. In a majority of manufacturing organisations rial constitutes the major fraction of cost, i.e. 60 to 80% of total cost. The cost of al blocked in inventories is substantial. If this part of working capital is not rly managed the subsequent losses may be enormous. The success of the ess, besides other factors, depends to a large extent on the efficient storage and material control. Material pilferage, deterioration and careless handling may lead to reduced profits. Stores management is concerned with carrying the right kind of materials in right quantity, neither in excess nor in short supply, providing it quickly as and when required, keeping it safe against any kind of deterioration, pilferage or theft, and to carry out the efficient performance of all these functions at lowest possible cost.

18.2 STORES FUNCTIONS

The major functions of the stores are as follows:

a) **Receipt:** Receiving and accounting of raw-materials, bought out parts, spares, tools, equipment and other items.

b) **Storage:** Provision of right and adequate storage and preservations to ensure that the stocks do not suffer from damage, pilferage or deterioration.

c) **Retrieval:** Facilitating easy location and retrieval of materials keeping optimum space utilisation.

d) **Issue:** Fulfilling the demand of consumer departments by proper issue of items on the receipt of authorised purchase requisitions.

e) **Records:** To maintain proper records and update receipt and issue of materials.

f) **Housekeeping:** Keeping the stores clean and in good order so that the handling, preservation, stocking, receipt and issue can be done satisfactorily.

g) **Control:** Keeping a vigil on the discrepancies, abnormal consumptions, accumulation of stocks etc., and enforcing control measures.

h) **Surplus Management:** Minimisation of scrap, surplus and obsolescence through proper inventory control, and effective disposal of surplus and obsolete items.

i) **Verification:** Verifying the bin card balances with the physical quantities in the bins and initiating the purchasing cycle at appropriate time so as to avoid the out of stock situations.

j) **Coordination and cooperation:** To coordinate and cooperate with the interfacing departments such as purchasing, manufacturing, production planning and control, inspection, etc.

18.3 STORES ORGANISATION

Usually the following two kinds of organisation are adopted in relation to stores:

(a)	(b)
Materials Manager or Purchase Manager	General Production Manager or Production Control Manager
|	|
Stores Manager or Stores Keeper	Stores Manager or Stores Keeper

In type (a) organisation the stores is considered to be a materials function closely related to the receipt, and is clubbed with the purchasing or materials management department. This kind of arrangement is justified on the basis of following considerations:

i) As the activities of stores are material oriented, it should report to a department whose primary interests lie in the materials and related operations.

ii) From the total control point of view the receiving and stores activities should be included with the rest of materials activities. This facilitates the coordination among related materials activities from the stand-point of operations. Further, the inter-relationship between stores, inventory control and purchase function will receive, proper attention in this type of organisational arrangement.

In type (b) organisation the issue in the face of stores is considered to be more significant and thus it is clubbed with the production department. The arguments for such an organisational arrangement are as follows:

i) In order to run the production operation smoothly the production management must have control over the immediate material supply from stores. This will ensure the smooth delivery of materials to the production centres as and when required.

ii) In order to avoid/discourage any kind of collusion and embezzlement of materials, the receiving and storing should be kept separate from the purchase department.

The objectives of the organisational decision regarding stores could be to store and manage the materials so that they are available in good conditions according to the need, to efficiently supply the materials recording to production schedules, and to perform stores functions at minimum cost.

In order to fulfil the objectives the organisation will depend on the situation under consideration. In addition to the reporting, an important consideration in organisational design is the centralisation vs. decentralisation. Both the centralised and decentralised organisations of stores are practised. The advantages of centralised and decentralised stores organisations are as follows:

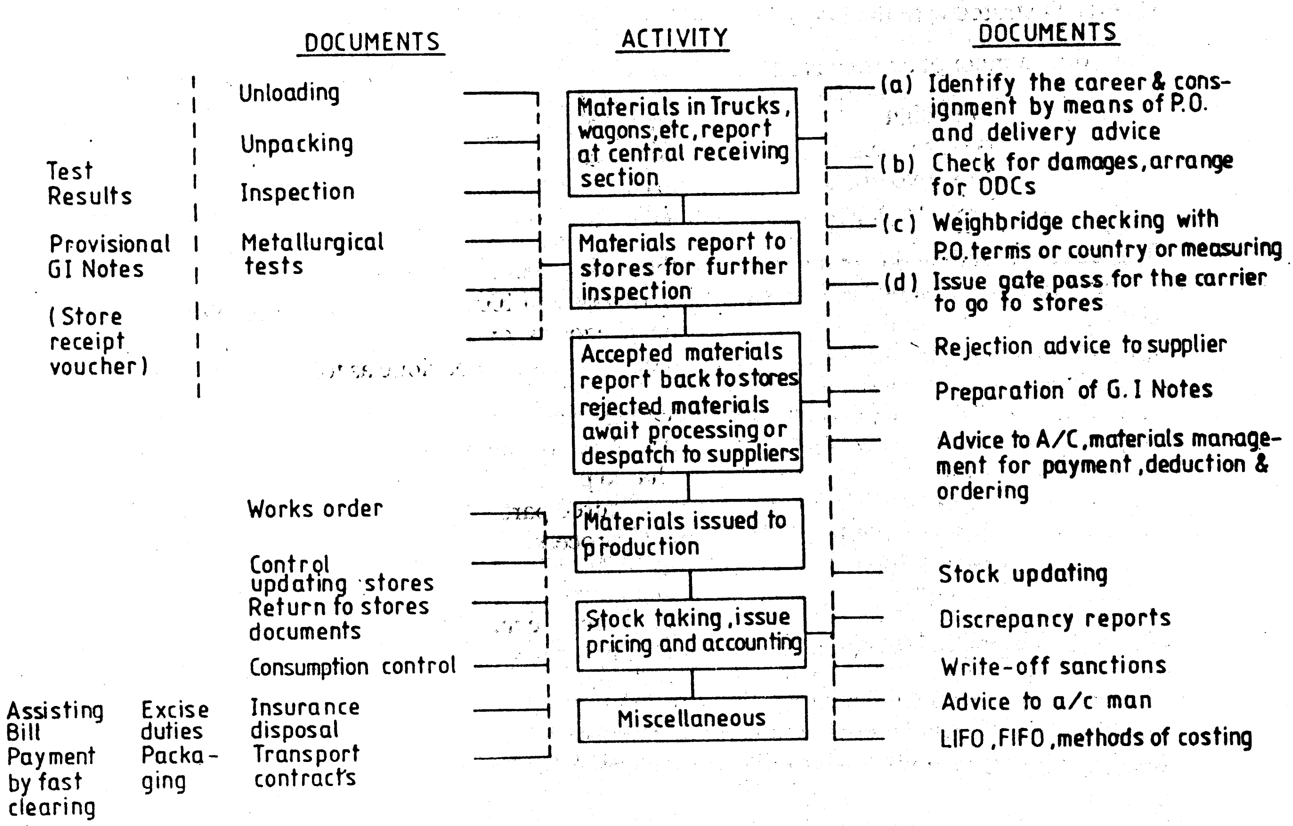
a) **Advantages of centralised stores organisation:**
   i) Effective and better supervision and control
   ii) Reduced personnel requirement, thus involving less related costs
   iii) Better and efficient layout of stores
   iv) Better inventory checks
   v) Maintenance of optimum stores
   vi) Fewer redundant and obsolete items
   vii) Provision of better security arrangements possible.

b) **Advantages of decentralised stores organisation:**
   i) Reduced material handling and associated work.
   ii) Convenient for every department to draw materials
   iii) Less risk of loss by fire etc.
   iv) Less chances of production stoppages owing to easy and prompt availability of materials.

18.4 STORES SYSTEMS AND PROCEDURES

The systems and procedures in stores can be broadly studied under four heads, viz. identification system, receipt system, storage system and issue system. The overall system of store functioning alongwith the major input-output documents at each state is shown in Figure I. A substantial amount of information is required, at every stage, for checking, controlling and feedback purposes. The stores systems have been discussed with reference to the physical system as well as the recording or information system.

Figure I: Stores Systems



Identification System

The stores management is concerned with the design and control of the systems utilised in conducting the store activities. A large number of materials are being handled by a typical stores. Thus the development of an unambiguous and efficient identification system is the first responsibility confronting a stores manager so as to facilitate clear internal communication.

The physical description of each item is usually lengthy and imprecise to be taken for the purposes of identification in day-to-day operations. Moreover, it cannot be operated on mechanical or electronic computing devices, the use of which is increasing every day in automating the clerical operations of the stores. One kind of identification of the parts can be done with the supplier's part numbers. But each supplier has got his own codification system and it will be cumbersome to operate on these numbers for the identification of different parts.

Thus the need to develop a proper identification system to coordinate the activities of purchasing inventory control and stores departments with possible integration with the operations of design engineering, production and cost accounting can hardly be overemphasised. The use of codification of parts can be done in any one of the following ways:

a) **Arbitrary approach:** The inventory items are given an arbitrary number in the sequence in which these are added in the stores account. Clearly, each item gets a discrete number but there is no systematic relationship to the numbers assigned to related items.

b) **The symbolic approach:** This is a very systematic approach to the design of codification system. The codes assigned to different parts may be numeric or monemonic (alpha numeric). A numerical system assigns a six to ten digit code number to each item to develop the classification from broader to specific categories. This is illustrated with the help of following example:

The code number of an item is 1 52 43 25; the explanation is as follows:

First digit	1	General class
Next two digits	52	Generic class
Next two digits	43	Sub class
Last two digits	25	Specific item number

This code is based on the assumption that there are maximum 10 general classes, 100 generic classes, 100 sub-classes in each generic class and 100 specific items in each sub class. If it is more than this limit in any of the categories, one more digit is to be added for that category. The general classification of the parts may be done as follows:

Code	General Class
1	Raw materials
2	Purchased parts
3	Manufactured parts
4	Work in process
5	Spares.

This monemonic or alphaneumeric system combines the numeric and alphabatic notations. This makes the visual identification easier because they are more descriptive and often shorter. A typical example is

R	Ba	RS	21
↓	↓	↓	↓
Raw material	Bars	Round, steel	Specific number of size

As the number of good alphabetical symbols is limited the system may not work with larger number of items.

c) **The use of engineering drawing number:** The number in the engineering drawing at times is used as an identification number in the stores. This has the advantage of better internal communication as this number is used by other departments. But it has the major limitation that it can be only for manufactured items; for bought out items a separate system is to be devised. Further, it has the non-sequencing disadvantage of arbitrary system.

Receipt System

The stores department receives the stores both from outside suppliers and internal divisions and accordingly there are separate receipt systems. The system of receipt start much before the physical receipt of the materials in the stores. It starts with the placement of purchase order by the purchasing department, a copy of which is sent to stores. This is maintained in chronological order, so as to give an idea at any time about the volume of receipt, and helps in the planning of receipt, unloading, unpacking and other related activities. Further, the supplies while despatching the goods normally send an advice note to the stores. This contains information regarding the date of despatch, carrier details, description of the consignment and value. Another document known as 'consignment note' is prepared by the transport carrier and is sent to the stores concerned. These documents help the stores manager to organise and plan for expeditious clearance of materials to minimise costly demurrages.

On actual delivery the receiving department unpacks the goods received and checks quantity and condition of goods using weighbridges, measuring devices, tapes, etc., and tallies it with that in previous documents. There is a packing slip inside each package detailing the contents in package and usually it gives the purchase order number.

A 'Provisional Goods Inward Note' (PGI) or a 'Materials Received Report' is prepared as soon as the materials are cleared from the receiving sections and sent for inspections. This gives information on materials code, quantity received, rate, date of receipt, carrier details, supplier details, location code and description of the material. All the items received are inspected and sample tested to ensure that the purchase order specifications are made. Results of the inspection are indicated in special testing report and a 'Clearance Report' or 'Rejection Note' is prepared and sent by inspection department to purchase, Production and Accounting departments. This forms the basis for the preparation of 'Final Goods Inward Note' (FGI) as shown in Figure II. FGI indicates quantity accepted and quantity received in addition to the information provided by PGI. FGI help in preparing shortage reports, claims documents, making appropriate payments and recoveries in case of shortages.

Figure II: Final goods Inward note

Final G.I. Note

Material Part No :— | Serial Number :—

Description :—

P.O. Reference :—

Carrier details: Truck / wagon; R/R: Consignment note

Supplier details: Supplier code; Supplier name

Inspection report: Test Results; Conclusions

Quantity received ____________ | Damage/Shortage :—

Quantity accepted ____________ | Shortage claim ref :—

Quantity rejected ____________

Sd/- Central Receiving Section Date :

Sd/- Inspection Department Date :

Sd/- Stores Department Date :

Copies to :

- Accounts : Attention bills / Insurance & claims
- Indentor : For information
- Materials Management Dept. : For updating and expediting
- Stores : For stock records and reference

In case of materials received from internal divisions or returned from user departments transfer notes or 'Return to Stores documents' are used. In some cases, Stores Department also handle the scraps. Usually scrap cards are prepared to indicate the nature and weight of the scrap.

Storage System

A **Physical Systems:** The design of proper shortage system is very important for easy location, proper identification, and speedy issue to the consuming department. The commonly followed systems for physically controlling stores materials are: closed stores system, open stores system and random access stores system. A single firm can follow a combination of these systems depending upon the nature of production operation and the use of materials.

a) Closed Stores System: In such a system all materials are physically stored in a closed or controlled area, usually kept in physical control by locking. Only stores personnel are permitted to enter the stores area. Entry and exit of the material from the area is permissible only with the accompaniment of authorising document. Maximum physical security and tight accounting control of inventory material are ensured by such a storage system.

b) Open Stores System: In this system no separate store room exists. The material is stored as close to the point of use as is physically possible. Such a system finds applicability in the highly repetitive, mass production type of systems exhibiting a continuous and predictable demand, e.g. automobile assembly plant. The storage facilities are arranged at each work station as per requirement and availability of space. The storage facilities are open and worker has direct access to it; no authorisation document is needed.

The open type of shortage system expedites the activities, cutting down the retrieval time. Since material is used relatively quickly it is not subject to high rate of deterioration or obsolescence. This system places little emphasis on the security of materials . The materials used in open system should not be easily damaged or pilferaged.

The responsibility of stores in this system is to deliver the material to production areas and to devise satisfactory physical storage arrangements with production supervisors. The further responsibility of the materials stored in production areas rests with the production supervisors.

The paper work is also considerably less in open system, as it places less emphasis on accounting control. No perpetual inventory records are kept. The actual usage can be determined by finding the difference between the number of items in the beginning and end of the period.

c) Random Access Stores System: This is a typical kind of closed stores system in which no material has a fixed location. All materials are stored at random locations throughout the store room. However, similar types and sizes of storage equipment are grouped together. When an item enters the stores, it is stocked at the first available storage location for that particular group, and when it leaves the storage, location becomes empty for any other item of the same group.

Usually a paper-work control system utilising punched card data processing equipment is employed. On the entry of any particular items a punched card is prepared with stores address. The requisitions are run on an electronic device that matches the requisition with stored material record which contains the store's address.

The most significant advantages of this system is that it utilises the space more efficiently than a fixed location, system. Further, it provides greater flexibility by accommodating different materials and inventory mixes with some storage facilities.

This type of storage system has got certain disadvantages too. It is feasible for large scale operations and requires a costly control system using electronic data processing equipment. The preservation of record card is very important; if it is lost the item is also literally lost for indefinite period. Moreover, the physical stock verification without this is very cumbersome and time consuming.

B Store Records System: Development of appropriate recording system for stores is important to provide right information regarding the physical inventory and accounting of the transaction. Two records are usually kept of materials and other goods received, issued or transferred, namely. on Bin (or Stock) Cards and in the Store Ledger.

a) Bin Cards: For each kind of material, a separate record is kept on Bin Card which shows details of quantities of each type of material received, issued and on hand each day. A typical Bin Card is shown in Figure III. The Storekeeper maintains the Bin Cards up-to-date and usually in duplicate. One card is attached to each bin on shelf containing the material and record remains with the storekeeper for reference. Some firms use the KARDEX System in which a Kardex is prepared and updated. Bin cards are also used as a check on the stock ledger accounts in the material accounting

Figure III: Bin or Stock Card

BIN CARD

Bin No..................... Maximum Quantity............

Material Ordering Level..............

Code No .... Minimum Quantity.................

Strores Ledger Folio..........

Date	Quantity Received	Quantity Issued	Balance	Remarks

b) Stores Ledger: It is identical with bin card except that here money values are shown. The store ledger may be maintained by a separate material accounting department. The entries regarding the materials ordered, received and issued are made from the purchase order, receiving section report and the material requisitions respectively.

Issue System

This is the last stage in the stores system. Issues can be of two kinds, i.e., issues to consuming departments, and issues to outside supplies for processing. In both the cases there are certain common requirements. The control of issues is regulated by production programmes. Based on the programme and the bill of materials work orders are prepared, listing for each material quantity to be issued and the corresponding quantity of the component to be manufactured. Any material requirement over and above indicated in the work order quantity means excessive wastage and scrapping. Usually, the junior stores personnel are not authorised to issue beyond the work order quantity which brings an inbuilt control.

Normally, two copies of the work order or Material Requisition Form (shown in Figure IV) are prepared by the foreman or concerned manager which are forwarded by the storekeeper to material accounting division for pricing and entry in store ledger. One copy is retained there and the other is returned to the originating department where it is used as the basis for a charge to the appropriate production order. Adhoc material requisitions are sometimes made. Periodically consolidated statements of such items must be prepared. When issues are made to outside supplies, controls have to be more formal and adequate enough to take care of payments and claims.

Figure IV: Material Requisition

MATERIAL REQUISITION

No ....

Material required for..............
(Job or Process)

Department ....

Date ....

Sr. No.	Description	Code No.	Quantity		Rate	Amount	Entered on store register page No.
			Demanded	Supplied			

Requisitioned by	Approved by	Material Issued by	Received by
....	....	....	....

18.5 STORES ACCOUNTING AND VERIFICATION SYSTEMS

Stores Accounting Systems

Stores accounting is important from the point of view of estimating the cost of the product for pricing decisions. The costing of material has to be done both for the materials consumed in the production and estimating the value of materials held in stock.

For the purpose of costing the receipt of materials, the factors that should be included are material price, freight charges, insurance, duties, taxes, packaging charges etc. The prices quoted and accepted in purchase order may often be stated in various ways such as net prices, prices with discount terms, free on board, cost, insurance, freight, etc. All these factors should be appropriately accounted while costing for the incoming materials.

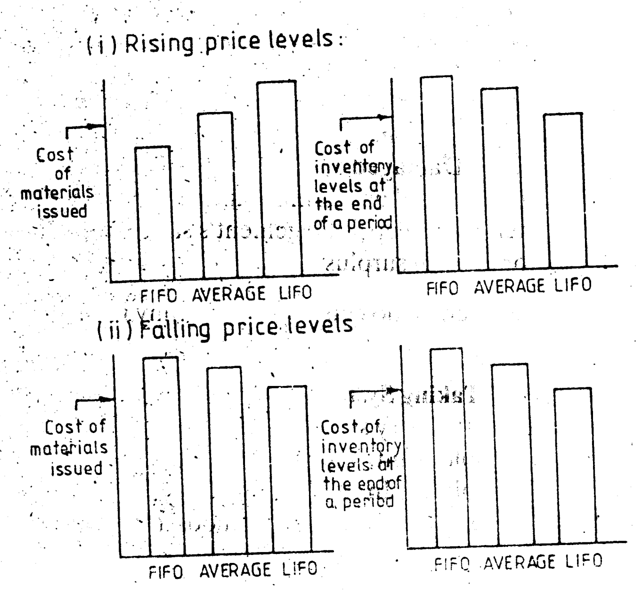
Another important accounting is to be done for the issue to production and of the stocks held at the end of accounting period. Let us discuss some of the important and frequently used system for this purpose:

a) **FIFO System:** This system known as First in First Out System is based on the assumption that the oldest stock is depleted first. Therefore, at the time of issue the rate pertaining to that will be applied. There is no 'profit' or 'loss' in the pricing arrangements. The value of the stocks held on hand is the money that has been paid for that amount of stock at latest price levels. In case of too many changes in price levels the FIFO System becomes unwieldy. Another limitations of this system is that it fails to provide a satisfactory answer to costing-returns from stores.

b) **LIFO System:** This system known as 'Last in First Out' System is based on the assumption that the most recent receipts are issued first. As the lastest prices are charged in this system, it leads to lower reported profits in the periods of rising prices and this offers savings in taxes. In case of wide fluctuations in prices this system tends to immunise unrealised gains or losses in inventory. It has almost the same limitations as that of FIFO System.

c) **Average Cost System:** This is based on the assumption that issues to production department are equally made from different shipments in stock, i.e. an average cost of shipment in stores is charged. It stabilises the cost figures. The average is to be calculated by dividing the total cost with the number of items and is to be updated with every new purchase.

Figure V: Comparison of stores Accounting Systems



d) **Market Value System:** This is also known as replacement rate costing, in which the materials issued are charged the prevailing market rates. This system underestimates the stock on hand in the case of price increase, whereas it overestimates the stock on hand in the case of price decrease. This may in turn lead to writing off huge amount to make it realistic. Moreover, a continuous monitoring of the market rates for all materials makes the system cumbersome.

e) **Standard Cost System:** In this system a detailed analysis of market price and trends is carried out to determine a standard rate for a fixed period, say six months or so. This standard rate is charged to materials issued during this period irrespective of the actual rate. After the period is over the standard rate is reviewed and updated.

This system reflects the efficient use of materials as the fluctuation in rates is not considered in accounting. Moreover, it adds to clerical efficiency as the fresh rates are not to be obtained every time. However, similar to Market Value Approach, this also leads to underestimating or overestimating stocks on hand in case of rising and falling prices respectively.

f) **System of Costing the Closing Stock:** The general guideline for this purpose is to use market price or stock at cost, whichever is less. The cost of closing stock is governed mainly by price units, obsolescence and deterioration. In rare cases the stock may appreciate with time. Appropriate formulae to account for these factors should be developed keeping in view the past experience.

Stock Verification Systems

Some discrepancies between the actual and the book balances of inventories are bound to occur despite the diligent store keeping. The process of stock verification is carried out for following purposes:

i) To reconcile the store records and documents for their accuracy and usefulness,

ii) Identification of areas deserving tighter document control,

iii) To back-up the balance sheet stock figures, and

iv) To minimise the pilferage and fraudulent practices.

Most companies keep an "inventory short and over" account to absorb such discrepancies, which is eventually closed into the manufacturing overheads account.

Some of the systems of physical stock taking are as follows:

a) **Annual or Periodic Physical Verification:** In this system the entire inventory is physically verified at the end of a period, usually the accounting period. That is, normally at the end of fiscal year. Stocks are closed for a few days. This may necessitate the shut down of production operations; the activities such as repair and overhaul of equipment and machinery are resorted to. A special crew of store inspectors and stores verifying officers, usually from the material audit, physically check each item and compare the entries on bin card and stores ledger. This leads to the formation of a list of surplus or short items. Damaged and obsolete items are traced and recorded. This needs to develop a detailed programme and schedule to complete the verifications, storewise and itemwise. Top management's sanction can then be sought for writing off deficiencies or valuing surplus.

As all the items are checked at one time there can be no confusion about any item being left unchecked.

b) **Perpetual Inventory and Continuous Stock Taking System:** In case of large firms dealing with a large number of items the final inventory system may take a lot of time and it may not be possible to shut down the whole plant. The perpetual inventory system is a more appropriate method for large plants. In this method the stock verification is done continuously throughout the year. Different methods are adopted by different firms for continuous verification.

Some firms divide the whole inventory into fifty-two equal parts. Each part is verified every week. Some firms record store balances after every receipt and issue, and a number of items are counted daily or at frequent intervals and checked with the bin cards and stores ledger. Discrepancies found, if any, owing to incorrect entries, breakage pilferage, over-issue, placing of items in wrong bins, etc., are investigated and corrected accordingly. The significant advantages of this system are as follows:

i) The shut down of the plant is not necessary for stock checking/taking.
ii) The method is less costly, less tiring, less cumbersome and hence is more accurate.
iii) Discrepancies and defects in stores are readily detected and are not carried over throughout the year. This prevents damages and losses.
iv) Slow moving stocks can be noted and proper action can be initiated in time.
v) The stock items are kept within the limits.

c) **Low Point Inventory System:** Some companies take the physical inventory, i.e. the stock level of stores is checked generally when it reaches its minimum level.

18.6 STORES ADDRESS SYSTEM

The storage and retrieval are matched processes. The quick location of any item in the stores is required to minimise the retrieval delays. It is possible only when there is definite place for keeping each item and the item is kept there. Moreover, the address of that place is conveniently defined.

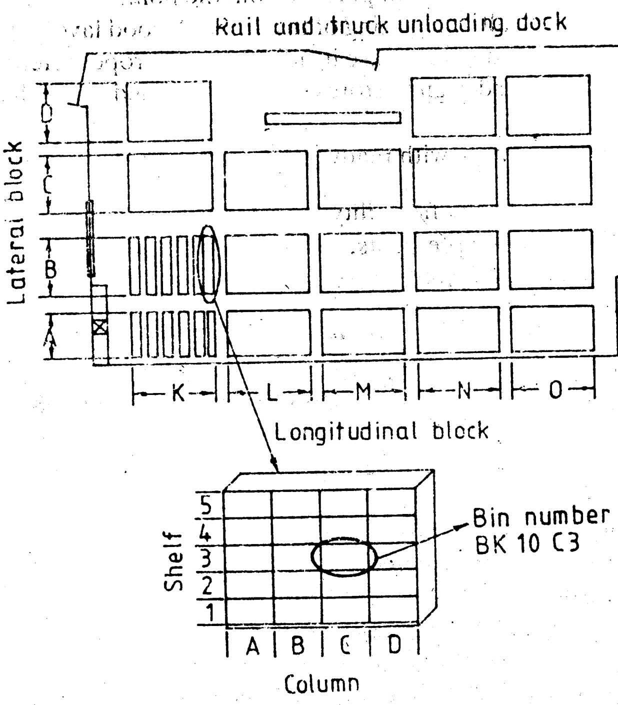
A variety of stores address systems are used to address storage locations. A typical address system is shown in Figure VI. In this system, the store room is divided into blocks; each block is identified by a lateral block letter and a longitudinal block letter. Every row of shelves, within each block, is given a number. Each row is divided vertically into columns and horizontally into shelves. A particular bin is identified by a six digit, alphanumeric address code as follows:

First digit — Lateral block
Second digit — Longitudinal block
Next two digits — Row
Fifth digit — Column
Sixth digit — Shelf

Blocks and rows should be clearly identified with painted signs. Columns and shelves are counted from lower left corner.

Every item carried thus has a specific store location address in the form of a code, which may be written in the inventory catalogue, or a separate store location index may be prepared. The location code should not be confused with the material identification code.

Figure VI: A Typical Store Address System



18.7 STORE LOCATION AND LAYOUT

Store Location

The location of stores is a strategic decision which if once taken cannot be easily undone. It would be extremely costly to change the storage location at a later stage. It should be carefully decided and planned so as to ensure maximum efficiency. The optimal location of stores minimises the total transportation, handling and other costs related to stores operation and at the same time provides the needed protection for stores items. The models of facilities planning can be applied to determine the optimal storage location in large size organisations. Store location depends upon the nature and value of the items to be stored and the frequency with which the items are received and issued to the different departments. Other important factors governing the location are the number and location of end users, variety and volume of goods to be handled, location of the central receiving station and accessibility to rail or road links.

In general, stores are located close to the point of use. Raw-materials stores is usually located near the first operation (in case of line layout), inprocess stores near to subsequent operation, and finished goods stores near the shipping area. The tools and supplies stores is located centrally to the personnel and equipment served.

In big plants it may not be possible to locate the stores which is convenient to all the departments and at the same time near to the receiving section. Usually a central stores is located near the receiving section and the issues are decentralised by setting-up substores conveniently located to serve user departments.

The location and building up of stores should be done with a futuristic outlook. The provision for the new departments and the increase in the volume to be stored should be kept.

Layout and Design of Stores

The efficient layout and design of stores is very important from the point of view of its functioning which is linked to the overall functioning of the plant. A good layout must bring the point of origin, store room and point of use in adjacent and proper reference of best material flow. The planning and design of stores should be carried out with the following objectives in mind:

i) To achieve maximum ease of operation with ready accessibility of major materials.
ii) To achieve minimum waste of space and flexibility of arrangement.
iii) Minimisation of material handling requirements.
iv) Minimisation of material deterioration and pilferage.

To assist the planning to meet the objectives, following information should be generated from the records:

i) Classification of store items by size, number, weight, frequency of handling (FSN—Fast moving, Slow moving, Non-moving), handling arrangements, perishability.
ii) Space requirement to store the item.
iii) Units withdrawn at a time
iv) Maximum number of units to be stored at one time.
v) Storage facility best suiting the item.
vi) List of available storage space for different kinds of storage facilities.
vii) Size and shape of the space available for laying out the stores.
viii) Prepare a flow diagram of the flow of materials through the stores.
ix) REL Chart for the storage of different classes of materials can be prepared.

While planning the layout and design of the stores, following factors should be considered:

i) The space for receipt and inspection should be provided adjacent to the main stores.
ii) Use of third dimension must be made effectively.
iii) Different storage facilities should be situated in clearly defined lanes, so that items are quickly stored and located.
iv) Main lanes or aisles should usually be 1.5 to 3 metres wide, depending upon the type of material and the amount of traffic involved.
v) Clear markings should be made at storage space to facilitate location and identification.
vi) The fast moving items should be stored near the dispensing window; the slow moving should be away from the window.
vii) The layout should permit the use of modern material handling equip..ent.
viii) Stores layout should encourage the FIFO, i.e the old stock should be used earlier and the storekeeper should not be compelled to keep the new stock above the old one.
ix) Due space should be left for expansion purposes in each portion.

x) A pleasing and hygienic environment must be provided within the store room. This may be done by proper selection of the colour of walls, provisions of exhaust removal, provision of cleaning etc.
xi) Adequate and clear lighting arrangements should be provided.
xii) Adequate safety provisions including fire fighting equipment, alarms, accident control and prevention methods should be inbuilt in the store room design.
xiii) Special facilities, such as cold room, heating equipment, air-conditioning etc., if required, should be carefully planned in advance.

18.8 STORE EQUIPMENT

The different kinds of equipments which are used in a store room can be broadly classified into two categories, viz., storing equipments and material handling equipments. A judicious selection of different store equipment is a key to the successful operation of a store room.

Storing Equipment

The commonly used equipment in a store room are as follows:

i) Platforms
ii) Pallets and skids
iii) Cabinets
iv) Stacking boxes
v) Special storage racks
vi) Gravity feed racks
vii) Outdoor platforms and racks
viii) Open and closed shelves
ix) Bins
x) Trays
xi) Drums
xii) Barrels

The selections of the equipment shall be governed by the size, shape, other physical characteristics, and the extent of preservation required. An open type of shelving should be preferred for easy accessibility unless the nature of the item needs a closed storage equipment. The selection of the material for racks etc., i.e. wood or steel should be carefully done. The steel equipment of 'knock down' variety that can be assembled and reassembled in different forms in numerous standardised shapes and sizes offer more flexibility. Steel equipment have advantages of strength, cleanliness and fire resistance.

Material Handling Equipment

The common type of material handling equipment used in stores are as follows:

i) Trolleys
ii) Fork-lift truck
iii) Hoists
iv) Monorail
v) Belt conveyor
vi) Roller conveyor
vii) Crane

The selection of the material handling equipment depends upon the size, shape and weight of the items, the location of the item in the stores, etc.

18.9 AUTOMATED STORAGE/RETRIEVAL

Significant developments have taken place in the area of stores management in the past few decades. The concept of a totally automated storage and retrieval system has been inviting the attention of professionals to match the storage system with the rapid developments in the technology. High rise storage systems have been commonly used in advanced countries. Automated material handling systems are used for the unit load type storage retrieval system. But for the systems in which different quantities of different items are to be retrieved the semi-automatic kind of material handling with manual operator are used. The operator carries with him the list of items to be retrieved. By making use of pre-defined system he goes through the store room, stops the handling equipment at respective bins and completes the list in a picking tour. He may go aisle by aisle or according to items in list or by any other system. Operations Research techniques of sequencing, routing, etc., can be applied to determine the optimal locations of items and optimal route in a picking tour. Some of the systems to improve the efficiency of automated storage/retrieval systems are as follows:

i) Sequencing in an optimal way by picking stops in a single picking tour.
ii) Allowing a single operator to perform all storage and order picking operations in an aisle.
iii) Generating a picking list based on a single customer's order.
iv) Storing items in pairs, e.g. nuts and bolts.
v) Locating items from the rack as per the structure and importance of orders.
vi) Allocating all items related to a specific facility to a single aisle.

18.10 CONCLUDING REMARKS

The storage system forms the key component of any materials management system. The efficient planning and design of the store system is very much important for the efficient and smooth operation of any plant. Due consideration should be given to the design of the store system of both physical and information processing. The stores system closely interacts with other sub-systems and these interactions must be clearly understood and interpreted. Efforts should be made to incorporate the latest developments in the area of stores management so as to provide the right kind of service at the right time with adequate preservation of the items and minimum blockage of capital.

18.11 SUMMARY

In this unit we have identified the basic functions of stores in an organisation. Effective Storage of goods is vital to the success of any organisation and efficient management of stores leads to higher productivity, fewer delays and lower overall costs.

The need of a proper identification, receipt and storage system has been highlighted. This is followed by a discussion of stores accounting and verification systems.

Systematic procedures to identify the location of an item in stores go a long way to reduce retrieval time. Some stores address systems have been presented in this regard

The location and layout of the stores deserve careful consideration as do the various storing equipment like bins, racks and other material handling devices.

Finally the basic concepts of automated storage and retrieval have been presented.

18.12 KEY WORDS

Automated Storage/Retrieval: This refers to the use of automatic or semi-automatic material handling devices programmed to store or retrieve items in a store very efficiently.

Identification System: A system to give codes (numeric or alphanumeric) to various items in store for easy identification and record keeping.

Receipt System: The procedure to monitor the receipt of goods in a store with indications of the condition of goods (satisfactory or otherwise) at delivery.

Store Accounting System: Collection of relevant data for estimating the cost of the product for pricing decisions.

Stores Address System: A procedure by which each store item has an address or a location for quick storage or retrieval.

Storage System: The manner in which goods are physically stored.

Stock Verification System: A check of the actual items in stock physically in the store with those in the record books.

18.13 SELF-ASSESSMENT EXERCISES

1 Discuss the major functions of stores in an organisation.
2 What are the advantages and disadvantages of centralised store room facilities?
3 What are the advantages and disadvantages of decentralised store room facilities?
4 What problems exist when a company attempts to use suppliers' part numbers in its material identification system? Comment upon the options the company may have in designing its own identification system.
5 Why is stores, accounting important for a firm? Discuss various systems that may be followed and their impact on product pricing.
6 Discuss the use of perpetual inventory record in both the closed and open stores systems.
7 How would you choose the best location for a new store?
8 What are the objectives of good store room layout? Explain.
9 What do you understand by automated storage and retrieval? For what kinds of goods and in which companies in India do you think such systems would be appropriate?
10 You have been given the responsibility of making a study of an existing store room and of taking charge of its reorganisation. Outline and explain briefly the approach you would use in planning this undertaking.

18.14 FURTHER READINGS

Baily, P. and D. Farmer, 1972. *Managing Materials in Industry,* Gower Press: London.

Francis, R.L. and J.A. White, 1974. *Facility Layout and Location: An Analytical Approach,* Prentice Hall: Englewood-Cliffs.

Gopalakrishanan, P. and M. Sundaresan, 1979. *Materials Management—An Integrated Approach,* Prentice Hall of India: New Delhi.

Khanna, O.P., 1983. *Industrial Engineering and Management,* Dhanpat Rai; Delhi.

Lee, L., and D.W. Dobler, 1977. *Purchasing and Materials Management, Text and Cases,* Tata McGraw Hill: New Delhi.

Moore, J.M., 1968. *Plant Layout and Design,* Macmillan: New York.

Tompkins, J.A., 1983. "The Automated Factory", *National Material Handling Forum,* April 1983.

Wilson, H.G. 1977. "Order Quantity, Product Popularity, and the Location of Stock in a Warehouse", *AIIE Transactions,* Vol. 9, No. 3.

UNIT 19 STANDARDISATION, CODIFICATION AND VARIETY REDUCTION

Objectives

After completion of this unit, you should be able to:

- familiarise with the need and role of classification, codification and standardisation in the context of materials management from the viewpoint of planning, control, purchase, inventory, stores, and so on
- appreciate the importance of standardisation in variety reduction
- design and implement codification system for situation other than materials
- design and implement standardisation for procedures, forms etc. in information system design
- introduce computerisation of data system for materials using codification and standardisation

Structure

19.1 INTRODUCTION

Almost all organisations use and store a large number of items. Some of these have relatively longer life, for example, buildings, plants, equipments, machines, furnitures etc. while others, in a rather large number, running into lakhs, spend shorter time with the organisation, for example, materials, components, tools, stationeries, etc. We shall concentrate mainly on materials and parts.

Several departments of the organisation require the information about the materials and their requirements are usually different from each other. For example, it is easy to visualise how the information requirements may have quite a wide spectrum by departments such as receipt, storage, inspection, design, engineering inventory, accounts, marketing etc. about a given material. Some departments are interested in the size, volume, shape, some in engineering properties, some in financial aspects while some in the commercial value of the material. It is quite likely and perhaps sometimes purposeful for an item to get identified by different names by different departments of the organisation. A dustbin may be known as refuse container, rubbish-box, etc. An electric company in UK had as many as 118 names, for a simple screw with a width of 3/8 in. and length of 6 in., depending on type of usage and the department using the screw. These may, however, result in confusion and tend to duplicate ordering or overstocking. The problem could really explode beyond dimension when the number of items is very large (as usually it is) and there are several external organisations, suppliers, wholesalers, retailers, customers etc. who prefer to call an item by different names: some by brand name, some by manufacturer reference number, some by engineering name, and some by serial number.

Quite often, a good number of products or parts may differ very marginally or insignificantly from each other in dimensional or some similar characteristics. The functional requirements will be equally well served if all such parts are made to the same common specifications. This is called standardisation. The process of standardisation logically leads to reduction in the number of part, variety that an organisation handles.

For the purpose of convenient understanding of the topic, we shall discuss classification, codification, standardisation, and variety reduction in that order.

19.2 CLASSIFICATION OF MATERIALS

When there are numerous items handled by an organisation, their planning and coordination becomes extremely difficult, if not impossible, if each one of them is handled separately. Classification of materials involves grouping of items according to some criteria. We are quite familiar with classifying our domestic articles into clothes, kitchenware, electric appliances, electronic gadgets, furniture, professional articles, entertainment articles, groceries, consumables, non-consumables etc. It is easy to see that an item may belong to more than one class depending on the criteria used. For example, a radio set is an electronic gadget as well as a non-consumable and entertainment article.

What is the purpose of classification? Following are the major objectives of classification:

i) To devise procedures of planning and control for materials in a class.
ii) To devise purchase procedures, inspection methods, and storing and issuing procedures, common to all materials in a class.
iii) To devise accounting and evaluation procedures common to all materials in a class.

Obviously, the concentration of effort according to class system would be more efficient and effective as compared to diluted effort corresponding to each individual item.

Following are the major classification systems.

On the Basis of Nature of Materials

a) **Raw Materials:** Raw materials include all those materials which are purchased from the original producer or other manufacturers and are used directly in producing the firm's product. For example, cotton and yarn are raw materials for cotton textile mills for they help in producing the final product—cloth. Cotton is purchased from the original producer, i.e., cotton grower, whereas yarn is procured from other manufacturers, i.e., spinners. The product in one trade may become the raw material for the other trade.

b) **Machinery and Equipment:** All the machinery, both power and hand-driven, such as, presses, lathe machines, typewriters, electric motors, fans, and other machines used in the production and other departments, is classified as such. Tools also come under this category, and they are issued on loan basis to the various departments for a definite period, generally till their life-time.

c) **Consumable Items:** Those materials used in the manufacturing process which cannot be used for the second time for the same purpose since their utility for the purpose in question has ceased and the shape changed are referred to as consumable items. Coal, coke, mineral oil, lubricants, cotton waste, paints, varnishes, oxygen, stationery items like pencil, paper, carbon papers, ink, etc., are a few examples of the consumable items.

d) Chemicals: Substances obtained after undergoing certain processes in chemistry according to a formula devised for the purpose may be known as chemicals. They should be stored, preserved and issued very cautiously after a careful scrutiny and proper analysis since their use involves risk even to life. Items like carbide, acids, etc., can be classified under the head

e) Inflammable Items: Items highly susceptible to fire, such as petrol, kerosene, films, dopes and paints, fall under the category. Due to their hazardous nature, they are generally stored as far away as possible from the main building with complete fire-fighting arrangements standing by.

f) Fuel Stock: These are also consumable items. But there is a slight difference between the two in respect of their uses. When an item is directly used for production and is a fuel for the furnace, oven, etc., it is classed as fuel stock. It is a necessary item for completing, rather starting, the manufacturing process and of course one of the important items in a manufacturing unit, but it can never constitute the finished product. However, sometimes it may rightly be taken as a raw material. Coal is a fuel stock but is also a raw material for an iron and steel industry.

g) Furniture: Movable contents of a house or a room like chairs, tables, almirahs, benches, stools, etc., are furniture items. Their repairs, renewals and replacements also require proper maintenance of records since they are issued temporarily on loan basis.

h) Scrap Materials: On the expiry of life of a particular item, the residue is called the scrap. Such material as is left over as waste in the process of production is also known as scrap. The scrap is sold out in the market so as to fetch some value out of it. Kabadis are the best purchasers of scrap in this country.

i) Packaging Materials: These include all kinds of wrapping materials, such as paper wood carvings, sawdust, straw, etc., containers like boxes, crates, drums and bottles, protective coatings, such as, wax, grease, as also plastic cans, bags, etc.

j) General Items: This category include all those items which do not fall under any of the above categories of items. In a large undertaking, general stores section is separated from other stores under an independent incharge since they cover a large number of items, which, although not directly linked with the production processes, are required for day-to-day smooth and efficient running of the enterprise. Cleaning materials like soap, brasso, brooms, uniforms for the staff, stationery and all other items of general use are handled in the general stores department.

On the Basis of Usability of Materials

a) Serviceable, Unserviceable and Obsolete Items: Serviceable items are those items which go temporarily out of order. After repairing and replacement they may become serviceable again and their usable life may thus be extended for some more time. Unserviceable items are those items which have outlived their life. No amount of repairs, renewals or replacements can bring them back to their usable life. They are thus fit only for disposal as scrap. Obsolete items are those items which have gone out of date because of new inventions in design, use, etc., and which cannot profitably be used again.

b) Finished and Semi-finished Items: Finished items are those goods which have been manufactured in complete form by the production department and are ready for sale. On the other hand, semi-finished items are those which have not yet been manufactured completely and need some further processing before they can be put to sale in the market. They are thus taken back by the production department for turning them into a final product.

c) Dead Stock Items: This term is generally used in government departments. Furniture, equipments, machinery and other items which have some definite life and which cannot be written off before the expiry date of their life are classed as dead stock items. They are issued temporarily on loan basis to their users.

d) Unused Items: These are not stock items in the real sense of the term. These cannot be used in the production unit, because, being defective, damaged beyond use, or because of some other reason they have been rendered unusable. Sometimes unused stocks are mistaken for scrap and unserviceable materials. But this is not the real position. Scraps are generally left out items from the production unit. They cannot be used, as either they are less in quantity or less in measurement, weight, etc. But unserviceable items are movable items which have been rendered unserviceable by constant use and are now beyond repair.

Activity A

Classify all the items used in the house on the basis of nature of materials and on the basis of the usability. How many groups do you find? Regroup them if possible.

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Activity B

Consider an officer dealing with personnel administration. Classify all the various files into some reasonable groups. State the criteria of classification.

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19.3 CODIFICATION

From the above, it is clear that there must be some means of identifying the items accurately, uniquely, and adequately. These identification attributes are achievable by appropriate classification and codification. We are familiar with the PIN Codes used by Post and Telegraph Department to uniquely and concisely identify various regions of the country. Codification is a process of representing each item by a group of numbers and alphabets indicating the group, the subgroup, the type and the dimensions of the item. Many organisations in the private and public sectors, railways and DGS & D, have their own system of codification. The number of digits in a code may typically be somewhere between eight and thirteen. The role of these digits and some fundamental principle of codification can be understood from the following example:

digits	1–2	major group (raw materials, spare parts, subcontracted items, hardware items, packing material, tools, oil, stationery, etc.),
	3–4	subgroup (ferrous, non-ferrous, etc.),
	5–7	dimensional characteristics (length, width, head diameter, etc.),
	8	minor variations,
	9	location of storage,

10–11 user departments of the organisation,

12 products or product lines requiring the item,

13 any other information (related to inventory accounting, purchasing etc.).

This is merely an illustration of codification, process. The codification process can be based on other aspects also. (i) The codes could be obtained by the nature of items in grouping all items of the same metal content, say ferrous, non-ferrous etc. (ii) The system could be built sometimes on the basis of the end-use of items, say maintenance, spinning, foundry, welding, packing, machine shop, etc. (iii) The codification could be thought of on the basis of source of purchasing where items obtained from one source are grouped together. (iv) The codification could also be built on the basis of alphabetical listing.

Objectives of Codification

In order to identify the items correctly and logically for processing the transactions, and to facilitate easy location in stores, a codification system should be evolved with the following objectives:

a) Accurate and Logical Identification: A separate code is allotted to each of the items available in the storehouse indicating the size, quality, price, usability, special characteristics, specification, etc. This distinguishes one item from the other, even if nomenclature is the same, helps in accurate identification and eliminates any possibility of confusion. For example, a lead pencil of black colour, HB quality, for writing purpose and within a price range of Rs. 1.00–1.50 may have its code as

07.39.1236

where 07 indicates the group (viz. stationery items)
3 indicates pencil,
9 indicates lead pencil,
1 indicates lead colour (viz. black)
2 indicates quality (viz. HB)
3 indicates use (viz. writing)
6 indicates price range (viz. Rs. 1.00–1.50).

b) Prevention of Duplication: All items are separately codified and are arranged in a logical order. Similar materials are grouped together (such as stationery items) and given a code (e.g., 07). Once a code is allotted to a particular group, it is a decision on a organisational level and in no case it is changed. Since each item has a different code number and various items are kept in different bins at different places, there can be no duplication in placing the orders, and no piling up of the materials will take place in the storehouse.

c) Standardisation and Reduction in Varieties: For codification, grouping of identical items is done and it enables the stores to examine the entire range of items. It facilitates the elimination of those varieties in place of which other varieties of the like quality can be used; this reduces the number of varieties to the minimum. If proper standardisation is achieved and the number of items is kept at the minimum, it will considerably reduce investment in various items as well as the cost of inventory carrying.

d) Efficient Purchasing: The filling up of purchase requisition, and preparation of purchase orders are simplified by the use of codes which easily indicate the materials required. Buying instructions to the suppliers become easy and quick if there is proper understanding of codification by the supplier. The entire operation of the purchase department can be organised according to grouping of items. In centralised purchasing such a system serves well in dealing with the purchase orders and in taking advantage of bulk purchasing.

e) Efficient Recording and Accounting: Codes lead to effective stock control, efficient recording and result-yielding accounting. Chances of mistakes are minimised. Pricing and valuation also become more accurate and reliable.

f) Easy Locating, Indexing and Inspection: The materials in the store have to be kept in an order which may facilitate their placement and location. For making it less time and energy consuming, items may be arranged according to the codes allotted to them. This would also facilitate a quick and efficient inspection.

g) Easy Computerisation: Small size computers such as Personal Computers (PC) are finding their wide applications in materials management. The computers work better with codes than with long description of materials.

Essential Features of Codification System

There could be many possible arrangements of coding symbols (numbers, alphabets, etc.) which can be used to design a code. However, a great deal of thought must go into the coding scheme if it is to satisfy a variety of users. The following considerations must be kept in mind when designing codes.

a) Brevity: The codification system should avoid long and unwieldy description. This implies that the codes should consist minimum possible number of digits. The size of the code would normally be dictated by the number and range of items and the number and types of applications of the data pertaining to the item. For example, for the pencil code 07.39.1236, the last digit representing the price range may be deleted if such information is not needed.

b) Logical: The coding system should be logically fit for the needs of the users and the methods of data processing employed. For the example of pencil code, the last digit representing price range should have an increasing price range with the value of the digit increasing, that is, a value of digit as 8 may indicate a higher price range of say Rs. 2.00–2.25.

c) Flexibility: The code design should be flexible to accommodate changes without disturbing existing codes. We are familiar with the library coding system in which codes do never get disturbed by addition of new books and all books to come in future are easily accommodated by the existing code structure.

d) Uniqueness: Each code must be a unique representation for the item it identifies. For example, an inventory item number or employee identification code must identify one and only one inventory item or employee.

e) Easy Understandability: The code structure must be easily understood by various users. It should be as simple, practical and meaningful as possible.

f) Proper Choice of the Coding Symbols: While a code may have numbers, alphabets or a mixture of both, certain precautions should be taken in selection of the symbols. Characters with similar appearances should be eliminated. For example, the letters O, Z, I, S and V may be confused with the numbers O(zero), 2, 1, 5 and U, respectively. Where possible, letters that sound the same should be avoided (for example, B, C, D, G, P and T or M and N).

g) Layout of Codes: The layout of code should be equal in length. For example a code 001-199 should be preferred over 1-199. Codes longer than four alphabetic or five numeric characters should be divided into smaller segments for human judgements.

h) Capacity of a System: When calculating the capacity of a given code for covering all situations while still maintaining code uniqueness, the following formula applies: $C=S^P$, where C is total available code combinations possible, S is the number of unique characters in the set, and p is the number of code positions. For example a 3-digit code with numbers 0 to 9 will have $10^3=1,000$ unique code combinations. The size of code structure, therefore, should be decided before hand by anticipating the requirements of the unique combinations.

Codification Systems

There are several systems possible for codification of materials depending on the choice of coding symbols—alphabets, numbers, or a combination of alphabets and numbers (alphanumeric). Two popular and fundamental systems—Brisch and Kodak—are described here.

Brisch System: The Brisch system is based on numbers from 0 to 9 and consists of blocks (typically three) separated by decimal points. The blocks are assigned specific classification of the materials. The first (left most) block represents the major classification (such as raw materials, packing materials, finished materials, etc.), the second block represents the next level classification (such as nature, use, quality, characteristics, etc.) while the third block represents the lowest level classification (such as quality of the material, its components, its facial appearance, price, availability, source of supply, marketability, frequency of use, etc.). The following example for stationery items explains the Brisch system. The major item stationery is classified into four groups based on the nature of each item and each group in turn is divided into further subgroups.

Item Particulars	CODES			
	Main	Subcode I	Subcode II	Full Code
Stationery	63			
Pencil	..	01	..	63.01
Pen	..	02	..	63.02
Paper	..	03	..	63.03
Ink	..	04	..	63.04
Pencil				
Black	..	..	41	63.01.41
Blue	..	..	42	63.01.42
Red	..	..	43	63.01.43
Blue Red	..	..	44	63.01.44
Pen				
Ball-point	..	..	51	63.02.51
Fountain	..	..	52	63.02.52
Holder	..	..	53	63.02.53
Inkstand	..	..	54	63.02.54
Paper				
White	..	..	35	63.03.35
Brown	..	..	36	63.03.36
Typing	..	..	38	63.03.38
Duplicating	..	..	39	63.03.39
Ink				
Blue	..	..	12	63.04.12
Black	..	..	14	63.04.14
Red	..	..	15	63.04.15
Duplicating	..	..	17	63.04.17

The system proceeds in the following steps:

a) The materials to be coded are grouped together so as to form a major group. The grouping should be accurate and unambiguous, and should not overlap. It is based on the classification system described in the previous section.

b) After the classification or preliminary grouping, the materials are further divided and sub-divided as explained earlier. The basis of these division and sub-division is described the materials in as great detail as possible and simultaneously making them relevant to the users.

c) The codes are assigned in three blocks separated by decimal points. Total number of digit could be any as per convenience but a general figure is 7 (seven).

Kodak System: The Kodak system has been developed by Eastman Kodak Co. of New York, USA and is supposed to be a very comprehensive system. It consists of 10 digits

Kodak System: A codification system consisting of 10 digits of numeric characters.

Standardisation: Process of grouping of items to conform to widely acceptable representative features and characteristics.

Variety Reduction: Process of reducing a large variety of items with close characteristics to fewer items (through standardisation).

19.7 SELF-ASSESSMENT EXERCISES

I Review Questions

1 What are reasons for classifications, codifications, and standardisation of materials?

2 What are the common classification systems?

3 What are the advantages of codification?

4 What are the possible disadvantages of the codification?

5 What are the essential requirements that a coding system should satisfy?

6 What are the differences between Brisch and Kodak systems?

7 How does standardisation help in variety reduction?

8 What are the steps in variety reduction programme?

9 What are the roles of Indian Standard Institution (ISI)?

10 How standardisation would help consumerism?

II Design Exercises

1 You are the incharge of the purchase department of an organisation. The department is responsible for receiving the requisition form from various departments, processing them, selecting the supplier, determining the price, time, and quantity of purchase. The department as usual would prepare various reports for the management. The organisation would also be interested in vendor development and evaluation.

You are to design a suitable coding system for identification of files of correspondence externally as well as outside the organisation.

2 Consider the following data pertaining to a shirt company.

Sleeve length	Price
Neck Size	Market region
Colour	Sales person
Style	
Material	

Design a suitable coding system with appropriate selection of the coding symbols.

19.8 FURTHER READINGS

Burch Jr., John G., et al. 1979. *Information Systems: Theory and Practice* (2nd edition), John Wiley and Sons: New York.

Gopalkrishnan P. and Sundaresan M., 1977. *Materials Management—An Integrated Approach,* Prentice-Hall of India: New Delhi.

Sharma, P.C., 1980. *Materials Management,* Ketab Mahal: Allahabad.

Varma, M.M., 1975. *Essentials of Storekeeping and Purchasing,* Sultan Chand and Sons: New Delhi.

UNIT 20 WASTE MANAGEMENT

Objectives

Upon completion of this unit, you should be able to:

- conceptualise Waste
- realise the scope and need for a systems' approach to waste management
- identify the multi-disciplinary character of waste management
- establish the relationship between wastivity, productivity and resource management
- realise the need for adopting a preventive policy of waste generations
- devise and apply suitable means for waste reduction
- realise the importance of devising good systems for waste collection, recycling and disposal
- appreciate the necessity of introducing concept of waste in the traditional input-output model
- devise a method of cost accounting for wastes.

Structure

20.1 INTRODUCTION

The diverse and seemingly boundless developments taking place in industry bring with them a whole new series of complexities associated with waste. From a systems' viewpoint, waste is any unnecessary input to or any undesirable output from any system encompassing all types of resources. Waste Management (WM) is a multi-disciplinary activity involving engineering principles, economic, urban and regional planning, management techniques and social sciences, to minimise the overall wastivity of the system under consideration. A systematic approach to waste management encompassing the waste of all kinds of resources at all stages should be adopted. However, as the material constitutes a major fraction of the total product cost, material wasted are of critical importance.

20.2 COMPLEMENTARITY OF WASTE MANAGEMENT AND RESOURCE MANAGEMENT

A system basically takes some input, processes it and gives the desired output, as shown in Figure I, i.e., some input is essential, in whatever form for the functioning of a system. An ideal system is conceptualised to transform the total input into useful or desirable output. In view of the known physical laws of nature the existence of an

The topics covered under standards can include purchase contracts, forms, sampling, testing, safety measures, etc. Thus, standardisation can be conceived on a three dimensional plane of levels, industries and topics.

In the context of materials, we are already aware of use of standards for specifying the items, especially for purchase purposes. Market grades, commercial standards, performance specifications are the popular examples of wide range applications of standardisation.

Standardisation enables the materials manager to achieve overall economy and ensures inter-changeability of parts. With standardisation more than one manufacturer can supply and this will imply better availability, better price and better delivery. Standardisation also implies routinising purchase efforts, less stock and hence less obsolete items. It also means less inspection efforts; as a matter of fact, many organisations do not check routine items bearing ISI marks in a very detailed manner but resort to inspection of only a small fraction of items. It is also possible to enter into rate/running contract with standard items. This facilitates the production planning and economic lot sizing at the supplier's end.

The process of standardisation logically leads to simplification or variety reduction. This implies reducing unnecessary varieties and standardising to the most economical sizes, grades, shapes,, colours, types of parts and so on. In large organisations handling lakhs of item, it is quite possible that there are several items having very little variation in quality, dimension or functional effectiveness. The items can be analysed for their frequency of usage over the past few years. Such frequency or movement analysis would bring out items which are seldom used or not used at all. On the basis of this analysis, the organisation could get the standards to replace these items. The process of standardisation and variety reduction can be summarised as foollows:

1 Prepare the list of all items used to make the final product. The list can be made out of the design blue-print in case the product design is just over but production has not started, or from the actual record of consumption in case the product is in production.

2 Classify the items according to their performance (or functional) and dimensional characteristics.

3 Group thee items with similar functional characteristics and then subgroup according to major dimensional values. For example, all bushes around 5 cm dia will be in one group while all around 3 cm dia will be in other group and so on.

For a group of items with similar functional characteristics, study the dimensional features. In case of large number of items, several item with the same or similar functional requirements, are likely to show the dimensions clustered in a very closed vicinity. Analyse the effect on performance of items if all items are made to the most representative (mean or mode of the frequency distribution) value of the dimension. If the performance characteristics are within satisfactory zone, these tems are produced of the same dimension. It may be noted that this is a very mportant step in variety reduction.

heck from the national or international standards if there is already a dimension xisting equal to the most representative dimension found after analysis in the evious step. If such a dimension is found, the items can be deemed as andardised. If an exact dimension is not found, select the closest dimension and udy again the performance of all items in the group around this dimension. If rformance is acceptable, the item has been standardised according to national or ernational standards. If the performance is not satisfactory, organisation will apt a local standard, the dimension being of the representative value.

dition to the dimensional and performance characteristics of materials, ardisation concepts are equally meaningful for the forms, procedures, reports relation to purchase, stores, and even planning activities.

Benefits of Standardisation

The important benefits are summarised as follows:

1 Standardisation helps reduce inventory items,

2 It helps in evolving better means of communication about an item in the company,

3 It forms a base for further inventory analysis,

4 The specification of items can be more clearly spelt out, making quality control firm, and

5 In a developing economy like ours, where the need is to promote exports, insistence on standards helps in creating confidence in the international market.

By using national standards, it is easier to locate sources of supplies and in the case of machine parts, the replacements can be obtained easily. It could also be used in advertising for the products as well as spare parts.

Effective steps have been taken in a number of organisations in India for cost reduction in the number of stores items. The aim of standardisation should be to have uniform standards for similar items, and the standards evolved should take cognizance of the indigenous availability of the materials to the maximum extent possible. With these broad national objectives in view, the Indian Standards Institution (ISI) has developed and promoted over 13,000 standards covering raw materials, components, and finished products.

19.5 SUMMARY

Organisations deal with a large number of materials with varying degree of characteristics in terms of size, shape, price, physical and chemical properties, sources of supply, modes of handling, user departments (destinations) accounting procedures, etc. In addition, there are several departments of the organisation which require only the information about the materials, e.g. design, engineering, production scheduling etc. In order to mee. these complex requirements the items need to be classified properly. The classification system is a major decision for the organisation in the sense that once introduced it might be difficult to alter in future. The purpose of this unit has been to expose the readers to popular classification systems.

Often, an item would require a very long description to get uniquely and adequately identified. Using number and alphabets with appropriate meanings, the description can be reduced to six to thirteen digits. This helps in easy retrieval of information and data processing. Several aspects of the codification have been discussed for the readers and users to follow a standard system or to enable to design own system.

Several items with similar functional and dimensional characteristics can be grouped to a single dimension and other technical characteristics with negligible loss of functional requirements through the standardisation. This helps in reduction of variety of items in the stores. This concept of standardisation is well suited for standardisation of things beyond materials such as processes, inspection, procedures, forms, charts, reports etc. The standardisation also makes the users aware of the performance expected from the product.

19.6 KEY WORDS

Brisch System: A codification system using numbers in blocks separated by decimal points. Usually it consists of 7 digits.

Classification: Grouping of items with similar attributes.

Codification: Condensing the long information with the help of few digits comprising alphabets and numbers. The location of digits and their values suggest the meaning of the information.

of numerical code. The basis of the major or first level grouping is source of supply. All materials are divided into 100 basic classifications based on purchase and procurement considerations. For instance, a bolt is listed as hardware item if this is listed in hardware catalogues and available with hardware suppliers. If this bolt, however, is available only as part of the machine, it will be available under maintenance. Each class is divided into 10 sub-classes. For example, if class 20 represents cutting tool, then 200 represents drills, reamers, counter bars, etc. The steps of classification can be understood by the following example:

Step I: Major (First Level) Classification (based on purchase and procurement consideration)

First Two Digits Class Code	Materials
00–20	Raw Materials
21–35	Machine and Mechanical Equipments
36–40	Mechanical Products and Loose Tools
41–49	Electrical Products and Electrical Equipments
50–52	Laboratory Equipments
53-68	Chemicals, Equipments, and Miscellaneous Chemical Products
69–78	Office Equipments and Other Misc. items.
79–83	Furniture and Fixtures
84–87	Fuel Stock
88–93	Semi-finished and Finished Product
94–99	Miscellaneous

Step II: Sub (Detailed) Classification of materials in class code say 53-68 (Chemicals, Equipments and Miscellaneous Chemical products).

Second two Digits Sub-class code	Materials
53	Tanks
54	Pumps
55	Mixers
56	Packaging Machines
57	Plastic Materials
58	Paints
59	Lubricants
60	Acids
61	Solvents
62	Phosphorus
63	Sulphur

Step III: Further Sub-classification indicating kinds in a particular sub-class of materials say 60 (acids).

Third Digit (0-9) Sub-sub-class code	Materials
600	Carbonic Acid
601	Sulphuric Acid
602	Sulphurous Acid
603	
604	
605	
606	Unassigned
607	
608	
609	

Step IV: The kind of the materials may further be divided into different types. For example 601 indicating sulphuric acid may further be classified indicating the type of the sulphuric acid. For example, one may classify the types of sulphuric acid as,

86	Type A
87	B
88	C
89	D
90	E
91	F

This level has two digits while the previous level had only one digit. This is possible. There is no strict pattern to be followed about the number of digits and the level of the classification. The two digit code in Step IV indicates suitably the percentage of acid content.

The process of classification and sub-classification may continue to accommodate subsequent levels of variations. The code may have some digits left unutilised for future expansion. For example a code 601–87–XX–XXX indicates chemical product (53–68 group) and in that acid (60), and in that sulphuric acid (1) and in that Type B(87). The digits XX–XXX are left for future expansion.

Colour Coding Systems: Sometime colour codes are used to identify the items. Common instances are, red, blue and green in an electric cable, red and green in electric switches, and so on. Some organisation use the codes locally such as to identify the steam, water and other pipes while there exist some national or international colour coding system. The limited number of colours available narrows the scope. Nevertheless, this is quite an effective system providing easy identification.

Activity C

Study the codification system of Library of Congress popularly used in libraries.

....

....

....

....

Activity D

Devise the codification system for the domestic articles classified in Activity I. How does it help to organize the management of articles for the housewife?

....

....

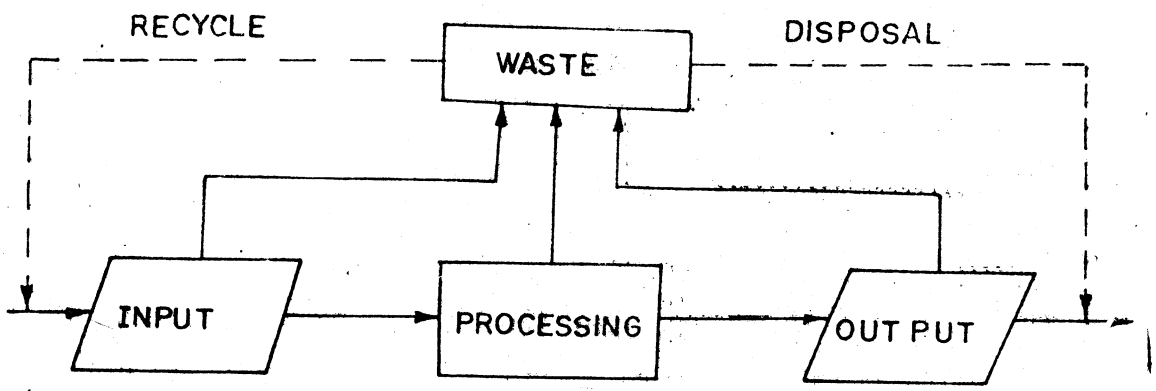
....

19.4 STANDARDISATION AND VARIETY REDUCTION

A standard is defined as a model or general agreement of a rule established by authority, consensus, or custom, created and used by various levels of interest. For instance, an individual may be the starting point of using standard and then his department will use the same standard to suit its needs. The firm may similarly prepare, by consulting different departments, a standard for guiding the activities. Related industries in the industry group may also prepare industrial standards. At the national level, by consulting manufacturers, scientists users and government departments, national standards are evolved. Such national standards lead to the evolution of international standards. The standards could cover a variety of industries, such as engineering, textile, chemical, pharmaceutical, agricultural as also education.

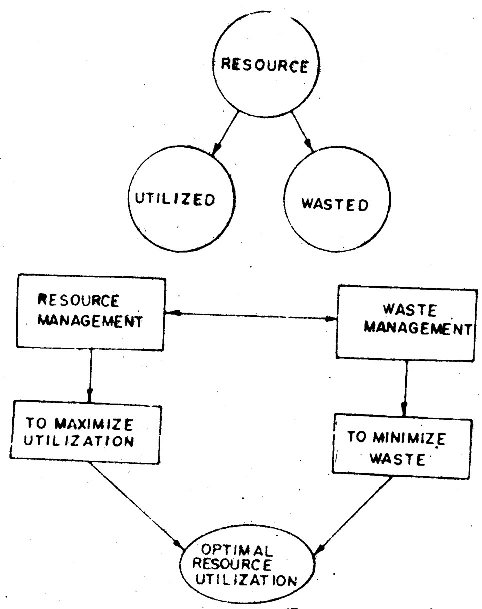
ideal system is not possible, i.e., 100 per cent utilisation of resources is not practically possible for any system. To paraphrase, some waste is inevitable in the functioning of any system.

Figure I: Input—Processing—Output System



The main objective of WM is to minimise the waste thus aiming at the ideal system, while the resource management aims to maximise the utilisation of the resources. The goal of waste and resource management is same, i.e., optimal utilisation of the available resources for higher efficiency and growth of the system; but the approaches are different. The relationship of waste and resource management is shown in Figure II.

Figure II: Complementary Relationshipd of Waste Management and Resource Management



It can be said that waste and resource management are complementary to each other. If one is primal formulation of a problem, the other is a dual. Both approaches have their advantages and limitations. Depending upon the situations, the constraints and primary and secondary objectives, resource management techniques prove to be promising in some cases, while in others WM offers an added advantage.

22 Less emphasis on PPC function
23 Inadequate supervision and control
24 Improper recruitment and lack of training
25 Lack of motivation and incentives
26 Unhygienic work environment
27 Insufficient skill and use of unsafe practices
28 Poor labour relations
29 Frequent power failures
30 Poor maintenance
31 Less emphasis on quality control
32 Poor distribution network
33 Less emphasis on collection and segregation of waste
34 Technological obsolescence.
35 Miscellaneous causes.

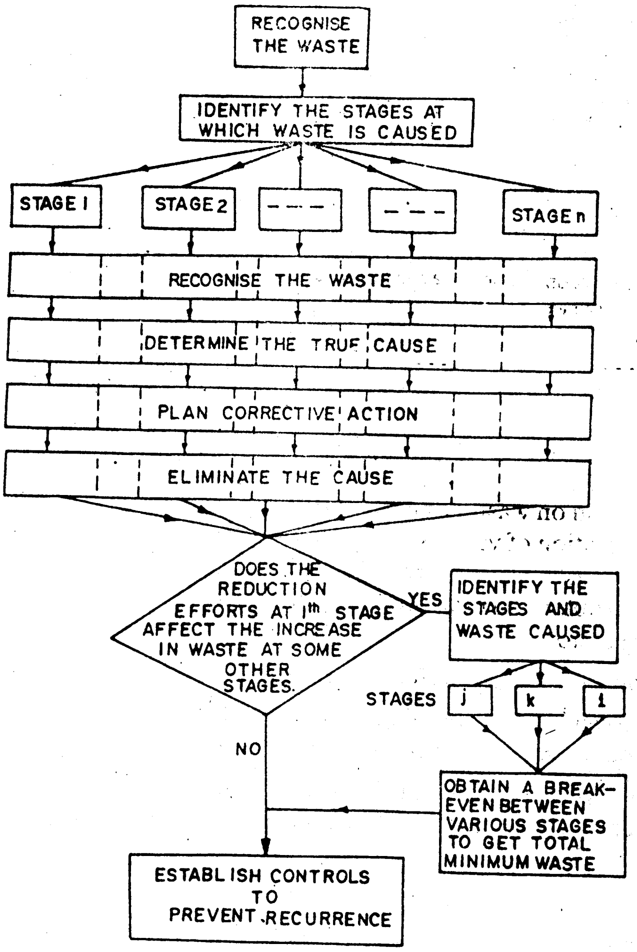
Accurate information on waste generation rates and composition provides a basis for the design and operation of various waste control programmes, recycling and processing plants, waste disposal projects, and the choice of most effective disposal alternative. The problems in obtaining the information on this aspect are complex and involve following factors:

- Various establishments may differ widely in their waste generating practices.
- Most firms are reluctant to reveal production and related statistics for fear of the data being used to the competitive advantage of others.
- Generally, the firms are reluctant to provide information on quantity and composition of waste for fear of it indicating non-compliance with pollution-control regulations.
- The quantum of waste generated reflects the inefficiency of the organisation.
- Some industrial activities are subject to seasonal variations.
- The extent of salvaging, recycling or other reclamation of wastes differ greatly among manufacturers.
- Many firms themselves have little understanding of, and few records on this aspect.

A Systematic Approach to Waste Reduction

A systematic approach to minimise the total system waste minimising the waste at individual stages in conjunction with other stages has been proposed in Figure V.

Figure V: Stage Wise Waste Reduction: A Systematic Approach.



It provides a scientific and systematic method for waste reduction at individual stages and finally for the whole system. The procedure for approaching from whole to part, and, then, from part to whole is proposed. The basic steps of the approach are as follows:

i) Recognise the waste for whole system.
ii) Identify the stages at which waste is caused/generated.
iii) Visualise the whole waste into fractions caused at various stages as identified in step (ii).
iv) Apply the systematic waste reduction procedure at each stage separately, i.e.,
   - recognise the waste,
   - identify the cause,
   - plan corrective action,
   - eliminate the cause.
v) Find the correlation of various stages to assess the effect on waste generation at one stage due to waste reduction at other stages.
   - If there is no such correlation, then establish controls separately at each stage to prevent recurrence of the cause of waste generation.
   - If such correlations exist and waste is caused, then find the stages affected.
vi) Try to obtain a break-even of wastes at the related stages so as to minimise the total aggregate waste at all the stages.
vii) Establish controls to prevent recurrence of the cause of waste generation.

Wastivity and Productivity

Waste can indirectly serve as a good measure of productivity. "Productivity of any system has been defined as the ratio of the desired output to input". Most of the productivity measures at present compare the total output to individual inputs, viz. labour, material, energy, capital etc., while they usually fail to directly compare the fraction of a particular input that goes into output.

Hence a new concept of 'Wastivity' had been propounded, which can serve as an adequate measure of performance of any system and is rather easy to measure.

Let I_r be the wastivity index of rth resource and W_r be the relative weightage (depends upon a number of tangible and intangible factors) of rth resource, then

$$\text{Composite Wastivity Index} = \sum_{r=1}^{n} W_r I_r$$

For n types of resources

$$\text{Where,} \quad \sum_{r=1}^{n} W_r = 1$$

It will be very convenient to measure the waste as well as input for each type of resource for a specified period.

We have,

$I = O + W$

Dividing both sides by I, we have

$$\frac{I}{I} = \frac{O}{I} + \frac{W}{I}$$

or 1 = Productivity + Wastivity

or Productivity = 1 − Wastivity

The Wastivity for each type of input thus indirectly assesses the productivity for each type of input. Both productivity and wastivity are complementary to each other, which bears in it the inherent cause effect phenomenon. If the cause, i.e. wastivity is checked, the effect, i.e. productivity, will automatically be improved.

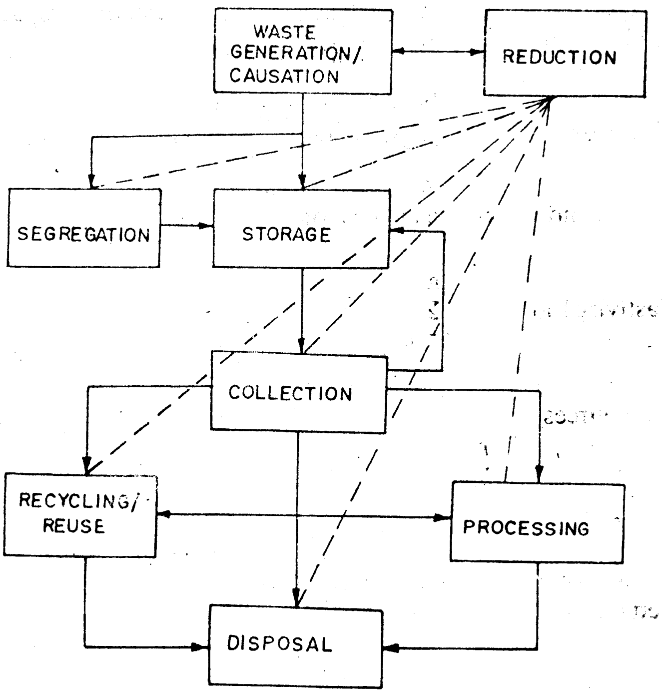
20.5 THE FUNCTIONAL CLASSIFICATION OF WASTE MANAGEMENT

The problems associated with the management of wastes in today's society are complex and diverse in nature. For an effective and orderly management of wastes the fundamental aspects and relationships must be identified and clearly understood. The efficient WM comprises of the quick identification of the waste generated/caused, economic reduction, efficient collection and handling, optimal reuse and recycling, and effective disposal of waste leaving no environmental problems. WM can thus be functionally classified into five basic elements, viz., generation, reduction, collection, recycling and disposal. However, WM should be viewed in totality considering the inter-relationship of basic functional elements/system as shown in Figure IV. One of the objectives of WM is to optimise these basic functional systems to provide the most efficient and economic solution, commensurate with the constraints imposed. By considering each element separately it is possible to:

i) identify the fundamental aspects and relationships involved in each element,

ii) develop, wherever possible, quantifiable relationships for the purpose of making engineering comparisons, analysis and evaluation.

Figure IV: Functional Elements of Waste Management



Generation of Waste

There may be numerous causes responsible for the generation of waste in different systems. However, some general causes of waste generation at different stages have been perceived. The check list of causes of waste generation is shown in Table 1 out of which some causes may be critical. If it is possible to account for the amount of waste generated against respective causes, then the most critical cause will be one that contributes to the highest aggregate cost of waste.

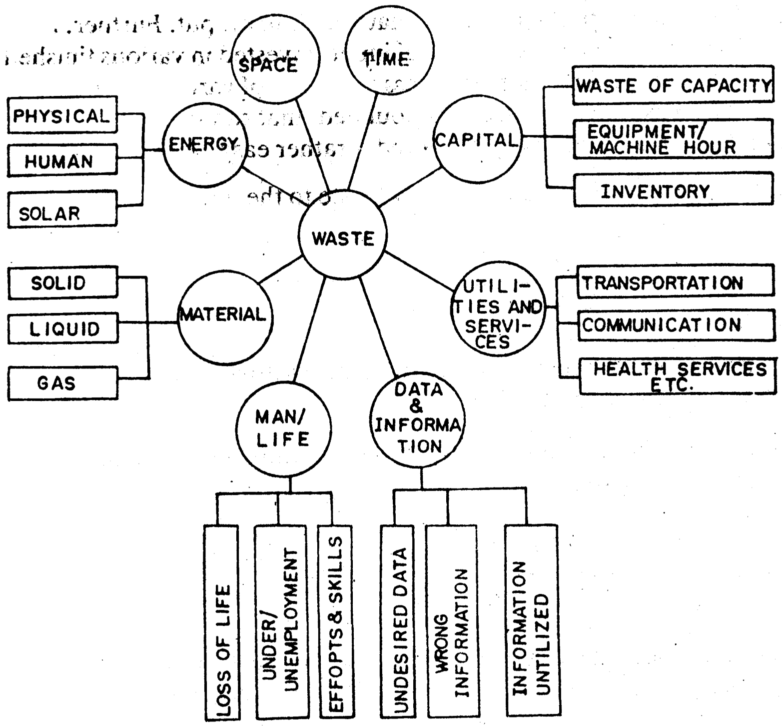
Table 1
Checklist of Causes of Generation

1 Ineffective policies
2 Lack of Planning
3 Political pressures
4 Defective organisational structure
5 More emphasis on sub-system objectives rather than organisational goals
6 Poor management
7 Faulty systems and procedures
8 Personal interests
9 Carelessness and neglect
10 Lack of individual responsibility
11 Non-acquaintance with latest technological development
12 Resistance to adopt automation and computerisation
13 Wrongly laid-down design standards
14 Lack of standardisation and codification
15 Wrong choice of raw material
16 Ignorance of inventory control
17 Inappropriate storage facilities
18 Poor handling of materials
19 Poor layout of facilities
20 Information delay
21 Improper work methods

20.3 TAXONOMY OF WASTE

Lack of coordinated work in the field of WM has given rise to multiplicity of terms and definitions of various types of wastes. The need for standardisation of the nomenclature has been felt for systematic research and effective implementation of WM programmes. Wastes can be classified in a variety of ways depending upon the purpose for which classification is done. There could be four basic classifications as follows:

Figure III: Resource Based Classification of Wastes.



a) **On the basis of the resource wasted:** Various types of resources are wasted at various stages in the system. Taking the resource as a basis the classification of waste is shown in Figure III.

b) **On the basis of source of origin:** The source of origin may serve as an efficient and practical way of classifying waste, e.g.,

i) Agriculture
ii) Industrial
iii) Municipal
iv) Residential or domestic
v) Commercial
vi) Office
vii) Construction and demolition etc.

c) **On the basis of property:** This classification is meant for material wastes only; depending upon the property that effects the environment, waste may be of two types:

i) Hazardous
ii) Non-hazardous

d) **On the basis of recoverability:** As per the characteristic of resource the waste may be:

i) **Recoverable:** The waste that can be converted into some useful resource, e.g. material waste, energy waste reused in other processes, etc.
ii) **Non-recoverable:** This includes the resources that are lost with time and cannot be regained afterwards, e.g. manpower, energy, capacity, services, etc.

20.4 DEFINITION OF WASTIVITY: GROSS AND NET WASTIVITY

Most of the productivity measures at present compare the total output to individual inputs, viz., material, energy, manpower, capital, etc., while they usually fail to directly compare the fraction of a particular input that goes into output. Further, it is difficult to measure the output of various individual inputs invested in various finished products, whereas it is comparatively easier to assess the waste of various inputs. Hence a new concept of "Wastivity" has been propounded, that can serve as an adequate measure of performance of any system, and is rather easy to measure.

"Wastivity of any system is defined as the ratio of the waste to the input".

$$\text{Wastivity} = \frac{\text{Waste (W)}}{\text{Input (I)}}$$

Depending upon the level of waste under consideration the wastivity may be categorised as gross wastivity, and net wastivity.

"The gross wastivity is defined as the ratio of total waste generated by a particular system to the total input to that system".

$$\text{Gross wastivity} = \frac{\text{Net waste generated}}{\text{Total input}}$$

However, a fraction of total waste generated is intermediate to the system and gets recycled. Thus the net waste to be disposed off or reused in other systems is less than the gross waste generated.

$$\text{Net waste} = \text{Total waste generated—Waste recycled within the system}$$

"The ratio of the net waste to be disposed of to the total input to the system is termed as net wastivity". The net wastivity will be dependent on the extent of recycling.

$$\text{Net wastivity} = \frac{\text{Net waste generated}}{\text{Total input}}$$

Wastivity as a Performance Measure

An ideal or perfect system will be one that consumes just the right amount of resources, leaving no idle, unutilised (nonrecoverable) or lost resource, or any undesirable output. The presently known laws of nature obviate the existence of any such idea system, indicating that the occurrence of waste is inevitable. The concept of "Wastivity" which is yet in the rudimentary stages may prove to be a good measure of performance, both at macro and micro levels, and will be helpful in the sound planning and monitoring of various systems at different levels of hierarchy.

Towards Zero Waste

The Waste Management systems for individual organisations, sectors as well as the whole economy should be designed to fulfil the goal of zero waste. Zero waste should not be misinterpreted as if no waste is generated. Such an interpretation will be neither feasible nor justified. As some waste is inevitable with the function of any system, a 100% efficient system is only hypothetical. Further, such a system will be closed and will have a zero growth rate which is not desirable. The main theme of the philosophy of zero waste is to first of all try to minimise the waste generated as far as it be technologically and economically feasible; and whatsoever little waste is generated should be put to some effective use.

The goal of zero waste should be visualised from systems point of view, i.e. to have zero waste of all types of resources simultaneously. Otherwise, it may be futile to aim towards zero waste for one type of resource if it cause the waste of another type of resource.

Waste Collection Systems

Waste collection has got a significant effect on subsequent functional elements, public health, aesthetics, housekeeping and public attitudes concerning the operation of the system. As collection and transportation constitute a major cost in waste treatment (up to 80 per cent), streamlining of collection techniques can greatly improve the efficiency, and effect a significant saving in the overall cost of WM. This will be beneficial in two ways, viz., reduced disposal efforts and advantages of resource recovery by effective recycling of waste.

The proposed strategies for waste collection are:

i) Design of economic basis to facilitate separation at source.

ii) To provide every organisation with a set of four standard bins to separately collect the metallic, plastic, paper and other miscellaneous waste, the bins should be designed after careful investigation of the types and quantum of waste generated.

iii) Design of appropriate collection system governed by public or private agencies to regularly collect the segregated waste at time intervals depending upon the generation rate.

iv) Incentives to encourage segregation of the waste at source.

v) Timely collection of scrapped organisations' appliances alongwith segregated waste, and its flow through salvage industry for ultimate reuse.

vi) Development of appropriate collection systems for the collection of miscellaneous organic and inorganic waste.

Recycling of Wastes

In the absence of conservation or recycling, certain of the World's finite resources will diminish to a level incapable of maintaining an acceptable environment and adequate life support. Fortunately, in India, there is a growing awareness to recycle/reuse the waste. The National Committee on Science and Technology (NCST) has identified a number of recycling projects.

The terms recycling, reuse, reclamation and recovery have different interpretations, though these terms are generally used as synonyms. In this study the term recycling is adopted to mean all these terms.

Recycling generally refers to the use of undesirable outputs or wastes as input to the same process or system, e.g., recycling of foundry scrap. Reuse may be termed as the use of waste generated from one process/system as input to some other process/system as a raw material, or for the generation of power or by-products.

The conversion of damaged, rejected and undesirable outputs into the desirable outputs by repair or processing is termed as reclamation. The term recovery is utilised to denote the gain of resources from the wastes.

Waste Disposal Systems

This element links the waste management system with environment and other systems, and has got a significant impact on the same. The adoption of poor disposal practices have resulted in severe environmental pollution in different parts of the world, particularly in the big industrial centres and have posed serious threat to human life. Some of the developed countries have taken the problem on war-footing and have started developing and adopting latest technology in this regard. In India the awareness has grown recently and the design of effective waste disposal systems has become a challenging problem area. From disposal viewpoint wastes may be categorised into:

i) Salvable waste, and
ii) Non-salvable waste.

The wastes that have got some salvage value are termed as salvable waste. The scrap, rejected goods, surplus/obsolete items and equipments etc. fall under this category. The well designed disposal system for salvable wastes may provide best return to the organisation, contribute to cost reduction and higher profit and aid to material conservation.

Wastes which do not have any salvage value, but need further processing and treatment for disposal are termed as non-salvable waste. The non-salvable wastes are primarily responsible environmental hazards. Proper management of salvable wastes may amount to resource recovery and reduced environment and other social costs.

a) **Guidelines For Disposal of Salvable Wastes:** The salvable waste, e.g. scrap, surplus/obsolete stores and equipment, unserviceable appliances and machinery, abandoned vehicle etc. is generated in almost all sorts of manufacturing and service establishments. No particular attention has been paid in most of the organisations for the disposal of salvable wastes. The most common practice is to dispose the scrap/surplus through auctioning. No systematic procedures have been developed in this regard. Another mode of disposal adopted is to salvage the scrap through specialised agencies. The traditional "Kabaris" or Junkmen are performing this work. Directorate General of Supplies and Disposals (DGS & D) is playing a vital role in public disposals. It disposes the stores worth 50 crores of Rupees approximately, every year for various Government Departments. A special Surplus Disposal Committee was set up for analysing the large quantities of accumulated surplus. The Committee in consultation with Metal Scrap Trade Corporation and MMTC has suggested some procedures for the manner of disposal and the market analysis of the huge ferrous and non-ferrous scrap in the country.

The procedures for the disposal of different types of salvable waste vary from situation to situation. Some broad guidelines have been suggested to aid the design of systems and procedures for disposal in individual cases:

i) First of all the feasibility of recycling should be analysed to dispose the scrap.
ii) Try to use the scrap for producing by-products.
iii) Try to transfer the surplus from one department to another or to other plants in case of multi-plant organisation.
iv) Analyse the feasibility to sell the scrap as raw material to other plants.
v) To sell the scrap/surplus to external export agencies dealing with it.
vi) Selling of scrap through advertisement and auctioning. The frequency of auctioning should be decided after analysing the generation rates and by obtaining a break-even between the scrap/surplus carrying cost and auctioning cost.
vii) Selling the surplus in open market, or to the employees itself, particularly in case

of consumer goods. If the product is not meeting the quality requirement, then classify it as seconds and give a discount. This may act as an incentive to employees.

viii) To consult the vendor and return the surplus to vendor.

ix) To sell surplus/obsolete equipment through advertisement and invite the offers from other parties.

x) In case of damaged equipments try to sell after the parts after classifying into good serviceable, repairable or reclaimable, and scrap.

xi) To donate the rejected material to charitable organisations to gain socio-economic respect.

b) Processing and Disposal Techniques for Non-salvable Waste: Processing techniques are used in solid waste management system to improve the efficiency of operations; i.e., to reduce storage requirements, facilitate disposal to recover resources, conversion products and energy, and to minimise environmental effects. Disposal is the 'no alternative' option and the ultimate fate of all wastes that are of no further value. Various alternative processing/disposal techniques have been briefly discussed as follows:

Mechanical Processing: The mechanical processing of the waste is done to reduce its volume and size for easy handling and disposal and to recover valuable materials by separation.

i) **Compaction:** This technique reduces the volume of the waste by mechanical compaction.

ii) **Baling:** This is also a mechanical volume reduction method which uses specialised compaction equipment to produce solid wastes in block or bales of various sizes. This offers the advantage of less landfill requirements, land reclamation, less leachate production, neat and clean operation of land filling, easy transportation saving in cost of covering material etc.

iii) **Shredding:** This refers to the mechanical size reduction of wastes by pulverising. The volume is reduced up to 50% and a homogeneous mass is obtained which is relatively odourless, unattractive to flies and vermins, and is relatively non-combustable leading to easier disposal. Milled refuse can be disposed of at locations close to residential areas.

iv) **Component Separation:** Component separation is a necessary operation in the recovery of resources from solid wastes both manual and mechanical method can be used. The separation may be done at the source or centralised separation may be adopted.

Thermal Processing: Thermal processing of wastes result in volume reduction, generation of energy and by-products. The overall heat contents of solid wastes including moisture and ash etc. is approximately 10.5 million BTU/Ton, which is most nearly comparable to that of low rank lignites.

i) **Incineration:** High temperature oxidation of the organic and toxic compounds present in gaseous wastes is employed to destroy the offensive effluents and odours by converting them into harmless gases, i.e. O_2 and waste vapour.

ii) **Pyrolysis:** The pyrolysis of solid wastes strictly refers to the destructive distillation or the thermal decomposition of the wastes in an inert atmosphere.

Bio-Processing: For agriculture based economy like India bio-processing is becoming an important research field to produce fertilisers, alternative fuels and feeds etc. Some bio-processing methods are composting, fermentation, hydrolysis etc.

Composting: Composting of solid wastes may be defined as the bio-chemical stabilisation of these organic materials to a humans like substance through scientifically producing and controlling an optimum environment for the process.

There is vast potential for composting as a disposal process in India. It has been used from link time in rural area, but there is a need to make the people aware of its

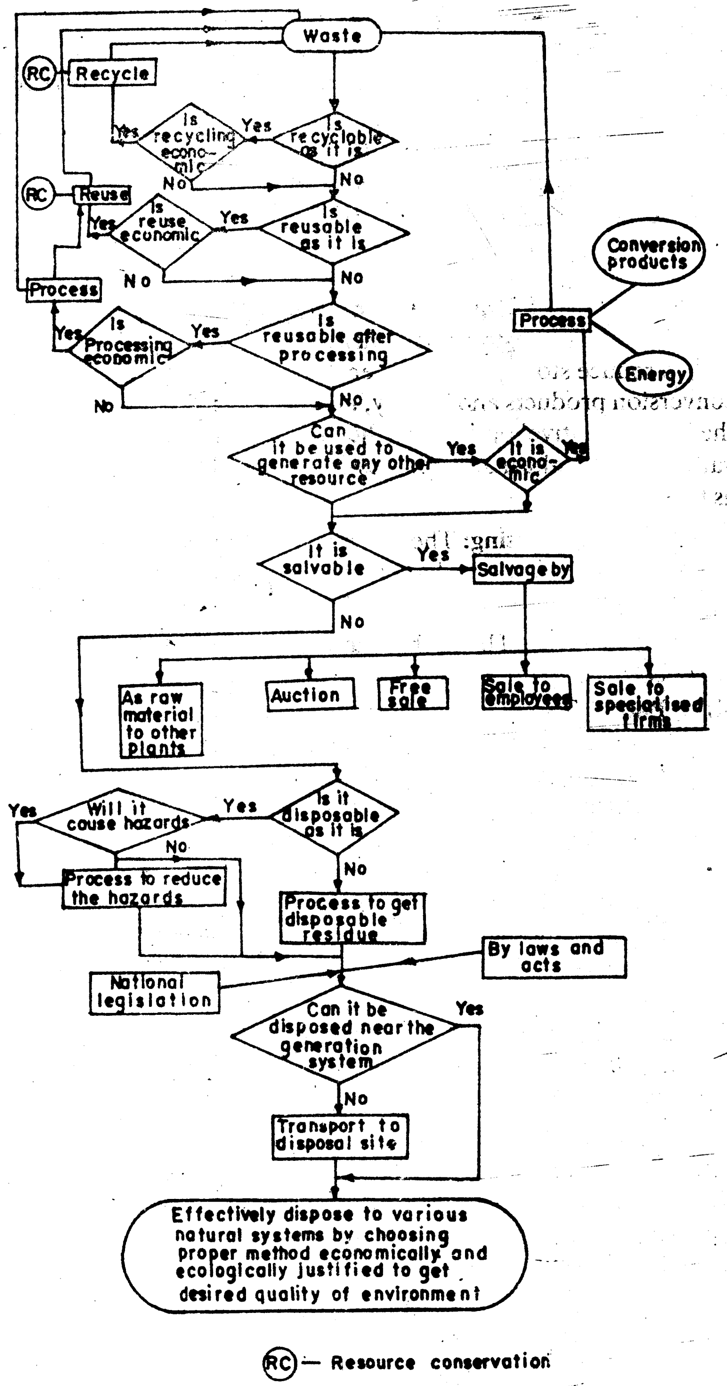


Figure VI: Flow Diagram of Waste Disposal System benefits and rigorous organised efforts should be made.

Ultimate Disposal: Ultimately something must be done to solid wastes that are of no use and are left after recycling, processing etc. The major options available are the disposal on or in the earth's mantle (e.g. land filling) and disposal at the bottom of the ocean.

Sanitary land-filling: Sanitary landfills have been proclaimed as the low cost, safe way of disposing of municipal refuse. Rain water and surface run off water percolates through the landfills and the resulting leachate has a high concentration of organic wastes and harmful salts. Also, the evolution of methane gas from the refuse can create fire and explosion hazards.

c) **Design of Effective Waste Disposal System:** The design of effective waste disposal system is an important aspect of waste management. The system should be designed to promote the maximum possible recycling/reuse of wastes, and for minimum environmental hazards. The flow diagram of waste disposal system has been shown in Figure VI.

First of all the technical economic and social feasibilities of recycling/reuse should be analysed and attempts should be made to recycle the waste as it is without any processing. If the residue left after optimal recycling reuse is disposed as it is, then the mode of disposal should be selected; otherwise various processing techniques should be evaluated by considering various social and economic factors. Both the source as well as centralised processing methods should be selected properly. Finally, plans should be prepared for the ultimate disposal.

Various factors that should be considered in the design of waste disposal system are:

i) The public attitudes
ii) The regional and national policies
iii) The economic considerations
iv) Land availability
v) Equipment requirements
vi) Ground water protection
vii) Environment control
viii) Fire prevention
ix) Litter control
x) Operation plans
xi) Employer facilities
xii) Equipment maintenance
xiii) Operational records

20.6 OUTLINE OF I-O-W (INPUT-OUTPUT-WASTE) MODEL

It has been visualised that it is possible to take waste as an explicit parameter and the existing input-output model can be modified to incorporate WM constraints. To provide a closer representation of real life system it is proposed to remodel them in the framework of an I-O-W (Input-Output-Waste) model. The proposed model will be able to define the resource balance more realistically by incorporating the reduction, recycling, abatement, disposal and related functions of WM. The I-O-W physical system defines the resource constrained for every viable system as the balancing of inputs to the sum of outputs and wastes for each type of resource:

$$\text{Input} = \text{Output} + \text{Waste}$$

Basic Framework: The basic framework of I-O-W model defines I-O-W flow matrix, I-O-W coefficient matrix and consistency equations. The I-O-W flow matrix consis' of a set of conventional intermediate demand or resource flow matrix extended to include WM sectors final demand matrix plus added waste flow matrix. An aggregated I-O-W matrix is shown in Table 2.

Table 2
I-O-W Flow Matrix

Intermediate demand or Resource flow matrix		**Final demand matrix**	**Total output**
Input of resources		Total final demand	
		Waste flow matrix	Total waste
Total input=Resource inputs	+	Recycled Wastes	

The I-O-W coefficient matrix consists of technological coefficient matrix, final demand coefficient matrix and WM coefficient matrix partitioned for intermediate and primary inputs, and intermediate and final wastes as shown in Table 3.

Table 3
I–O–W Coefficient Matrix

Consuming Sectors		
	Technological coefficient matrix (intermediate input coefficient)	Final demand coefficient matrix
	Primary input coefficient	Primary input to Final demand
	WM Coefficient Matrix Intermediate Waste Coefficient	Final Waste Coefficient

The model may be generalised for 'n' production sectors and 'm' WM sectors. The source of primary inputs are aggregated as trade, habitat and nature, whereas the final demand is clubbed into domestic consumption trade and change of stocks. The inter-sectoral waste flow is treated as intermediate waste, while final wastes include waste recycled in habitat by changing life styles, waste disposed of by trade and the wastes ultimately disposed of to nature.

20.7 TREATMENT OF WASTAGE IN COST ACCOUNTS

It is realistic to expect that all materials put into process will not end up as good saleable product. Some loss, scrap and wastage in inevitable in process industries. These losses must be computed in advance before the processing operation begins. Process loss can be divided into two categories; (i) Normal loss, (ii) Abnormal loss. Normal loss is the loss which is unavoidable, uncontrollable and expected in normal conditions. It may be inherent in the manufacturing process. If the loss is inevitable. i.e. unavoidable and within the limit, it is called normal process loss. Abnormal process loss is controllable and generally caused by abnormal or unexpected conditions, such as bad designing, poor materials, accident and negligence, etc.

The treatment of normal and abnormal losses differ in inprocess accounts. Normal losses are absorbed by good production. Assume, for example, that 25,000 units of a mixtures were put into process and that during processing 5,000 units were lost through evaporation. This is an unavoidable loss. If the total cost recorded was Rs. 25,000 the remaining 20,000 units would be assigned a unit cost of Rs. 1.25

$$\frac{\text{Cost of production}}{\text{No. of units completed}} = \frac{\text{Rs.}25{,}000}{\text{Rs.}20{,}000} = 1.25$$

Abnormal losses are valued as good units. The unit cost which is used to value good units is also applied for the valuation of abnormal loss units. The cost of abnormal loss units computed in this manner is transferred to a separate abnormal loss account and credited to the relevant process account. Subsequently, this loss is transferred to the costing profit and loss account and the abnormal loss account is thus closed.

The following procedure will help in the preparation of process cost accounts that do not present any difficulty:

1 Normal loss should be computed on the basis of information given in the question.

2 The cost per unit of production, after making into account normal loss units, should be determined assuming that abnormal loss does not exist. The cost per unit is calculated on the basis of the following information:

a) Normal production, i.e., inputs (units) minus normal loss units.

b) Normal cost of production, i.e., all costs incurred (appearing on the debit side of a process account) minus proceeds (if any) realised from the sale of normal loss units.

Normal cost of production divided by normal production will give the cost per unit of output.

3 The cost per unit determined as above is used to value abnormal loss units and that would be the cost of abnormal loss.

4 The abnormal loss account is debited and the relevant process credited with the amount and quantity of abnormal loss as calculated in (3) above.

5 The cost per unit as obtained in (3) will also be applied to determine the cost of good production units produced by the process.

6 The proceeds realised from the sale of normal loss representing scrap (if any) is transferred to the relevant process account.

7 The proceeds realised from the sale of abnormal loss representing scrap is transferred to a separate abnormal loss account and not to the relevant process account.

8 The abnormal loss account is closed by transferring the total cost of abnormal loss units to the costing profit and loss account if there is no scrap. In case abnormal loss represents scrap, only the net amount (total cost of abnormal loss units minus scrap) will be transferred to the costing profit and loss account.

20.8 CONCLUDING REMARKS

The problem of Waste Management should be visualised in a broader perspective and an organised systems' approach to Waste Management should be adopted. It is unfortunate that despite the cruciality of Waste Management in socio-economic resource structure in its ecological and environmental compatibility, it has been ignored most of the time. There is a need to standardise the taxonomy of the wastes and to critically analyse the functional elements of waste management. Waste management is a dynamically emerging field with vast scope. Though awareness in this field is growing slowly, if proper attention is paid, it may rapidly gain momentum.

20.9 *SUMMARY*

In this unit we have proposed a new enlarged concept of waste and wastivity. The best way of waste management is not to generate waste at all, viz. a preventive policy of waste generation is advocated. We have established the close relationship between wastivity, productivity and resource management. A seven step systematic approach has been given for waste reduction. Guidelines for waste collection, recycling and disposal have been discussed. Some processing and disposal systems have also been overviewed. A brief outline of an input-output waste model has been given. It is difficult to accurately account for all wastages. Yet another procedure has been suggested that will help in the preparation of appropriate cost accounts.

20.10 KEY WORDS

Gross Wastivity: Ratio to total waste generated to total input.

Incineration: High temperature oxidation of the organic and toxic compounds present in gaseous wastes that is employed to destroy the offensive effluents and odours by conversion into harmless gases.

Productivity: Ratio of output to input.

Pyrolysis: Destructive distillation or the thermal decomposition of solid wastes in an inert atmosphere.

Waste: Any unnecessary input to or any undesirable output from any system encompassing all types of resources.

Waste Management: A multi-disciplinary activity involving engineering principles, economic, urban and regional planning, management techniques and social sciences.

Wastivity: Ratio of waste to input.

20.11 SELF-ASSESSMENT EXERCISES

1 Explain how the system concept can be used in explaining the terms waste and waste management.

2 'Waste Management' is complementary to 'Resource Management'. Critically comment.

3 Differentiate between wastivity and productivity and explain whether reducing wastivity and increasing productivity imply one and the same thing.

4 Why are the basic waste generation stages in a production system? Explain with the help of an example.

5 Explain how would you proceed in designing a waste disposal system for a manufacturing enterprise.

6 Write short notes on:
   a) Systematic waste reduction procedure
   b) Wastivity Indices

7 Write short notes on:
   a) Identification of waste
   b) Taxonomy of wastes

8 Briefly explain what you understand by the term I-O-W (Input-Output-Waste) model.

9 Devise a method of cost accounting for wastes.

20.12 FURTHER READINGS

Agrawal, S.K. (Sushil), 198?. *Systems Modelling of Waste Management in National Planning*, Ph.D. Thesis, I.I.T. Delhi.

Anderson, L.L. and Tillman D.A., 1977. *Fuels from Waste, Energy Science and Technology Management—An International Series.*

Bond, R.G. and Straub, C.P. (Eds.), 1973. *Handbook of Environment Control, Vol. 2-Solid Waste*, CRC Press.

Gopalakrishnan P. and Sundaresan M., 1979. *Materials Management: An Integrated*

Approach, Prentice-Hall of India Pvt. Ltd.: New Delhi.

Kirov, N.Y., 1975. *Waste Management? Reuse*, ANN Arbour Science.

Lee Jr. L. and Dobler, D.W. 1977. *Purchasing and Materials Management: Text and Cases*, Tata Mc-Graw Hill Publishing Co. Ltd.: New Delhi.

Lochr, R.C., 1974. *Agricultural Waste Management: Problems, Processes and Approaches*, Academic Press, Inc.: New York.

Neal, A.W., 1971. *Industrial Waste, Business Books Ltd.*: London.

Pawnoi, J.L., 1975. *Handbook of Solid Waste Disposal*, VNB.

Pratt, A. (ed.), 1978. *Directory of Waste Disposal and Recovery*, George Godwin Ltd.: London.

Tchbanoglous G. Theisen, H. and Eliassen, R., 1977. *Solid Wastes: Engineering Principles and Management Issues*, McGraw Kogakusha Ltd.: Tokyo.

Thome-Kozmiensky, K.J., 1979. *Recycling Berlin '79 Vol. I and II*, International Recycling Congress: Berlin.

Wilson, D.G., 1977. *Handbook of Solid Waste Management* Van Nostrand Reinhold: New York.

Vrat P., 1979. *Waste Management in India: The Need for Organised Systems Approach: Proceedings of APO Symposium on Waste Management*, Asian Productivity Organisation: Tokyo.

Treatment and Disposal of Wastes (1967). WHO Technical Report Series, 367.

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