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INTRODUCTION TO OPERATIONS MANAGEMENT

Introduction to Operations Management, applications in product and service industry, use of competitive advantage

Unit Structure

1.0 Objectives

After going through this unit, you will be able to understand

- concept of a manufacturing process
- appropriateness of the process to overall organization objective
- effective process strategy for a good process design
- production and service matrices
- volume – variety matrix for production
- service process matrix for service organizations.

1.1 Introduction to Operations Management

The Operations Management is as old as human civilization. The emergence of Production and Operations Management is seen from the beginning of homo sapiens species. The human beings used the production of agriculture produces as a part of production and operations management. Then labour used to carry out production activities and now due to industrial revolution upto 5th generation and application of Information and Communication Technology, the men are replaced by automated machines to operate the production and operations system. The efficiency and volume have been enhanced due to the applications of principles and practices of operations management in production plant.

Production Function

An organization carries out four major functions namely finance, human resource management, production and marketing functions. These functions are inter-related to each other function. The finance function generates funds and applies these funds to all functional areas of management. The human resource management functions are done by employees of the organization. As far as production function is concerned, the employees are the vital element to convert raw material into the finished product. The production function or operation function is the core function of organization without which product development is not possible. The production function coverts the raw material into finished products. The marketing function exhibits the function of transporting, allocating, distributing and selling these finished products to different distribution channel in order to sell the product and earn the profit for the organization. Hence all these functions are inter-related to each other and production function is the core part of an organization.

The 5.0 Industrial revolution made complex production activities into simplified systematically programmed and machine operated easy production process. In ancient time, the traditional labour work was used to develop finished product and now these tedious, monotonous and expensive labour work is replaced by advanced, automated, robotic enabled and programmed technology using artificial intelligence that saved time and cost and improved the efficiency and capacity of the production plant.

Ambiguity among Manufacturing Management, Production Management and Operations Management

The manufacturing management is the process of converting the raw material into the finished goods whereas the production management is the process of transforming raw material into the finished goods with quality output as Unique Selling Proposition (USP). The Operations Management is the process of creating services for the consumption purpose or it is the process of converting raw material into finished services.

The major difference between the manufacturing and production are as follows

- Manufacturing is the process by which raw material is transformed into tangible salable goods whereas production creates the product or goods as a utility.
- Manufacturing convert raw materials into finished products with the help of some machinery that is used as a medium to convert raw material into finished goods on the other hand production cannot be using medium to form utility.
- Manufacturing is a smaller part of production whereas production is a broader concept as compared to manufacturing as it involves different operations, utility and quality output.

- Tangibility is seen in case of manufacturing whereas tangibility and intangibility both are seen in case of production.

- Manufacturing unit use any definite formula for preparing the goods whereas production has a definite formula called as output / input for preparing utility consumable products.

- The man power and machinery are mandatory in the case of manufacturing where as men power and machinery may or may not be used in the case of production process.

The major difference between the production and operations are as follows

- The production management is concerned with creation of finished goods as utility related to production function whereas operations management is concerned regular business functions and production and delivery of services.

- The scope of production management is limited in nature as it is limited to production of goods and it is limited to the price of the product, quantity to be produced, and quality of goods to be produced. On the counter part, the scope of operations management is wider in nature as it is restricted to regular production function along with manpower planning in the production department and price of the product, quantity to be produced, and quality of goods to be produced and so on.

- The focus of production management is to deliver the right quality of product at right price at desired time in the ordered quantity. The focus of operations management is to use all available resources of the organization to deliver routine business activities and for the delivery of services purpose.

- The production management is useful in every production organization where raw material is converted into finished goods. The operations management is used in service industry such as hotels, hospitals, educational institutes, banks, manufacturing firms, consultancy service providers and so on.

Operations function

Every organization creates and delivers services for the internal routine work as well as for external tasks. Operations function is essential part of every organization. There are certain areas where operation functions are considered as a vital task. These functional areas are as follows

1. Marketing function: The Integrated marketing communication requires services to deliver information to the target customers about their products and services that is why marketing function including sales function consider operations management as a part of their regular duty.

2. Product or Service Development Function: Production or operation department develops goods or design services with the help of operations management.

3. Operations Functions: As per the customers' needs, wants and preferences; new products and services are created and delivered to the customer.

1.1 (a) Importance of Operations Management in Organization

The basic objective of an organization is to earn more profit. The profit can be earned with more sales in volume. The operations management creates and delivers the services or any other function to make product known to the customer and hence in all organizations, the operation function exists even if it is named or not. The profitable organization as well as non-profit making units utilizes resources to create and deliver the services to the society and hence operations management exists even in micro, small, medium or large organizations.

Few Examples of Operations Management in Organization are as follows

1. Beauty Saloons: They create and deliver fairness and beauty to their customers by rendering their beauty making services.

2. Doctors (Medical Practitioners): The patients are treated with the knowledge and practice of services of medical practitioners.

3. Tax Consultancy Services: The Chartered Accountants and Tax Consultants provide their consultancy services.

There are many examples of different organizations where services are created and delivered to the customers as per their demands.

Operations Management in the Smaller Organizations

The operations management in the smaller organizations is identical to that of operations management in the larger organizations. The larger organizations have their own set up to create and deliver their products and services. On the other hand smaller organizations do not possess the separate mechanism to create and deliver their products and services as their employees are small in number. Hence the employees of smaller organizations have to manage many duties in their capacity as to create and deliver the services.

Operations Management in the Non-Profit Organizations

The operations management in the non-profit organizations is identical to that of operations management in the smaller and larger organizations. The larger organizations have their own set up to create and deliver their products and services. On the other hand non-profit organizations do not possess the separate mechanism to create and deliver their products and services as their decisions are taken by the Government Auhorities, Non-Government Organizations or Charitable societies. The resources are limited in number and the service demands are more. There is sometime mismatch between the demand and supply of services. The few examples of operations management in the non-profit organizations are medical services delivered by government hospitals and educational services delivered by Government schools.

1.1 (b) New Challenges in Operations Management

Due to 5.0 industrial revolution and information and communication technology, the cut throat competition has been seen in every field. The Changing business environment, Globalization, Internet access and financial competencies of customers raised many new challenges in the field of operations management. The new challenges in Operations Management are as follows

- Demand for quality products or services
- Lowering Cost of Services
- Many Options and Varieties
- New Service Innovations
- Environmental impact
- Political and legal pressure
- Rapidly changing technologies
- Security alerts
- Changing needs, taste and preferences of customers
- And many more

1.1 (c) Strategies to meet challenges of Operations Management

Even though there is cut throat competition in the business world, every business organization strives to get success in their business by overcoming the different challenges in their business. The challenges of operations management are overruled by different strategies to convert the challenges of operations management into the strengths of operations management. The different strategies to overcome the challenges of operations management are as follows

- Co-creation of services
- Use of internet facilities to create and deliver the service
- Globalization of service technologies
- Customer Relationship management
- Failure analysis
- Mass customization
- Fast delivery of operations or services
- Lean process design

- Horizontal and vertical partnership
- Recovery planning

1.1 (d) Process of Operations Management

The process of operations management includes 3 important steps as Input, Transformation and Output Process. The process is similar for all types of products and services. Based on the nature of business, the process of operations management differs at micro-level. The operations management involves creation and delivery of services through different models of process of operations management. These processes include input of raw material, transformation by service providers and the output as the customers' demand. The general process is similar but the elements of process of operations management differs. Let us take an example that many shops in the same market look similar as they provide services to their customers just take into accounts the travel agency shop, hotel and hospital in the same market. These three shops create (input and transformation) and deliver (output) their services as per the customers' demand. The travel agency books journey services, hotel provides the food services and hospital gives medical services. It means that the input, transformation and output is common in all these three shops but their services and elements differs.

1. Input to the processes
2. Transformation part
3. Output from the processes

Let us discuss all these elements one by one as follows

1. Input to the processes

The input to the processes includes men, Money, Methods, Machine, Materials, Information and other resources available in the organization. These available resources are transformed and converted into the output as delivery of services. The fundamental input to the process of operations management is as follows

a. Materials:

The term materials differ in different context as per the nature of business. The physical properties such as shape, color or composition can be changed in the manufacturing operations. Parcel delivery organizations such as Flipkart, Amazon etc. consider location as material whereas in the case of warehouses, store act as material similarly in the case of retail outlet, possession of material acts as input material.

b. Information:

Information is one of the vital sources of service providers. The information is used as input to the process. The few examples of information as input to the process includes consultancy service providers such as accountants, medical practitioners, research agencies and so on,

c. **Customers:**

The customers may become input to the process when they want services for their consumption purpose. When customers want saloon services, beauty services, massage or when they want to have any other such services, they become input to the process as they get services.

2. **Transformation**

The transformation in case of operations management is always attached to the input to the process as it converts input to the output as per the demand of the customers. As the services are intangible, it should be delivered as soon as it is produced or it should be consumed as soon as it is created. The service providers of operations management process should convert the input to the output rapidly because the creation of services and delivery of services are non-separable part. Hence when food services are ordered in the hotel, food is prepared and delivered to you as per the demand of customers. In the case of theaters, when customers visit to watch movie on screen, the movie is projected on the screen as soon as the customer is available in the theatres. In postal services, when parcel is posted, the services of creating and delivering the parcel starts when customers gives an order of parcel. In the case of private coaching classes, the tutor transforms his knowledge into your conceptual learnings, understandings and output it.

The transformation process involves following parameters

- Service Design
- Service Planning
- Service Control
- Maintenance
- Continuous stock
- Continuous quality check
- Continuous cost monitoring

3. **Output from the processes**

The output to the process is the finished, final and consumable product. The products are classified into goods and services on account of their tangibility. The goods are tangible products and services are intangible and inseparable products. When you visit to hotel for lunch or dinner, the food is tangible product and serving the food is services of the hotels. When you purchase newspaper, the newspaper is tangible product and the news is services rendered by that newspaper and hence it may be said that product and services are attached to each other. They are inseparable to each other. Sometimes output to the processes is services only. For example the services rendered by the accountants, management consultants, medical practitioners or other pure service providers are the output to the process having output as services only.

1.1 (e) Operations Management Framework

The operations management is framed with the assistance of functions of the management. The planning, organizing, coordinating, controlling and other functions of management affecting human behavior and models are used in the operations management as follows

1. Planning in Operations Management
2. Organizing in Operations Management
3. Coordinating in Operations Management
4. Controlling in Operations Management
5. Affecting human behavior in Operations Management
6. Models in Operations Management

The elements of framework of operations management are explained as follows

1. Planning in Operations Management

Basically, the planning in operations management involves planning and scheduling transformation process. The planning transformation phase involves strategy framing, forecasting, produce choice, process alternatives, planning of operations capacity, facility location planning and layout planning etc.

2. Organizing in Operations Management

The organizing function in operations management involves organizing for the purpose of transformation of input to the output called transformation organizing function. It is composed of job design, operations standards, work measurement and project management.

3. Coordinating in Operations Management

The coordination function in the operations management involves coordination among all resources such as men, money, method, material, machine, information and capital to transform the input into desired output for the customers.

4. Controlling in Operations Management

The controlling function in operations management involves input control, material control, transformation control, quality control, volume control, mistake control and inventory control.

The execution of planned activities are monitored and if there is discrimination in the process, then control measures are implemented to achieve the objectives of operations management.

5. **Affecting human behavior in Operations Management**

The operations management process is handled by the manpower and they are human beings i.e. living material and human behavior cannot be neglected as the complete operations management process is handled by the human beings and hence human behavior is vital element in operations management.

6. **Models in Operations Management**

It is observed that the plans are not executed properly as there are uncontrollable factors which may deviate the execution and difficulties may arise in the plan execution process and hence the appropriate operations management model has to be designed so that models will assist to control and monitor the process of operations management. The models are developed using computer simulation, algorithm, decision tree analysis and linear programming models.

1.1 (f) Objectives of Operations Management

There are twin objectives of operations management. These objectives are satisfactory customer service and resource utilization. These objectives are as follows

1. **To provide satisfactory customer service.**

The customers' demand for right product at right time and at right price is satisfied using operations management. The right product means providing the service as per the needs, wants and preference of the customer. The product specifications are demanded by customer and such customized products have to be created and delivered to the customer. The right products should meet to the right thing, right expectation and right specification of customers. The customer service is at top priority in concerned with operations management.

The services should be delivered at the expected time ordered by the customer as right time otherwise services will not be bought by the customers. The right price illustrates the price of service at competitive price or expected price of the customer. Hence it is inferred that the customer service should be created and delivered for right service at right time and at right price.

2. **To utilize the resource optimally.**

The objective of an organization is to earn profit by utilizing available resources. The resources such as materials, machine, manpower, method and money should be utilized properly. The available resources should be used properly so as to transform the input to output as customer service. The productivity can be increased with the maximum utilization of available resources.

1.1 (g) Scope of Operations Management

Operations management is the process of transforming input into customer service as output. The scope of operations management is concerned with creation of utilities as customer service. The scope of operations management is explained as follows

1. Plan location and facilities location
2. Plant Layout
3. Material Handling
4. Product Design
5. Process Design
6. Production Planning and Control
7. Quality Control
8. Materials Management
9. Maintenance Management

The scope of operations management is explained in detail as follows

1. Plan location and facilities location

Selection of plant location and facility location is long term capital decision as it involves purchase of plant or factory or firm for creating and delivering the customer services or utilities. Hence while selecting plant location and facilities location, the utmost care is taken to make investment in plant location. The decision of selection of Plan location and facilities location leads to the success and failure for the service operations.

2. Plant Layout

Plant layout refers to the physical arrangement of facilities. The operations management assists to understand and to arrange plant design so as to create and deliver utilities to the customers.

3. Material Handling

The production and operations management assists to handle the material with proper care and to transport it and to store it at the proper location. The concept of material handling is being learnt in the production and operations management.

4. Product Design

Creativity is converted into innovation in the product design. The idea generated is transformed into the services in the product design. New product development or modifications in the existing services or products are made with the help of product design function. The research and development department of the organization in association with sales manager, production manager and operations manager decide the product design. The product specification should match to the demand, need, wants and preference of the customers.

5. Process Design

The process design is the flow diagram or layout of the process of conversion of input to the output services. The process design is the decision tree diagram or overall process path for the product development. The process flow analyses, choice of technology and workflow diagram are the parts of product design.

6. Production Planning and Control

The Production planning and control is defined as the process of planning in advance the production volume, order timing, production scheduling, follow up procedure and control measures. The production planning and control is essential to deliver the services at right time at right price in right volume at right specification. The production planning and control carries out managerial function such as planning, routing, scheduling, and dispatching and follow up of the production process or operations process.

7. Quality Control

The quality control is the maintenance of standards in the quality of product or in the quality of services. The quality control measure detects the defects in the product or services and eliminates the defects in the product or services.

8. Materials Management

The material management is the process of purchasing material at desired process, at desired volume and controlling the material as and when needed and making the use of materials in the operations process to create and deliver the utilities or customer service.

The objectives of materials management are to purchase the inventory at minimum cost, to control the material requirement and to have flow of materials in the production process or operations process.

9. Maintenance Management

The maintenance management is the crucial part in the production and operations management. The maintenance of machinery needed in the production and operations department is essential without which production or operations can't be augmented. If the machines remain idle, then the breakdown or damage to the system may occur leading to the expensive repairs in the machinery. This can be avoided with the help of maintenance management.

1.1 (h) Process Analysis Terms

- Process: Is any part of an organization that takes inputs and transforms them into outputs
- Cycle Time: Is the average successive time between completions of successive units
- Utilization: Is the ratio of the time that a resource is actually activated relative to the time that it is available for use

Process flowcharting

It is the use of a diagram to present the major elements of a process. The basic elements can include tasks or operations, flows of materials or customers, decision points, and storage areas or queues. It is an ideal methodology by which to begin analyzing a process

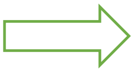
Flowchart Symbols

 Task or Operations  Decision Point

E.g., giving an admission ticket to a customer is a task

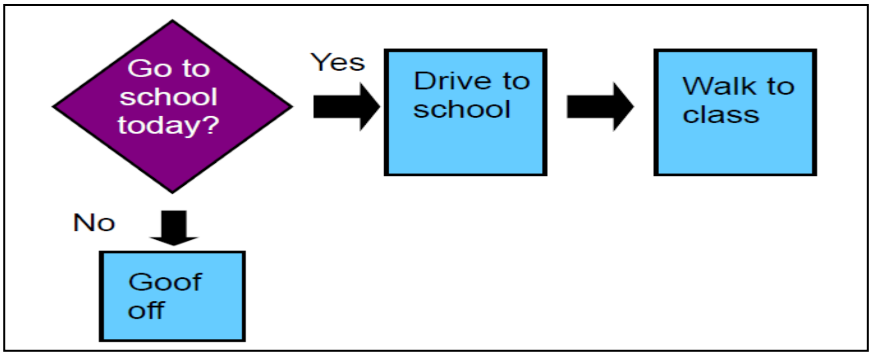
E.g. how much change should be given to a customer is a decision

Flowchart Symbols

 Storage area or Queue,  *Flow of materials*

E.g., shed or lines of people waiting for a service E.g., *mechanic getting a tool*

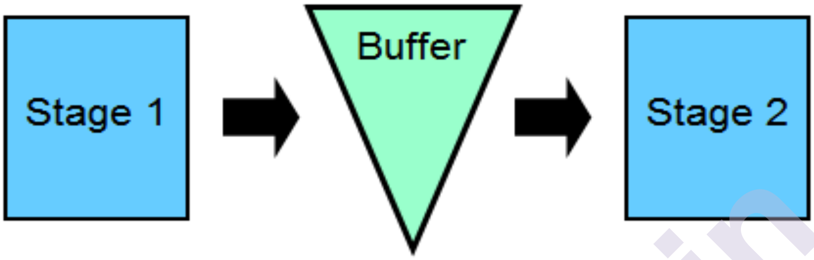
Flowchart of Student Going to School



1.1 (i) Types of Processes

Single Stage Process

Multi Stage Process



A buffer refers to a storage area between stages where the output of a stage is placed prior to being used in a downstream stage

Other Process Terminology

- **Blocking**

  Occurs when the activities in a stage must stop because there is no place to deposit the item just completed

  If there is no room for an employee to place a unit of work down, the employee will hold on to it and not able to continue working on the next unit

- **Starving**

  Occurs when the activities in a stage must stop because there is no work

  If an employee is waiting at a work station and no work is coming to the employee to process, the employee will remain idle until the next unit of work comes

- **Bottleneck**

  Occurs when the limited capacity of a process causes work to pile up or become unevenly distributed in the flow of a process. If an employee works too slowly in a multi-stage process, work will begin to pile up in front of that employee. In this case, the employee represents the limited capacity causing the bottleneck.

- **Pacing**

  Refers to the fixed timing of the movement of items through the process

Other Types of Processes

Make-to-order

- Only activated in response to an actual order.
- Both work-in-process and finished goods inventory kept to a minimum

In this production environment, the product is built directly from raw materials and components in response to a specific customer order.

Make-to-stock

- Process activated to meet expected or forecast demand.
- Customer orders are served from target stocking level

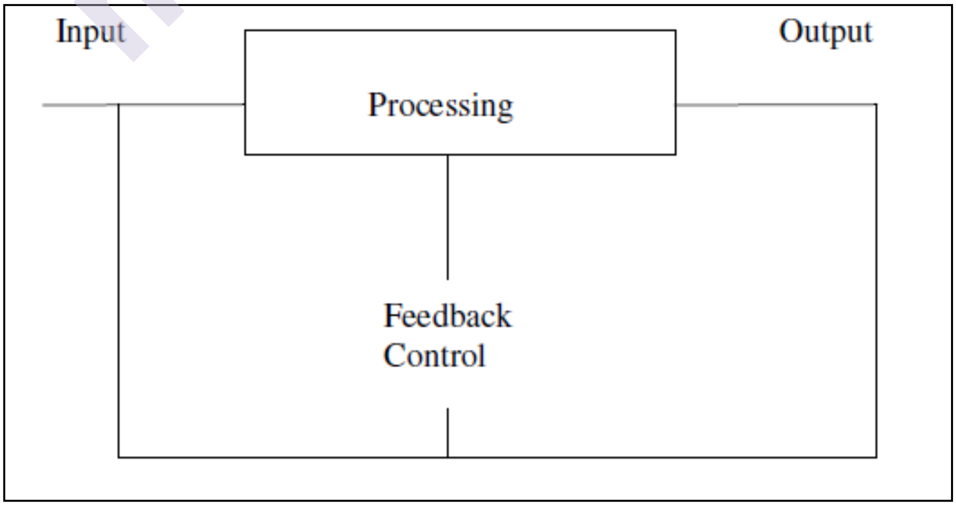
It is a production environment where the customer is served "on- demand" from finished goods inventory.

Hybrid combines the features of both make-to-order and make-to-stock.

1.1 (j) Operations / Production Process System

It consists of elements or components. The elements or components are interlinked together to achieve the objective for which it exists. Eg: human body, educational institutions, business organizations.

Components of a system are the input, processing, output and control of a system are called the components of a system.



Control

There are two types of control, namely Proactive Control and Reactive Control.

Proactive Control

When an operation is carried out on a product in a workstation, the quality inspector goes to the workstation and inspects the product. When the samples that he has taken for the inspection are not confirming to the quality, he stops the machine and identifies the reason for the deviation and corrects the problem, so that the produced product thereafter conform to the specifications. This type of control prevents any major quality setback after the production. This is an example for proactive control.

Reactive Control:

In a planning period, usually the quality target is fixed. Suppose, an organization feels to fix 5% defective is safe in the targeted production quantity and assumes that at the end of the planning period it finds that the defective output exceeds the targeted defective products. Then, it has to find out the reason for the deviations, namely, whether the problem is due to the method of doing the work or the resources used in the process. Then the planner uses this knowledge to prevent any problem in the future. Thus a Reactive Control is a post mortem case.

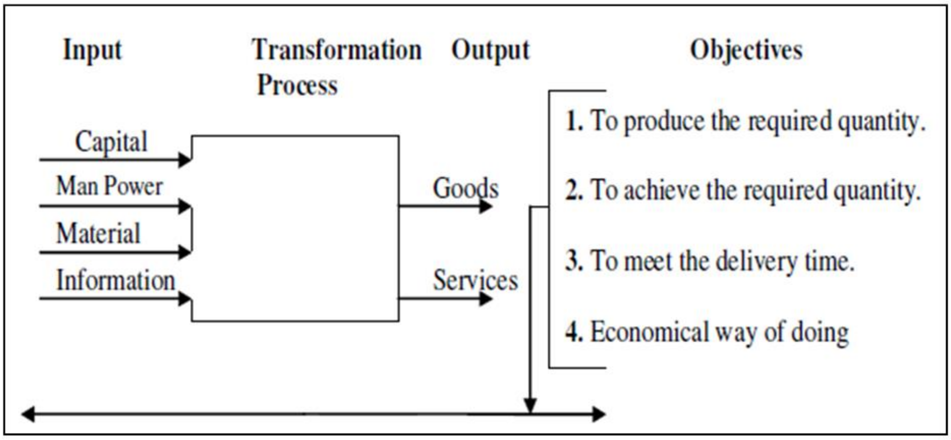
Business System

The business organization is classified into different subsystems based on the functions like marketing, production/operation, finance and human resource etc.

Marketing	Finance
Human Resource	Production/Operation

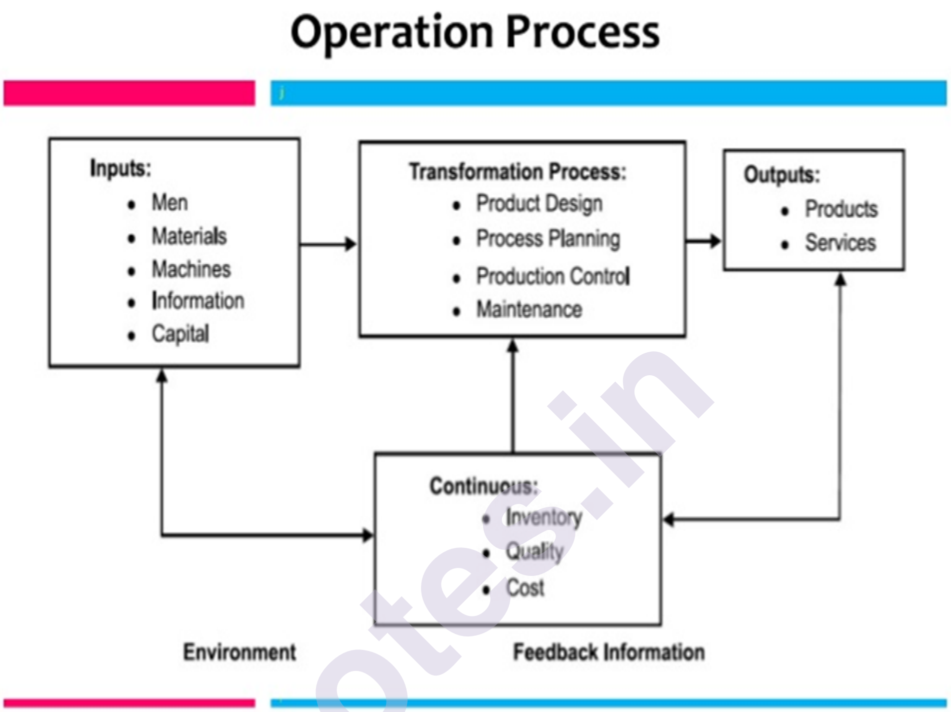
Each system will have more subsystems.

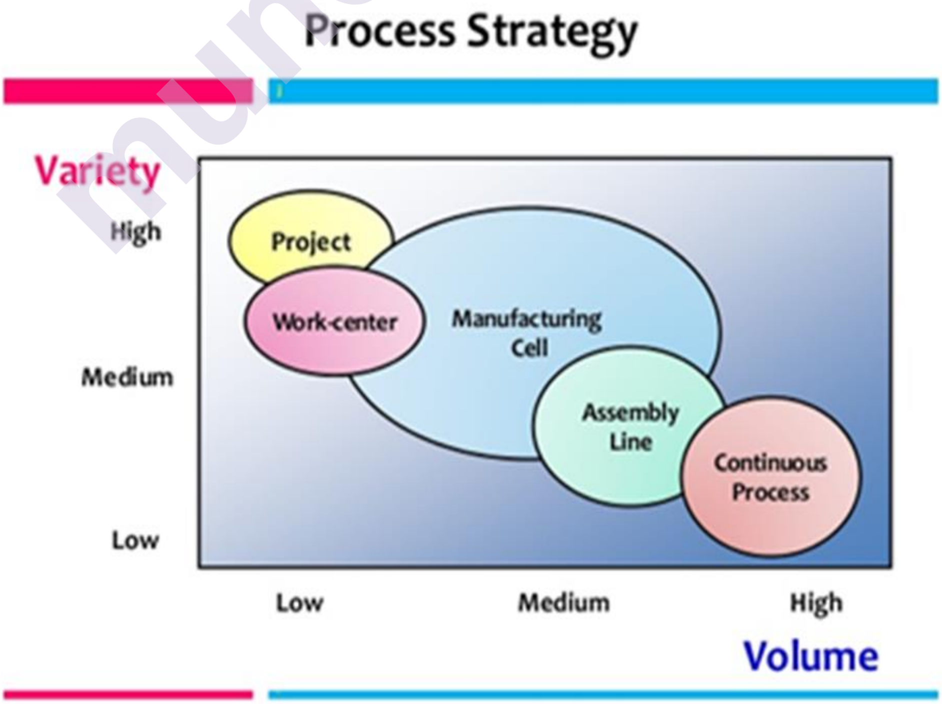
Production / Operation System or Process

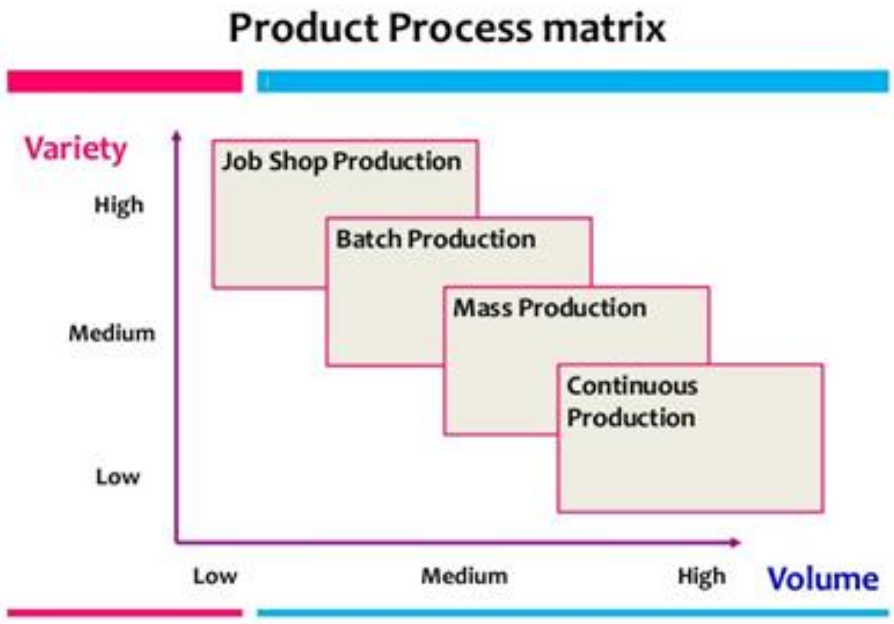


Volume – Variety Matrix for Production

The production system of a company mainly uses facilities, equipment and operating methods (called the production system) to produce goods that satisfy customers' demand. The above requirements of a production system depend on the type of product that the company offers and the strategy that it employs to serve its customers.







Determinants of process characteristics are volume, variety and flow. Operations processes have different characteristics and they differ in four distinctive ways: the volume of their output, the variety of their output, the variation in the demand for their output and the degree of visibility which customers have of the production of the product or service.

Operations processes have different characteristics.

Although all operations processes are similar in that they all transform inputs, they do differ in a number of ways, four of which, known as the four Vs, are particularly important:

- The volume of their output;
- The variety of their output;
- The variation in the demand for their output;
- The degree of visibility which customers have of the production of their output.

The volume dimension

Let us take a familiar example. The epitome of high-volume hamburger production is McDonald's, which serves millions of burgers around the world every day.

Volume has important implications for the way McDonald's operations are organized. The first thing you notice is the repeatability of the tasks people are doing and the systematization of the work where standard procedures are set down specifying how each part of the job should be carried out. Also, because tasks are systematized and repeated, it is worthwhile developing specialized fryers and ovens. All this gives low unit costs.

Now consider a small local cafeteria serving a few 'short-order' dishes. The range of items on the menu may be similar to the larger operation, but the volume will be far lower, so the repetition will also be far lower and the number of staff will be lower (possibly only one person) and therefore individual staff are likely to perform a wider range of tasks. This may be more rewarding for the staff, but less open to systematization. Also it is less feasible to invest in specialized equipment. So the cost per burger served is likely to be higher (even if the price is comparable).

The variety dimension

A taxi company offers a high-variety service. It is prepared to pick you up from almost anywhere and drop you off almost anywhere. To offer this variety it must be relatively flexible. Drivers must have a good knowledge of the area, and communication between the base and the taxis must be effective. However, the cost per kilometer travelled will be higher for a taxi than for a less customized form of transport such as a bus service. Although both provide the same basic service (transportation), the taxi service has a high variety of routes and times to offer its customers, while the bus service has a few well-defined routes, with a set schedule. If all goes to schedule, little, if any, flexibility is required from the operation. All is standardized and regular, which results in relatively low costs compared with using a taxi for the same journey.

The variation dimension

Consider the demand pattern for a successful summer holiday resort hotel. Not surprisingly, more customers want to stay in summer vacation times than in the middle of winter. At the height of 'the season' the hotel could be full to its capacity. Off-season demand, however, could be a small fraction of its capacity. Such a marked variation in demand means that the operation must change its capacity in some way, for example, by hiring extra staff for the summer. The hotel must try to predict the likely level of demand. If it gets this wrong, it could result in too much or too little capacity. Also, recruitment costs, overtime costs and under-utilization of its rooms all have the effect of increasing the hotel's costs operation compared with a hotel of a similar standard with level demand. A hotel which has relatively level demand can plan its activities well in advance. Staff can be scheduled, food can be bought and rooms can be cleaned in a routine and predictable manner. This results in a high utilization of resources and unit costs which are likely to be lower than those in hotels with a highly variable demand pattern.

The visibility dimension

Visibility is a slightly more difficult dimension of operations to envisage. It refers to how much of the operation's activities its customers experience, or how much the operation is exposed to its customers. Generally, customer-processing operations are more exposed to their customers than material or information processing operations. But even customer processing operations have some choice as to how visible they wish their operations to be.

For example, a retailer could operate as a high-visibility 'bricks and mortar', or a lower-visibility web-based operation. In the 'bricks and mortar', high-visibility operation, customers will directly experience most of its 'value-adding' activities. Customers will have a relatively short waiting tolerance, and may walk out if not served in a reasonable time.

Customers' perceptions, rather than objective criteria, will also be important. If they perceive that a member of the operation's staff is discourteous to them, they are likely to be dissatisfied (even if the staff member meant no discourtesy), so high-visibility operations require staff with good customer contact skills.

Customers could also request goods which clearly would not be sold in such a shop, but because the customers are actually in the operation they can ask what they like! This is called high received variety. This makes it difficult for high-visibility operations to achieve high productivity of resources, so they tend to be relatively high-cost operations.

Conversely, a web-based retailer, while not a pure low-contact operation, has far lower visibility. Behind its web site it can be more 'factory-like'. The time lag between the order being placed and the items ordered by the customer being retrieved and dispatched does not have to be minutes as in the shop, but can be hours or even days. This allows the tasks of finding the items, packing and dispatching them to be standardized by staff that needs few customer contact skills. Also, there can be relatively high staff utilization.

The web-based organization can also centralize its operation on one (physical) site, whereas the 'bricks and mortar' shop needs many shops close to centres of demand. Therefore, the low-visibility web-based operation will have lower costs than the shop.

Mixed high- and low-visibility processes

Some operations have both high- and low-visibility processes within the same operation. In an airport, for example: some activities are totally 'visible' to its customers such as information desks answering people's queries. These staff operates in what is termed a front-office environment. Other parts of the airport have little, if any, customer 'visibility', such as the baggage handlers. These rarely-seen staff performs the vital but low-contact tasks, in the back-office part of the operation.

The implications of the four Vs of operations processes

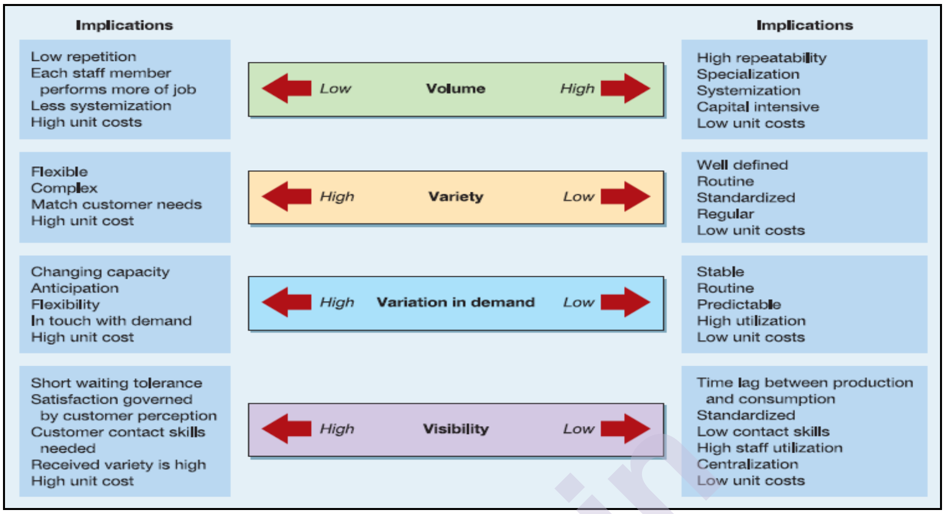
All four dimensions have implications for the cost of creating the products or services.

Put simply, high volume, low variety, low variation and low customer contact all help to keep processing costs down.

Conversely, low volume, high variety, high variation and high customer contact generally carry some kind of cost penalty for the operation.

This is why the volume dimension is drawn with its 'low' end at the left, unlike the other dimensions, to keep all the 'low cost' implications on the right.

A typology of operations



Types of production system

Job shop production

- Job shop is appropriate for manufactures of small batches of many different products, each of which is custom designed and requires its own unique set of processing steps or routing through production process.
- The production system in which different types of product follow different sequences through different shops. Ex. Furniture manufacturing company, restaurant, prototype industry.
- Much time is spent waiting for access to equipment. Some equipment overloaded.
- A process technology suitable for a variety of custom designed products in some volume.
- This production system adopts process layout as by this production system we manufacture more variety of products at low product volume.

Batch production

- A process technology suitable for variety of products in varying volumes.
- Here limited product variety which is fixed for one batch of product. Ex., Bakery shop, medicine shop.
- Within the wide range of products in the facility, several are demanded repeatedly and in large volume.

- This type of production system should be preferred when there is wide variety of products in wide variety of volumes.
- Assembly line (mass) Production
- A process technology suitable for a narrow range of standardized products in high volumes.
- The successive units of output undergo the same sequence of operation using specialized equipment usually positioned along a production line.
- The product variety is fixed here. Ex. Assembly of television sets, assembly of auto, assembly of computer keyboard, cold drinks factory etc.

Continuous production

- A process technology suitable for producing a continuous flow of products.
- The product is highly standardized.
- Material and products are produced in continuous, endless flows, rather than in batches or discrete units.
- Continuous flow technology affords high volume, around-the clock operation with capital intensive, specialized automation.

1.2 Applications in product and service industry

The operations management has many applications in the product and service industry. These applications of operations management in the product and service industry are as follows

1. Product selection
2. Product Design
3. Selection of Equipment and Processes
4. Production Design of items processed
5. Job Design
6. Facility Layout
7. Inventory control
8. Production Control
9. Maintenance Management
10. Quality Control
11. Labour Control
12. Cost Control and Improvement

Let us discuss these applications of operations management in details as follows

1. Product selection

The operations management assists to select the product or service to be created or delivered to the customers. The products or services being selected for the operations management should be having demand and standard quality at cheaper price with faster delivery.

2. Product Design

The products or services should be designed as per the market requirement. The customer service needs, competitors' analysis and market research should be carried out before launching the product to the market. The operations management assists to get insights to the product design and appropriate product designs are developed using operations process.

3. Selection of Equipment and Processes

The equipment required for the Operations Management to convert the raw material into finished products or to transform the input to customer service is selected in the operations management. The operations management provides scientific tools to select the equipment and processes by considering financial feasibility, demand feasibility and realistic approach.

4. Production Design of items processed

The items processed in the production design are properly handled in the operations management. The items are properly processed and designed as per the demand of the customers.

5. Job Design

The study of operations management is applicable for job design. The jobs of various machines and labor are managed effectively using operations management.

6. Facility Layout

The operations management provides physical arrangement of facility layout. The operations process from the input to the output including sequencing of jobs, machines, labor is done using operations management system.

7. Inventory Control

The Production planning and control requires control over the inventory. The Economic Order Quantity is to be managed. The surplus inventory lead to failure of investment in inventory and deficit inventory leads to work breakdown due to scarcity of material. Hence balanced inventory are handled using inventory control measures of operations management.

8. Production Control

The right quantity is to be served to the customers. The production control measures ensure the appropriate quantity to be served in the operations department.

9. Maintenance Management

The machinery or equipment maintenance are managed by the way of maintenance management. This technique assists to avoid high expenses and work breakdown due to machine failures. These critical factors are studied in the operations management

10. Quality Control

Quality control measures employed in the operations management assist to detect the defects in the products or services. Here the operations management tries to detect the defects and avoid the defects and wastage. The quality circles are developed to provide standard quality services to the customers. The standards are set and quality is checked and compared with that standards and better quality is delivered to the customers.

11. Labour Control

The manpower planning for the transformation of input to the customer service or utilities are properly planned and controlled by using operations management as the right quantity of services to be created are known in the process.

12. Cost Control and Improvement

In this way, costs are properly utilized and controlled and the improvement in the production and operations department is seen.

Hence there are has many applications of operations management in the product and service industry.

1.2 (a) Service Process Matrix for service organizations

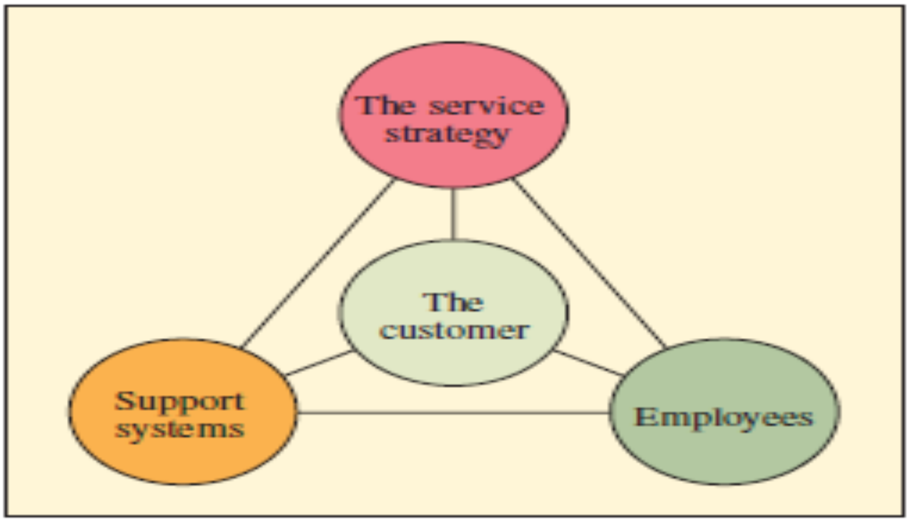
The customer is (or should be) the focal point of all decisions and actions of the service organization.

Organization exists to serve the customer, and the systems and the employees exist to facilitate the process of service

Service Environment includes:

- Nature and importance of services
- Designing service organization
- Service blue printing
- Service guarantees.

The Service Triangle



The role of operations in the triangle is a major one. Operations are responsible for service systems (procedures, equipment, and facilities) and are responsible for managing the work of the service workforce, who typically makes up the majority of employees in large service organizations.

Service package is a bundle of goods and services that is provided in some environment and consists of the following five features:

Supporting facility: The physical resources that must be in place before a service can be offered. Examples are an Internet website, a golf course, a ski lift, an airline, and an auto repair facility.

Facilitating goods: The material purchased or consumed by the buyer or the items provided to the customer. Examples are golf clubs, skis, beverages, auto parts, and services sold by the firm.

Information: Operations data or information that is provided to the customer, to enable efficient and customized services. Examples include detailed descriptions of the items offered, tee-off times, weather reports, medical records, seat preferences, and item availability.

Explicit services: The benefits that are readily observable by the senses and that consist of the essential or intrinsic features of the service. Examples are the response time of an ambulance, air conditioning in a hotel room, and a smooth-running car after a tune-up.

Implicit services: Psychological benefits that the customer may sense only vaguely, or the extrinsic features of the service. Examples are the status of a degree from an Ivy League school, the privacy of a loan office, and worry-free auto repair.

Service organizations are generally classified according to who the customer is, for example, individuals or other businesses, and to the service they provide (financial services, health services, transportation services, and so on).

Customer contact refers to the physical presence of the customer in the system, and creation of the service refers to the work process involved in providing the service itself. Extent of contact here may be roughly defined as the percentage of time the customer must be in the system relative to the total time needed to perform the customer service. Generally speaking, the greater the percentage of contact times between the service system and the customer, the greater the degree of interaction between the two during the production process.

Service systems with a high degree of customer contact are more difficult to control and more difficult to rationalize than those with a low degree of customer contact. In high-contact systems, the customer can affect the time of demand, the exact nature of the service, and the quality, or perceived quality, of service because the customer is involved in the process.

For example, a bank branch offers both simple services such as cash withdrawals that take just minute or so and complicated services such as loan application preparation that can take in excess of an hour. Moreover, these activities may range from being self-service through an ATM, to coproduction where bank personnel and the customer work as a team to develop the loan application.

Design Decision	High-Contact System (A Branch Office)	Low-Contact System (A Check Processing Center)
Facility location	Operations must be near the customer.	Operations may be placed near supply, transport, or labor.
Facility layout	The facility should accommodate the customer's physical and psychological needs and expectations.	The facility should focus on production efficiency.
Product design	The environment, as well as the physical product, define the nature of the service.	The customer is not in the service environment, so the product can be defined by fewer attributes.
Process design	Stages of production process have a direct, immediate effect on the customer.	The customer is not involved in the majority of processing steps.
Scheduling	The customer is in the production schedule and must be accommodated.	The customer is concerned mainly with completion dates.
Production planning	Orders cannot be stored, so smoothing production flow will result in loss of business.	Both backlogging and production smoothing are possible.
Worker skills	The direct workforce constitutes a major part of the service product and so must be able to interact well with the public.	The direct workforce need only have technical skills.
Quality control	Quality standards are often in the eye of the beholder and, thus, are variable.	Quality standards are generally measurable and, thus, fixed.
Time standards	Service time depends on customer needs, so time standards are inherently loose.	Work is performed on customer surrogates (such as forms), so time standards can be tight.
Wage payment	Variable output requires time-based wage systems.	"Fixable" output permits output-based wage systems.
Capacity planning	To avoid lost sales, capacity must be set to match peak demand.	

1.2 (b) Differences in Service Design and Manufacturing Product Development

Several major factors distinguish service design and development from typical manufactured product development.

First, the process and the product must be developed simultaneously; indeed, in services, the process is the product.

Second, although equipment and software that support a service can be protected by patents and copyrights, a service operation itself lacks the legal protection commonly available to goods production.

Third, the service package, rather than a definable good, constitutes the major output of the development process.

Fourth, many parts of the service package are often defined by the training individuals receive before they become part of the service organization. In particular, in professional service organizations (PSOs) such as law firms and hospitals, prior certification is necessary for hiring.

Fifth, many service organizations can change their service offerings virtually overnight. Routine service organizations (RSOs) such as barbershops, retail stores, and restaurants have this flexibility.

Difference between manufacture and service

Manufacturing Organization	Service Organization
→Physical, durable product →Output can be inventoried →Low customer contact →Long response time →Regional, national or international markets →large facilities →Capital Intensive →Quality easily Measured	→Intangible, perishable product →Output that cannot be inventoried →Short response time →Local markets →Small facilities →Labor intensive →Quality not easily measured

1.2 (c) Product vs. Services

Product	Services
1-tangible, durable products. 2- Output can be inventoried. 3-consumption/use takes more time. 4-low costumer's involvement. 5-long response time. 6-available at regional, national and international market. 7-Reqire large facilities. 8-Capital intensive. 9-Quality easily measured. 10-Demand variable on weekly, monthly, seasonally.	1- Intangible, perishable products. 2- Output can't be inventoried. 3-Immidiate consumption. 4- High costumer's involvement. 5- Short response time. 6-local market. 7- Require small facilities. 8-Labour intensive. 9- Quality not easily measured. 10- Demand variable on hourly, daily, weekly basis.

Manufacturing organization generally transfer tangible inputs or raw materials into some tangible output (ex: steel, refrigerator, toothpaste, soap etc.) Other inputs such as labour skills, management skills, capitals are used as well. Manufacturing organizations perform some chemical /physical processes (such as blending refining, welding, grinding.etc) to transfer their raw material into tangible products. Service providing organization though transform a set of input into set of output, they don't produce a tangible output.(ex: mail service, library service, restaurant etc.).or provide service(ex: health care, hair care, watch and automobile repair etc.). The service of service providing organization is intangible.

A 2nd distinction is based on inventories .durable goods can be kept for longer time these goods can be stored for longer time and can be transported in anticipation in future demand .Thus with durable goods ,operation manager can co up with the peaks and valleys in demand by creating inventories and smoothing out output levels. Whereas service can't be pre produced. For example: getting fast food from a fast food center, getting treatment from hospital etc.

A 3rd distinction is based on consumption/use of output. The products (goods) generally take longer period for its use, for ex refrigerator, T.V. automobile etc. can be used at least for 10 years. On the other hand, the output produced from a service operation (i.e. service) is consumed within a small time. E.g., consumption of fast food, taking hair care, enjoying journey by a bus/train/aero plane and enjoying entertainment program.

A 4th distinction is based on customer contact. Most of the consumers/customers have little or no contact with production system/organization, whereas, in many service providing organization consumers/customers are directly involved, for example: students in an educational institution, patients in hospital.

The 5th distinction is based on lead time/response time to customers demand. Manufacturers take generally some lead time (i.e. time period from placing the order to get the product) in terms of days/week, whereas the services are offered within few minutes of customers arrival. For ex: ATM Service, getting postal stamps, getting grocery from a retail shop and getting examined by a doctor etc.

The 6th distinction is on availability. Products can be available from regional, national or international markets due to availability of transportations and distribution facilities whereas, service can't ship to distant locations. Thus service organization requiring direct customer contact must locate very near to the customers.

The 7th distinction is based on liabilities/facilities. Manufacturing unit/organization producing products generally require larger facilities, more automation and greater capital investment than service providing organization.

The 8th distinction is based on capital/labour priority. Generally manufacturing firm producing goods/products require more capital than a service provider, for e.g., an automobile firm requires more capital than a post office/Nursing home. The 9th and 10th distinction is based on quality and demand variation.

1.3 Use of competitive advantage

The operations management is used for competitive advantage in the service industry as operations management is used for creating and delivering valuable customer service or utilities.

Many people observe that the production and operations management are the routine activity and hence there is no extra efforts required but when there is obstacle, the total system collapse and it becomes expensive to recover the damages. Hence it is essential to carefully look after the activities or functions of production and operations management.

The operations management gives the competitive advantage to the organization in true sense as follows:

1. Specified product delivery
2. Faster delivery
3. Cheaper price
4. Better Quality
5. Customer loyalty
6. Right Volume
7. Timely delivery
8. Creation of Goodwill
9. Branding
10. Increased responsiveness
11. Increased output
12. Customer Database

These uses of operations management for competitive advantage are explained in details as

1. Specified product delivery

The operations management transforms the input material into the required services of customers as utilities. The right things are created and delivered to the customers. The product specifications are noted and accordingly products or services are designed, created or developed and the product and services are delivered to the customer. Hence as per the customers' demand, the products are specially designed and delivered to the customer. This is one of the essential usages of operations management in the competitive era leading to the competitive advantage for the organization.

2. Faster delivery

The operations management converts raw ingredients into the customer service. The scheduled dispatch and timely delivery of products or services are possible due to the proper implementation of operations management. The services are rendered to the customers as and when ordered by the customer. The faster delivery of services are properly planned and executed by the way of production planning and control measures in the operations management. The services are created and delivered faster as per the requirement of the customers.

3. Cheaper price

As the operations management executes the operations process designing and serving the services. Due to global competitive environment, new technology, augmented production and high volume production lead to the reduction in the variable cost of production leading to reduce the total cost of production. This results into the cheaper prices for the customer service.

4. Better Quality

Quality control measures employed in the operations management assist to detect the defects in the products or services. Here the operations management tries to detect the defects and avoid the defects and wastage. The quality circles are developed to provide standard quality services to the customers. The standards are set and quality is checked and compared with that standards and better quality is delivered to the customers.

5. Customer loyalty

The operations management provides the right things at right time at right price to the customer. This develops the brand image in the mindset of customers leading to the brand loyalty to the customer. The customers become loyal to the service provider and customers are automatically retained by the organization.

6. Better Volume

As the customer become loyal to the service provider, they repeatedly purchase the product or service from the same service provider. The demand for the product or service will increase. Then the operations management produces the higher quantity of products or services leading to the better volume of the product or services.

7. Right Quantity

The operations management converts the input into the customer service as output. The customer services are created and delivered as per the specification of the services, the ordered number and at ordered schedule. The huge quantities are demanded by the customer and the same right quantities are delivered by the service provider by the operations process. If more quantities are produced than the demand, the service become perishable and will not be sold and hence right quantity of services as per the customers’ demand are created and delivered by the process of operations management.

8. Timely delivery

The operations management provides the right things at right time at right price to the customer. The delivery of services is as per the schedule given by the customer. The scheduling and routing process are managed to provide the timely delivery of services. The execution of timely delivery of services leads to more sales for the organization.

9. Creation of Goodwill

The operations management converts the input into the customer service as output. The customer services are created and delivered as per the specification of the services, the ordered number and at ordered schedule. It creates goodwill of the company in the market. This goodwill helps the organization to capture the market shares. The Goodwill generated the long term customers and wealth for the organization.

10. Branding

The operations management executes the operations process designing and serving the services. The operations management provides the right things at right time at right price to the customer. The delivery of services is as per the schedule given by the customer. This leads to the creation of brand image of the services and ultimately the organizational name and fame will be on higher side.

11. Increased responsiveness

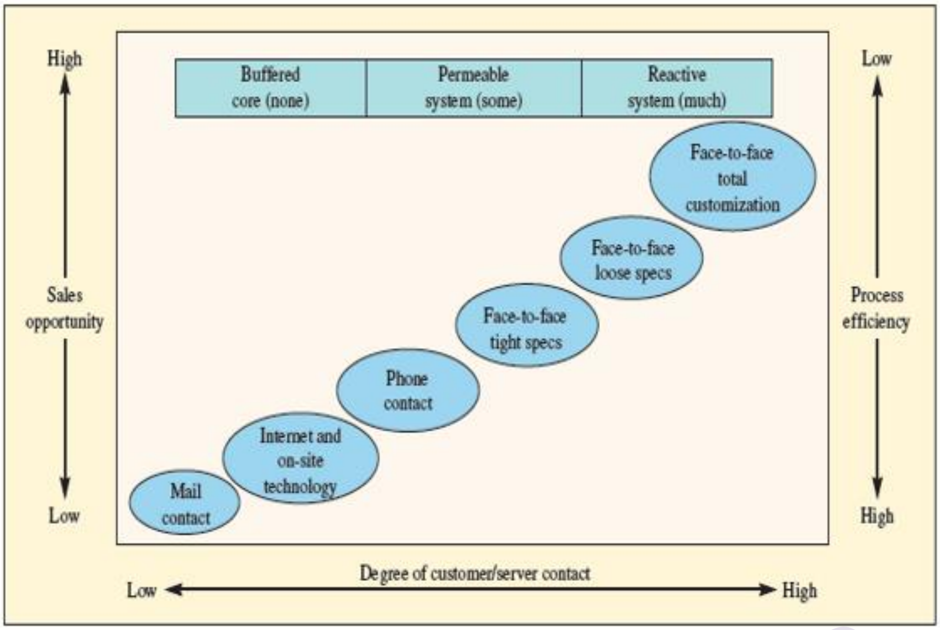
The operations management provides the right things at right time at right price to the customer. The response and feedback of the customers towards the services can be increased when operation management is done properly and implemented effectively in the organization.

12. Increased output

The output of operations management as customer service or utilities can be increased if the services are created and delivered at right time at right price to the customer.

1.3 (a) Structuring the Service Encounter: The Service-System Design Matrix

Service encounters can be configured in a number of different ways. The service-system design matrix identifies six common alternatives. The top of the matrix shows the degree of customer/server contact: ***the buffered core***, which is physically separated from the customer; the ***permeable system***, which is penetrable by the customer via phone or face-to-face contact; and the reactive system, which is both penetrable and reactive to the customer's requirements.



The left side of the matrix shows what we believe to be a logical marketing proposition—namely, that the greater the amount of contact, the greater the sales opportunity; the right side shows the impact on production efficiency as the customer exerts more influence on the operation.

The entries within the matrix list the ways in which service can be delivered. At one extreme, service contact is by mail; customers have little interaction with the system. At the other extreme, customers "have it their way" through face-to-face contact. The remaining four entries in the matrix contain varying degrees of interaction.

As one would guess, process efficiency decreases as the customer has more contact (and therefore more influence) on the system. To offset this, the face-to-face contact provides a high sales opportunity to sell additional products. Conversely, low contact, such as mail, allows the system to work more efficiently because the customer is unable to significantly affect (or disrupt) the system. However, there is relatively little opportunity for additional product sales.

Characteristics of Workers, Operations, and Innovations Relative to the Degree of Customer/Service Contact

Degree of customer/server contact: Low ⟷ High

Worker requirements	Clerical skills	Helping skills	Verbal skills	Procedural skills	Trade skills	Diagnostic skills
Focus of operations	Paper handling	Demand management	Scripting calls	Flow control	Capacity management	Client mix
Technological innovations	Office automation	Routing methods	Computer databases	Electronic aids	Self-serve	Client/worker teams

1.3 (b) Strategic Use of the Matrix

The matrix has both operational and strategic uses. The strategic uses include:

- Enabling systematic integration of operations and marketing strategy. Trade-offs become more clear-cut, and, more important, at least some of the major design variables are crystallized for analysis purposes. For example, the matrix indicates that it would make little sense relative to sales for a service firm to invest in high-skilled workers if it plans to operate using tight specs.

- Clarifying exactly which combination of service delivery the firm is in fact providing. As the company incorporates the delivery options listed on the diagonal, it is becoming diversified in its production process.

- Permitting comparison with how other firms deliver specific services. This helps to pinpoint a firm's competitive advantage.

- Indicating evolutionary or life cycle changes that might be in order as the firm grows. Unlike the product–process matrix for manufacturing, however, where natural growth moves in one direction (from work center to assembly line as volume increases), evolution of service delivery can move in either direction along the diagonal as a function of a sales–efficiency trade-off.

1.3 (c) Virtual Service: The New Role of the Customer

With the advent of virtual services through the Internet, we need to account not just for a customer's interactions with a business, but for his or her interaction with other Service customers as well.

We have two categories of contact:

- *pure virtual customer contact* where companies such as eBay and Second Life enable customers to interact with one another in an open environment; and

- *mixed virtual and actual customer contact* where customers interact with one another in a server moderated environment such as product discussion groups, YouTube, and Wikipedia. In these environments, the operations management challenge is to keep the technology functioning and up to date and to provide a policing function through monitoring the encounters that take place.

Managing Customer-Introduced Variability

Variability is the major problem with services that require direct customer contact. Innovative approaches are needed to manage this variability.

The standard approach is to treat this decision as a trade-off between cost and quality. The five basic types of variability, along with examples, are:

arrival variability—the arrival time of customers at a restaurant may be inconsistent with average demand, leading to times when servers are overloaded or underutilized (this is the type of variability that is dealt with in the waiting line analysis;

request variability—travelers requesting a room with a view at a crowded hotel;

capability variability—a patient being unable to explain his or her symptoms to a doctor;

effort variability—shoppers not bothering to put their shopping carts in a designated area in a supermarket parking lot; and

subjective preference variability—one bank customer interpreting a teller addressing him by his first name as a sign of warmth, while another customer feels that such informality is un-businesslike.

The four basic accommodation strategies for customer variability accommodation are:

- ***classic accommodation,*** which entails, for example, extra employees or additional employee skills to compensate for variations among customers;
- ***low-cost accommodation,*** which uses low-cost labor, outsourcing, and self-service to cut the cost of accommodation;
- ***classic reduction,*** which requires, for example, customers to engage in more self-service, use reservation systems, or adjust their expectations; and
- ***uncompromised reduction,*** which uses knowledge of the customer to develop procedures that enable good service, while minimizing the variation impact on the service delivery system

Effective management of variability generally requires a company to influence customer behavior.

1.3 (d) Applying Behavioral Science to Service Encounters

The customer's perception related to a poor encounter may be changed if the problem is addressed quickly.

1. **The front end and the back end of the encounter are not created equal.**

   It is widely believed that the start and finish of a service, or the so-called service bookends, are equally weighted in the eyes of the customer.

   While it is essential to achieve a base level of satisfactory performance at the beginning so that the customer remains throughout the service, a company is likely to be better off with a relatively weak start and a modest upswing on the end than having a great start and a so-so ending.

	Classic Accommodation	Low-Cost Accommodation	Classic Reduction	Uncompromised Reduction
Arrival rate variability	• Make sure plenty of employees are on hand	• Hire lower-cost labor • Automate tasks • Outsource customer contact • Create self-service options	• Require reservations • Provide off-peak pricing • Limit service availability	• Create complementary demand to smooth arrivals without requiring customers to change their behavior
Variability in the services requested by the customers	• Make sure many employees with specialized skills are on hand • Train employees to handle many kinds of requests	• Hire lower-cost specialized labor • Automate tasks • Create self-service options	• Require customers to make reservations for specific types of service • Persuade customers to compromise their requests • Limit service breadth	• Limit service breadth • Target customers on the basis of their requests
Variability in customer capability	• Make sure employees are on hand who can adapt to customers' varied skill levels • Do work for customers	• Hire lower-cost labor • Create self-service options that require no special skills	• Require customers to increase their level of capability before they use the service	• Target customers on the basis of their capability
Variability in the effort customers are willing to expend	• Make sure employees are on hand who can compensate for customers' lack of effort • Do work for customers	• Hire lower-cost labor • Create self-service options with extensive automation	• Use rewards and penalties to get customers to increase their effort	• Target customers on the basis of motivation • Use a normative approach to get customers to increase their effort
Variability in customer preferences and expectations	• Make sure employees are on hand who can diagnose differences in expectations and adapt accordingly	• Create self-service options that permit customization	• Persuade customers to adjust their expectations to match the value proposition	• Target customers on the basis of their subjective preferences

2. **Segment the pleasure; combine the pain.**

   Events seem longer when they are segmented. This suggests that we want to break pleasant experiences into multiple stages and combine unpleasant ones into a single stage.

3. **Let the customer control the process.**

   Giving people control over how a process is to be conducted enhances their satisfaction with it. In the medical area, allowing people to choose which arm a blood sample is drawn from reduces the perceived pain of the procedure. For certain repair jobs, allowing people to select a future date they want it to be scheduled may be preferred to doing it right away.

4. **Pay attention to norms and rituals.**

   Deviations from norms are likely to be overly blamed for failures. This is particularly true for professional services whose processes and outcomes are not clearly ascertainable by the client, and hence adherence to norms is the central basis for evaluation. Consulting firms are expected to make presentations to the boss, even if he or she has little or nothing to do with the problem being studied. At such presentations, all members of the client team are to be lauded for their assistance even if they were less than helpful in accomplishing the work.

5. **People are easier to blame than systems.**

   When things go wrong, people's gut reaction is to blame the server rather than the system. We want to put a human face on the problem.

6. **Let the punishment fit the crime in service recovery.**

   How do you make up for an encounter error? Research suggests that the most appropriate recovery action depends upon whether it is a task (outcome) error or a treatment (interpersonal process) error.

   For example, having a copying job done poorly at a copy store, of course, calls for a quick apology, but more importantly, it calls for quick rework and perhaps some compensation for the customer's inconvenience. On the other hand, if the copying job is done correctly but the clerk is rude, a sincere apology from the store manager and the clerk is far more likely to result in a satisfied customer than giving the customer a free coupon or some other minor tangible form of compensation.

1.4 Let us sum up

We have discussed the process, process flowcharts, types of processes, variety matrix for production, Service Process Matrix for service organizations, its strategic use and the applications of behaviour science in service encounter situations.

1.5 Exercises

1. Some suggest that customer expectation is the key to service success. Give an example from your own experience to support or refute this assertion.

2. Suppose you were the manager of a restaurant and you were told honestly that a couple eating dinner had just seen a mouse. What would you say to them? How would you recover from this service crisis?

3. Identify the high-contact and low-contact operations of the following services:

   a. A dental office

   b. An airline

   c. An accounting office

   d. An automobile agency

1.6 Suggested Reading

- Operations & Supply Chain Management by Chase, Shankar, Jocaobs
- Operations Management (6th Edition) by Nigel Slack, Stuart Chambers, Robert Johnston
- Theory & Problems in Production & Operations Management- S N Chary, Tata McGraw Hill
- Production & Operations Management -Kanishka Bedi , Oxford University Press
- Operations Management for competitive advantage-Chase & Jacob, McGraw-Hill/Irwin
- Production and Operations Management- Chunawalla & Patel, Himalaya Publishing

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2

PROCESS ANALYSIS IN INDUSTRY

Process Design: Volume – Variety Matrix for production, Service Process Matrix for service organizations.

Process Choice and Layout Decisions in Manufacturing and Services: Manufacturing Processes; Product Customization within the Supply Chain; Service Processes; Layout Decision Models.

Business Processes: Mapping Business Processes; Managing and Improving Business Processes; Business Process Challenges and the SCOR Model

Unit Structure

2.0 OBJECTIVES

After going through this unit, you will be able to understand

- Types of Manufacturing Processes
- Product Customization within the Supply Chain
- Service Processes
- Layout Decision Models

2.1 INTRODUCTION

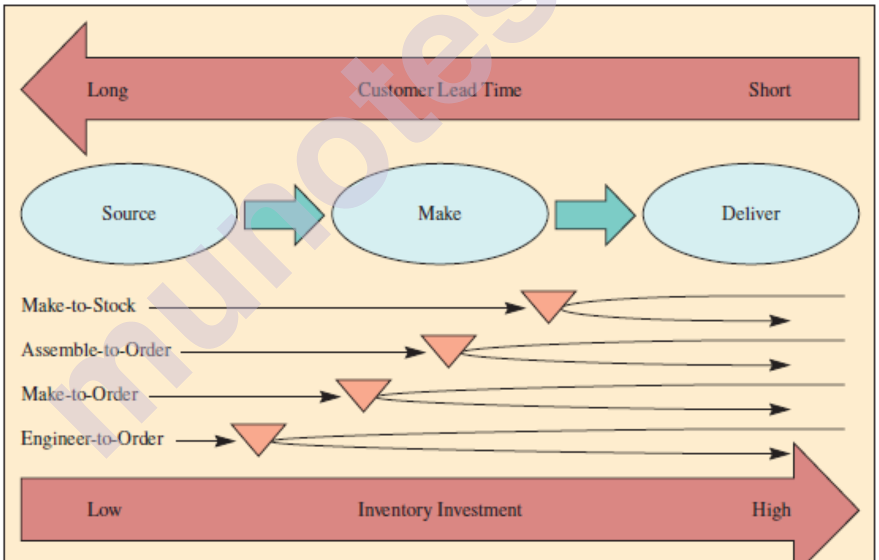
Processes are used to make tangible goods or deliver services. Manufacturing processes are used to make everything that we buy ranging from the apartment building in which we live to the ink pens with which we write. The high-level view of what is required to make something can be divided into three simple steps.

The first step is sourcing the parts we need, followed by actually making the item, and then sending the item to the customer. A supply chain view of this may involve a complex series of players where subcontractors feed suppliers, suppliers feed manufacturing plants, manufacturing plants feed warehouses, and finally warehouses feed retailers. Depending on the item being produced, the supply chain can be very long with subcontractors and manufacturing plants spread out over the globe (such as an automobile or computer manufacturer) or short where parts are sourced and the product is made locally (such as a house builder).

Depending on the strategy of the firm, the capabilities of manufacturing, and the needs of customers, these activities are organized to minimize cost while meeting the competitive priorities necessary to attract customer orders.

For example, in the case of consumer products such as televisions or clothes, customers normally want these products "on-demand" for quick delivery from a local department store.

Figure below illustrates the Source step where parts are procured from one or more suppliers, the Make step where manufacturing takes place, and the Deliver step where the product is shipped to the customer.



The inverted triangles represent customer order decoupling points.

As a manufacturer of these products, we build them ahead of time in anticipation of demand and ship them to the retail stores where they are carried in inventory until they are sold. At the other end of the spectrum are custom products, such as military airplanes, that are ordered with very specific uses in mind and that need to be designed and then built to the design. In the case of an airplane, the time needed to respond to a customer order, called the **lead time**, could easily be years compared to only a few minutes for the television.

A key concept in manufacturing processes is the **customer order decoupling point** which determines where inventory is positioned to allow processes or entities in the supply chain to operate independently. For example, if a product is stocked at a retailer, the customer pulls the item from the shelf and the manufacturer never sees a customer order. Inventory acts as a buffer to separate the customer from the manufacturing process. Selection of decoupling points is a strategic decision that determines customer lead times and can greatly impact inventory investment. The closer this point is to the customer, the quicker the customer can be served. Typically, there is a trade-off where quicker response to customer demand comes at the expense of greater inventory investment because finished goods inventory is more expensive than raw material inventory. An item in finished goods inventory typically contains all the raw materials needed to produce the item. So, from a cost view it includes the cost of the material, plus the cost to fabricate the finished item.

2.2 MANUFACTURING PROCESSES

Positioning of the customer order decoupling point is important to understanding manufacturing environments. Firms that serve customers from finished goods inventory are known as **make-to-stock firms**. Those that combine a number of preassembled modules to meet a customer's specifications are called **assemble-to-order firms**. Those that make the customer's product from raw materials, parts, and components are **make-to-order firms**. An **engineer-to-order firm** will work with the customer to design the product, and then make it from purchased materials, parts, and components.

The essential issue in satisfying customers in **the make-to-stock environment** is to balance the level of finished inventory against the level of service to the customer. Examples of products produced by these firms include televisions, clothing, and packaged food products. If unlimited inventory were possible and free, the task would be trivial. Unfortunately, that is not the case. Providing more inventory increases costs, so a trade-off between the costs of the inventory and the level of customer service must be made. The trade-off can be improved by better estimates (or knowledge) of customer demand, by more rapid transportation alternatives, by speedier production, and by more flexible manufacturing. Many make-to-stock firms invest in lean manufacturing programs in order to achieve higher service levels for a given inventory investment. Regardless of the trade-offs involved, the focus in the make-to-stock environment is on providing finished goods where and when the customers want them.

In the **assemble-to-order environment**, a primary task is to define a customer's order in terms of alternative components and options since it is these components that are carried in inventory. A good example is the way Dell Computer makes desktop computers. The number of combinations that can be made may be nearly infinite (although some might not be feasible). One of the capabilities required for success in the assemble-to-order environment is an engineering design that enables as much flexibility as possible in combining components, options, and modules into finished products. Similar to make-to-stock, many assemble-to-order companies have applied lean manufacturing principles to dramatically decrease the time required to assemble finished goods. By doing so, they are delivering customers' orders so quickly that they appear to be make-to-stock firms from the perspective of the customer.

In the **make-to-order and engineer-to-order environments**, the customer order decoupling point could be in either raw materials at the manufacturing site or possibly even with the supplier inventory. Boeing's process for making commercial aircraft is an example of make-to-order.

The need for engineering resources in the engineer-to-order case is somewhat different than make-to-order because engineering determines what materials will be required and what steps will be required in manufacturing. Depending on how similar the products are, it might not even be possible to pre-order parts. Rather than inventory, the emphasis in these environments may be more toward managing capacity of critical resources such as engineering and construction crews.

Organization of Manufacturing Processes

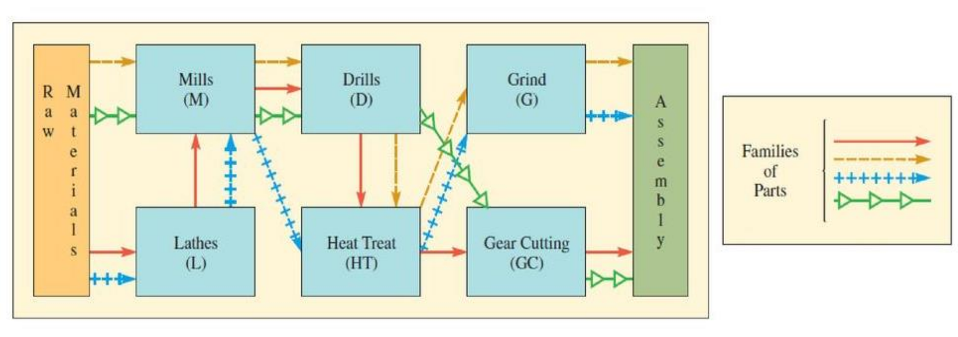
Process selection refers to the strategic decision of selecting which kind of production processes to use to produce a product or provide a service.

For example, in the case of Toshiba notebook computers, if the volume is very low, we may just have a worker manually assemble each computer by hand. In contrast, if the volume is higher, setting up an assembly line is appropriate. The format by which a facility is arranged is defined by the general pattern of workflow; there are five basic structures (project, work center, manufacturing cell, assembly line, and continuous process).

In a **project layout**, the product (by virtue of its bulk or weight) remains in a fixed location. Manufacturing equipment is moved to the product rather than vice versa. Construction sites (houses and bridges) and movie shooting lots are examples of this format. Areas on the site will be designated for various purposes, such as material staging, subassembly construction, site access for heavy equipment, and a management area.

(Building construction project)

A **workcenter** layout, sometimes referred to as a job shop, is where similar equipment or functions are grouped together, such as all drilling machines in one area and all stamping machines in another. A part is worked on travels according to the established sequence of operations, from workcenter to workcenter, where the proper machines are located for each operation.



(Workcenter layout)

A **manufacturing cell** layout is a dedicated area where products that are similar in processing requirements are produced. These cells are designed to perform a specific set of processes, and the cells are dedicated to a limited range of products.

A firm may have many different cells in a production area, each set up to produce a single product or a similar group of products efficiently, but typically at lower volume levels. These cells typically are scheduled to produce "as needed" in response to current customer demand.

MANUFACTURING CELL
Source: Official US Navy photo

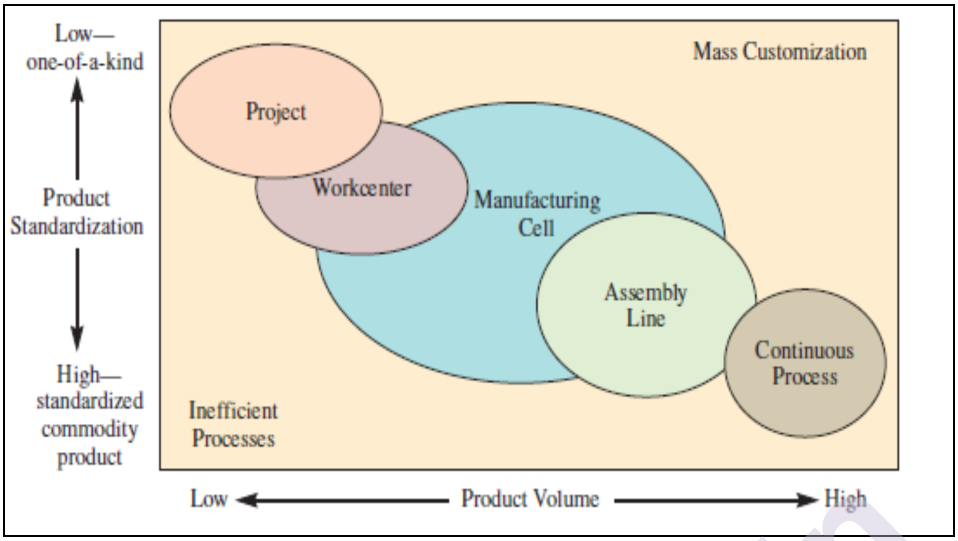
An **assembly line** is where work processes are arranged according to the progressive steps by which the product is made. These steps are defined so that a specific production rate can be achieved. The path for each part is, in effect, a straight line. Discrete products are made by moving from workstation to workstation at a controlled rate, following the sequence needed to build the product. Examples include the assembly of toys, appliances, and automobiles. These are typically used in high-volume items where the specialized process can be justified.

ASSEMBLY LINE
© Jeff Kowalsky/Bloomberg/Getty Images

A **continuous process** is similar to an assembly line in that production follows a predetermined sequence of steps, but the flow is continuous (such as with liquids) rather than discrete. Such structures are usually highly automated and, in effect, constitute one integrated "machine" that may operate 24 hours a day to avoid expensive shutdowns and startups. Conversion and processing of undifferentiated materials such as petroleum, chemicals, and drugs are good examples.

AN EXAMPLE OF A CONTINUOUS PROCESS
© Andrew Holt/Photographer's Choice/Getty Images

The relationship between layout structures is often depicted on a **product–process matrix** similar to the one shown in the figure. Two dimensions are shown. The horizontal dimension relates to the volume of a particular product or group of standardized products. Standardization is shown on the vertical axis and refers to variations in the product that is produced. These variations are measured in terms of geometric differences, material differences, and so on. Standardized products are highly similar from a manufacturing processing point of view, whereas low standardized products require different processes.



Product–process matrix is a framework depicting when the different production process types are typically used, depending on product volume and how standardized the product is. In general, it is desirable to design the processes approximately on a diagonal. For example, if we produce nonstandard products at relatively low volumes, workcenters should be used. A highly standardized product (commodity) produced at high volumes should be produced using an assembly line or a continuous process, if possible. As a result of the advanced manufacturing technology available today, we see that some of the layout structures span relatively large areas of the product–process matrix. For example, manufacturing cells can be used for a very wide range of applications, and this has become a popular layout structure that often is employed by manufacturing engineers.

2.3 PRODUCT CUSTOMIZATION WITHIN THE SUPPLY CHAIN

In a global business environment that is becoming more and more complex, a high number of existing supply chains do not contribute enough to the required performance of an organization. In many cases, they are designed to serve stable demand with high reliability. Other examples show extremely customized network structures tailored to very specific customer requirements, virtually regardless of cost considerations. In many cases, this is caused by a lack of alignment with other business functions such as Sales, Finance or Marketing.

However, increasing customer needs and changing market conditions are challenging factors that cannot be addressed with a one-size-fits-all strategy. Many global companies are facing considerable changes in their supply chain, i.e. changing transport prices, currency fluctuations, rising labor costs, local shifts in customer demands and competitive pressure on both price and technology. So the question is: how does one handle such diverse customer expectations in an efficient manner, considering existing trade-offs and conflicting targets?

A word commonly heard in discussions of manufacturing is customization. But what does this term mean? True customization requires customer-specific input at some point in the supply chain. For instance, manufacturers of specialized industrial equipment often start with an individual customer's specifications, which drive subsequent design, purchasing, and manufacturing efforts. And hardware stores mix ready-made paints to match a customer's particular color sample. In both cases, the product is customized. However, the degree and point of customization differ radically between the two.

Supply Chain Customization allows organizations to configure their supply chain networks according to relevant clusters so that client demands can be addressed in both an efficient and effective manner.

Four Levels of Customization

Manufacturers typically talk about four levels of product customization. From least to greatest customization, these are:

- Make-to-stock (MTS) products
- Assemble-to-order (ATO) or finish-to-order products
- Make-to-order (MTO) products
- Engineer-to-order (ETO) products.

Make-to-stock (MTS) products involve no customization. They are typically generic products and are produced in large enough volumes to justify keeping a finished goods inventory. Customers typically buy these products "off the shelf." Examples include basic tools (e.g., hammers, screwdrivers), consumer products sold in retail stores, and many raw materials.

Assemble-to-order (ATO) or finish-to-order products are products that are customized only at the very end of the manufacturing process. Even then, the customization is typically limited in nature. A T-shirt with a customer's name airbrushed on it is a simple example. The T-shirt itself is generic until the very last step. Many automobiles are also ATO products because the final set of options—deluxe or standard interior, navigation systems, and so on—is not determined until the very last stage, based on the dealer's or customer's order.

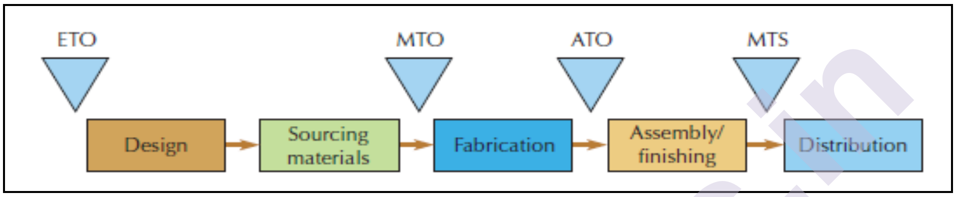
Like ATO products**, make-to-order (MTO)** products use standard components, but the final configuration of those components is customer specific. To illustrate, Balley Engineered Structures builds an endless variety of customized walk-in industrial coolers or refrigerators from a standard set of panels. MTO products push the customization further back into the manufacturing process than ATO products do.

The most highly customized products are **engineer-to-order (ETO)** products. These products are designed and produced from the start to meet unusual customer needs or requirements. While these products might include standard components, at least some of these components are specifically designed with the help of the customer. One can imagine, for example, that some major components that go into the rockets made by SpaceX would fit into this category.

The Customization Point

To manufacturing personnel, the key difference between these four product types is not so much the degree of customization but the point at which it occurs. That is, when and where do a customer's specific requirements affect operations and supply chain activities?

Where does customization occur in supply chain?



For ETO products, the customer's needs become apparent at the design stage (at the far left in the above figure). The exact content and timing of all subsequent activities, from design through distribution, are determined only after the customer's order arrives. Not surprisingly, ETO products are often found in job shop environments.

In contrast, MTS products (at the far right in the above figure) move along from the design stage to finished goods inventory, the warehouse, or even the retail outlet, without direct input from the final customer. The timing and volume of production activities for MTS products are more likely to be driven by internal efficiency or capacity utilization goals. As a result, production lines or even high-volume batch processes are usually the best choice for MTS products.

Drawing attention to the point at which customization occurs allows us to make crucial distinctions between manufacturing activities that occur on either side of the customization point. We refer to activities that take place prior to the customization point as upstream activities, while those that occur at or after the customization point are called downstream activities.

By definition, upstream activities are not affected by the particular nuances of an individual customer order. Thus, they can be completed offline, or prior to the arrival of a customer order.

Completing activities offline has two advantages. First, it reduces the lead time to the customer, as only the downstream activities remain to be completed. This can be particularly important in competitive situations where delivery speed is critical.

At Dell Computer, all value chain activities in the manufacturing system except final assembly and shipping, which are downstream activities, take place before the customer order arrives. Upstream activities include the ordering, manufacturing, shipping, and stocking of standardized components. The result is two- to three day lead times for the customer.

A second advantage has to do with the law of variability. The greater the random variability either demanded of the process or inherent in the process itself or in the items processed, the less productive the process is. Completing upstream activities offline helps isolate these activities from the variability caused by either the timing or the unique requirements of individual customers.

But in ETO, MTO, and ATO environments, some activities must be completed online, once the customer's needs are known. This tends to increase lead times to the customer.

2.4 SERVICE PROCESSES

Business textbooks have traditionally differentiated between manufacturing and service operations. The reason for this distinction was that manufacturers produce tangible, physical products, while service operations provide intangible value.

Unfortunately, this distinction has led some readers to assume that service operations are somehow "softer," or more difficult to pin down, than manufacturing operations.

In reality, service operations are more diverse than manufacturing operations. Some service operations even have more in common with manufacturing than they do with other services.

Consider package sorting at a UPS center. Packages are sorted using highly specialized sorting and reading equipment. This activity occurs "behind the scenes," out of the customer's view. Furthermore, the equipment is arranged sequentially, following a product-based layout.

One can readily see that package sorting has more in common with batch manufacturing than it does with other services, such as consulting or teaching. On the other hand, services frequently have to deal directly with customers, who introduce considerable variability into the service process (see the following Supply Chain Connections feature).

Customer-Introduced Variability in Services

What if manufacturers had to deal with customers on the plant floor, just like service businesses do? For example, manufacturers typically carefully control the timing, quantity, and quality of raw material coming into their plants. They then schedule and carry out production, almost always out of the sight of the customer.

But what is done about services? In many cases, the "raw materials"–that is, the customers–arrive at inconvenient times and often with idiosyncratic needs. Furthermore, service customers often participate directly in the transformation process, creating a host of unique challenges.

There are five distinct forms of customer-introduced variability:

1. **Arrival variability.** Customers arrive when they desire service. In some cases, this can be controlled (e.g., a hotel reservation system). In other cases, it cannot (e.g., emergency medical services).

2. **Request variability.** Customers demand and expect different services outcomes, even from the same service provider. One customer might want a restaurant to make a menu substitution, while another might want the restaurant to serve her after closing time.

3. **Capability variability.** Some customers are capable of performing many service tasks themselves, while others require substantial hand-holding.

4. **Effort variability.** Even if they are capable of performing certain tasks, customers can differ from one another with regard to the amount of effort they are willing to apply to these tasks. For example, some customers at a grocery checkout will bag their own groceries; others will wait for the cashier or someone else to do it.

5. **Subjective preference.** Different customers can perceive the same service outcome differently. What one customer might interpret as a "quick and efficient" answer to a question might strike another customer as a "cold, unsympathetic" response.

Service organizations can use different strategies to manage these different forms of variability. For example, services can use targeted marketing to attract customers with very similar needs and capabilities, thereby reducing request and capability variability. In addition, services can use well-designed automation systems and low-cost labor to take over some of the "hand-holding" that might otherwise be done by more expensive skilled labor.

Consider three dimensions on which services can differ: the nature of the service package, the degree of customization, and the level of customer contact. These dimensions have a great deal to do with how different services are organized and managed.

Service Packages

A service package includes all the value-added physical and intangible activities that a service organization provides to the customer. For some service operations, the primary sources of value are physical activities, such as the storage, display, or transportation of goods or people. Airlines move passengers from one city to another; hotels provide travelers with rooms and meeting facilities; retailers add value by providing customers with convenient access to a wide range of products at a fair price. Many of the same rules and techniques that are used to manage physical goods in a manufacturing setting apply equally well to these services, even though airlines, hotels, and retail stores do not actually "make" products.

For other services, the service package consists primarily of intangible activities. A lawyer or an editor, for example, creates value primarily through the knowledge he or she provides. The fact that this knowledge might be captured on paper or electronically is secondary. Most service packages include a mix of physical and intangible value-adding activities.

Table lists some of the activities in the service packages offered by a university and by a logistics services provider.

SERVICE	INTANGIBLE ACTIVITIES	PHYSICAL ACTIVITIES
University	Teaching Conducting research Performing service and outreach	Supporting the "physical plant" Providing transportation services Providing dining services
Logistics services provider	Finding the best transportation solution for the customer Handling government customs issues	Moving goods Storing goods

While the primary source of value that logistics companies provide might be the movement and storage of goods, such companies also routinely determine the best transportation options for customers and handle customs paperwork. Airlines are another example of a mix of physical and intangible services. In addition to providing physical transportation, airlines help travelers plan their itineraries and track their frequent flier miles.

The greater the emphasis on physical activities, the more the management's attention will be directed to capital expenditures (buildings, planes, and trucks), material costs, and other tangible assets. Retailers, for instance, frequently spend more than 60 cents of every sales dollar on products. These products must be moved, stored, displayed, and in some cases returned. Hotel and airline executives also spend a great deal of time managing expensive tangible assets.

The greater the emphases on intangible activities, the more critical are the training and retention of skilled employees and the development and maintenance of the firm's knowledge assets. Labor cost tends to be quite a high percentage of total cost in such environments. In some intellectually intensive services, such as consulting, labor costs may far outstrip expenditures on buildings and other physical assets.

Knowledge assets generally refer to the intellectual capital of the firm, which may be embedded in the people, the information systems, or the copyrights and patents owned by a firm.

For example, Oracle spends an enormous amount of time developing, refining, and protecting its software offerings. Oracle's market intelligence about competitors' products and customer needs can also be viewed as a key knowledge asset.

Service Customization

Customization has an enormous impact on how services are designed and managed. As the degree of customization decreases, the service package becomes more standardized. To deliver a standardized service, managers can hire workers with more narrow skills and employ special purpose technology. Within the same business sector, for instance, one law firm might specialize in divorce or traffic cases, while another might offer a full range of legal services, depending on the customer's needs. Law firms that specialize in divorces can use special software packages designed to help clients reach a quick and equitable settlement.

Controlling the degree of customization also allows better measurement and closer control over the service process. In some cases, managers might draw up a precise, step-by-step process map of the service and establish standard times for performing each step. Many fast-food restaurants follow such an approach.

Not surprisingly, businesses that offer less-customized services have more opportunity to focus on cost and productivity. A classic example is an automotive shop dedicated only to oil changes. Employees in this type of business do not need to be master mechanics or skilled electricians, nor do they need a broad range of expensive equipment and tools. Furthermore, customers can be handled at a predictable and relatively fast rate. The standardized nature of the service allows many such shops to guarantee that a customer's car will be serviced within some precise period, usually an hour or less.

As the degree of customization increases, the service package becomes less predictable and more variable. Efficiency and productivity, while they are important, become much more difficult to measure and control, as each customer may have unique needs. Organizations that offer customized services tend to compete less on cost and more on their ability to provide customers with exactly what they need.

Consider, for example, a general hospital that offers a full range of health care services, from pediatrics to surgery. On any given day, the mix of patients and ailments the hospital must treat is only partially predictable. The breadth and depth of skills required to deal with any and every eventuality are high, and labor costs are, therefore, high as well. Such a hospital also needs to invest in a wide range of technologies, some of which might be quite expensive.

Customer Contact

A third consideration in managing service processes is the level of customer contact. Contact is not the same as customization. A fast-food restaurant provides a high degree of customer contact but little customization. On the other hand, a health clinic provides a high degree of contact and customization: Physicians may need to see patients frequently to make diagnoses, prescribe treatments, and monitor the effectiveness of treatments.

The degree of customer contact determines the relative importance of front-room and back-room operations in a service process. The front room in a service organization is the point (either physical or virtual) where the customer interfaces directly with the service organization. It may be the sales floor in a retail store, the help desk for a software provider.

The front-room operations of an airline include the reservation desk, baggage check in, and terminal gate, as well as the planes themselves. As a rule, as the degree of customer contact increases, more of the service package is provided by front-room operations.

In designing front-room operations, managers must consider how the customer interfaces with the service. Layout, location, and convenience become key. The physical layout must be comfortable, safe, and attractive, and the location must be convenient. In addition, front room service must be available when the customer needs it. FedEx Kinko's is an example of a high-contact service: Its copying services are available 24 hours a day at locations convenient to colleges and universities.

As the degree of customer contact decreases, more of the service package is provided by back-room operations. The back room refers to the part of a service operation that is completed without direct customer contact. The back room is often hidden from the customer's view. Package sorting at FedEx or UPS is a classic example of a back-room operation, as is the testing of medical samples.

Such services can be located to reduce transportation costs and laid out to improve productivity. Because back-room personnel do not deal directly with customers, the hours of operation are not as crucial as they are in front-room operations, and employees do not have to be skilled in dealing with customers.

FedEx and UPS personnel sort packages in the middle of the night, while customers are sleeping. As you might expect, back-room service operations are usually easier to manage than front-room operations.

Table summarizes the different managerial challenges faced by services, depending on the nature of the service package, the degree of customization, and the degree of customer contact.

Nature of the service package	**Primarily physical activities →** Greater emphasis on managing physical assets. (Airline, trucking firm)	**Primarily intangible activities →** Greater emphasis on managing people and knowledge assets. (Law firm, software developer)
Degree of customization	**Lower customization →** Greater emphasis on closely controlling the process and improving productivity. (Quick-change oil shop)	**Higher customization →** Greater emphasis on being flexible and responsive to customers' needs. (Full-service car repair shop)
Degree of customer contact	**Lower contact →** More of the service package can be performed in the back room. Service layout, location, and hours will be based more on cost and productivity concerns. (Mail sorting)	**Higher contact →** More of the service package must be performed in the front room. Service layout, location, and hours must be designed with customer convenience in mind. (Physical therapist)

Service blueprinting is a specialized form of business process mapping that allows the user to better visualize the degree of customer contact. The service blueprint does this in two ways. First, it lays out the service process from the viewpoint of the customer. It then parses out the organization's service actions based on (1) the extent to which an action involves direct interaction with the customer and (2) whether an action takes place as a direct response to a customer's needs.

The first layer represents specific customer actions, such as placing an order, calling up a service support hotline, or entering a service facility, such as a doctor's office or a retail store.

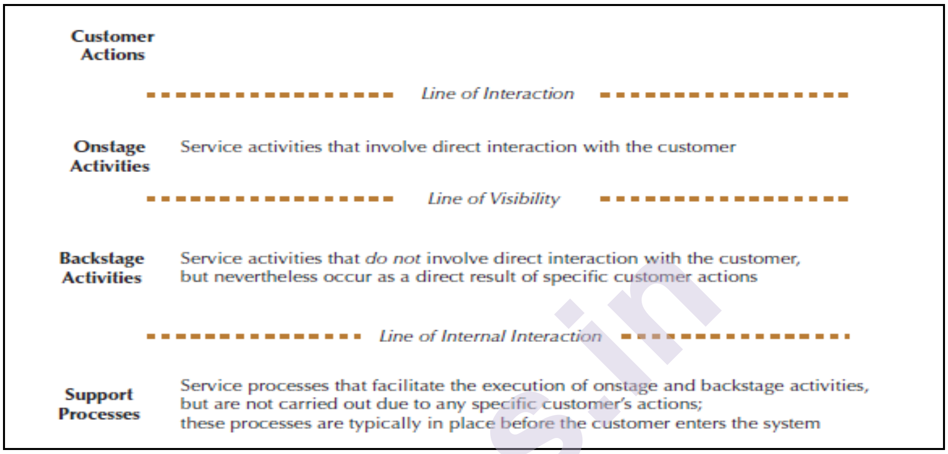
The second layer represents onstage actions carried out by the service provider. Onstage actions provide a point of direct interaction with the customer. Some proponents of service blueprinting reserve this layer for activities that involve direct face-to-face interaction with the customer. Others argue that any form of direct interaction, whether it is a phone call or a visit to a Web site, would appear here. In this sense, onstage activities are synonymous with front-room operations. Because onstage actions involve direct interaction with the customer, they cross the line of interaction and occur above the line of visibility.

The third layer of the service blueprint consists of backstage actions. These actions take place in direct response to a customer action, but the customer does not "see" these activities carried out. They therefore take place below the line of visibility and are analogous to back-room operations. An example would be the activities required to pick, pack, and ship books and videos you order from Amazon.com. You don't see these activities take place, but nevertheless they occur as a direct result of your placing an order.

The fourth layer of the service blueprint contains support processes. Unlike onstage and backstage actions, these processes do not occur as a result of any particular customer's actions. Rather, these processes facilitate the execution of onstage and backstage actions. In the language of service blueprinting, they do this by crossing the line of internal interaction. Continuing with our example, Amazon's Web site development and inventory management processes ensure that there is a Web site that can take your order (and credit card information!) and that the products you want are in stock.

A template for the service blueprint that has these four layers is shown in the next figure.

(Service Blueprinting Template)



Service Positioning

Service operations compete and position themselves in the marketplace based on the three dimensions—nature of the service package, degree of customization, and degree of customer contact—that were just discussed. Figure shows a conceptual model of service processes containing these three dimensions. The three dimensions of the cube represent the nature of the service package, the degree of customization, and the level of contact with the customer.

A Cubical Model of Services
(Three Dimensions)

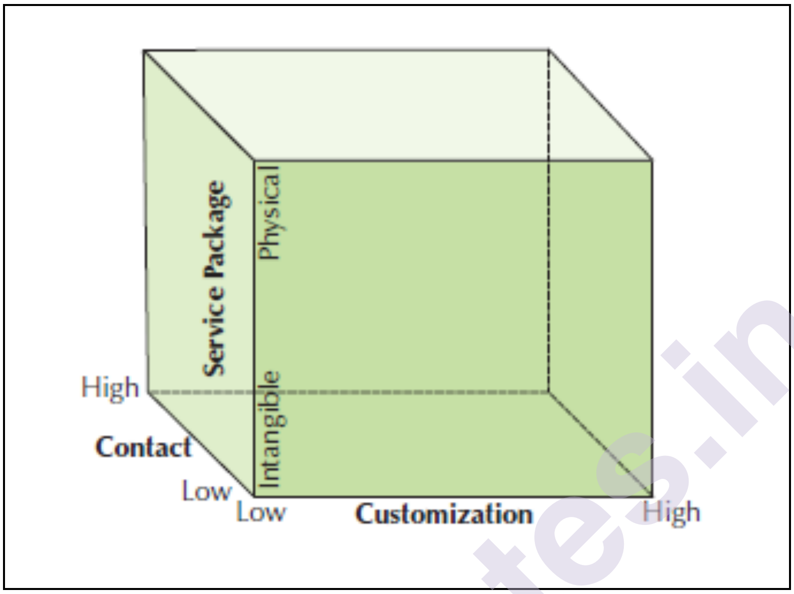
Nature of the Service Package	Primarily Physical Activities (Airline, trucking firm)	Primarily Intangible Activities (Law firm, software developer)
Degree of Customization	Lower Customization (Quick-change oil shop)	Higher Customization (Full-service car repair shop)
Degree of Customer Contact	Lower Contact (Mail sorting)	Higher Contact (Physical therapist)

To illustrate how positioning works, consider the case of public hospitals. Such community-sponsored hospitals are typically chartered to provide a wide selection of health services to the local population. These hospitals are characterized by:

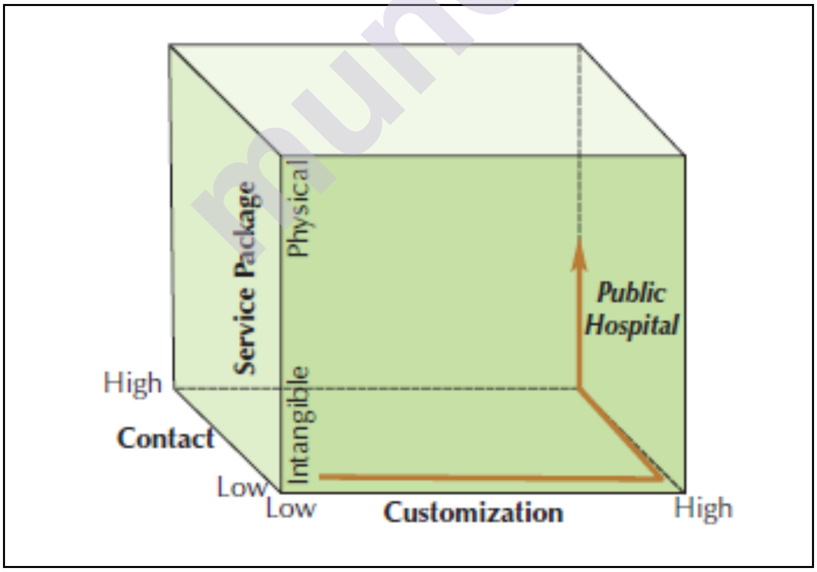
- High levels of service customization;
- High levels of customer contact; and
- A mix of physical and intangible service activities.

These characteristics make community hospitals very expensive to run and very challenging to manage.

A Conceptual Model of Service Process



Positioning a Typical Community Hospital



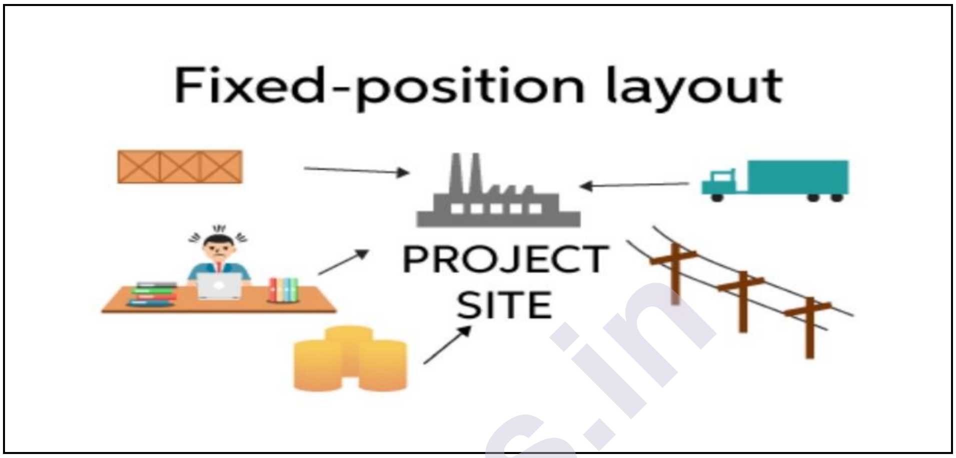
Services within the Supply Chain

Many people view supply chains as being dominated by manufacturers. The point is that services are an integral part of any supply chain. Of course, some services have very little to do with supply chains, due to the nature of the service package. But for others, supply chains are a source of both products and business opportunities.

2.5 LAYOUT DECISION MODELS

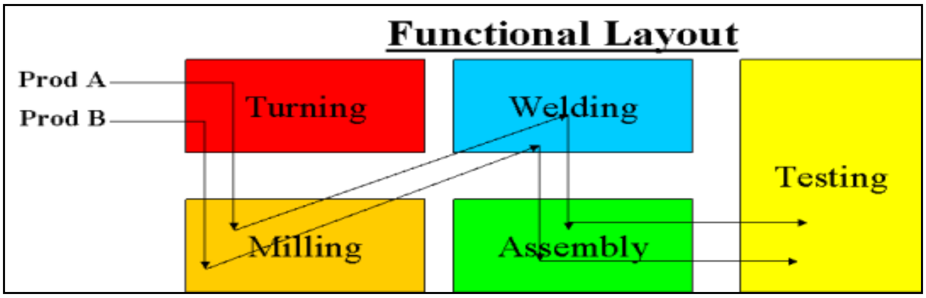
An important part of process choice is deciding how the various resources will be logically grouped and physically arranged. There are four types of layouts: product-based, functional, cellular, and fixed-position layouts.

For a fixed-position layout, there is really little discretion regarding how the process is laid out because the productive resources have to be moved to where the product is being made or the service is being provided.

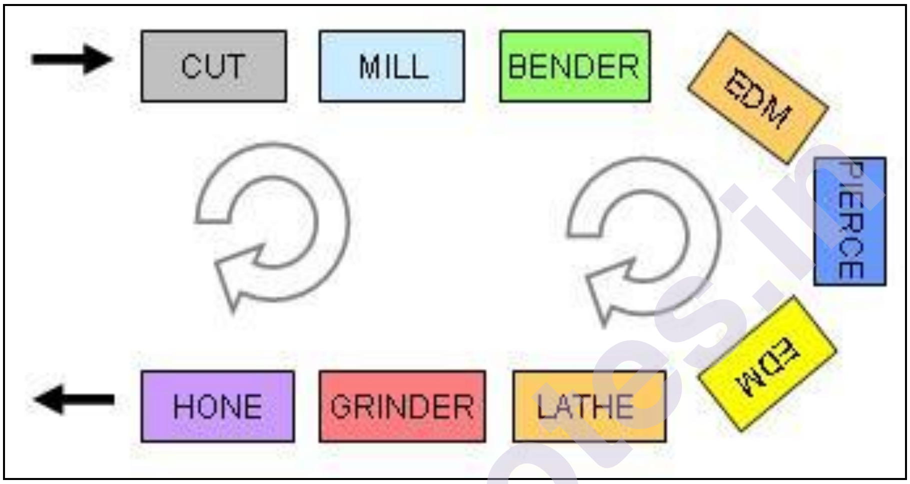


For the remaining three, however, managers face choices regarding how the processes are laid out. A product-based layout arranges resources sequentially, according to the steps required to make a product or provide a service. The security check-in at an airport is an example of a service process that follows a product-based layout (where the "product" is the passenger). Such an arrangement makes sense when the sequence of activities does not change from one period to the next. In contrast, a functional layout physically groups resources by function.

A functional layout is better suited to environments where the process steps can change dramatically from one job or customer to the next. An example of this would be a full-service auto repair facility, with inspections done in one area, alignments in another, and major repairs in a third area.



Finally, a cellular layout is similar in many ways to a product-based layout. The primary difference is that the cellular layout is used in a group technology cell, where the production resources have been dedicated to a subset of products with similar requirements, known as a product family.



2.6 LET US SUM UP

In this chapter, we looked at some of the important issues managers face when selecting a manufacturing or service process. We started with a discussion of manufacturing processes, emphasizing the strengths and weaknesses of different types, and we described the impact of customization on the manufacturing process and the supply chain. Managers must be careful in selecting both the manufacturing process and the degree and point of customization. We then turned our attention to service processes. We looked at three defining dimensions of services: the service package (the mix of physical and intangible activities), service customization, and customer contact. We showed how services face different managerial challenges, depending on where they stand on these dimensions. We also discussed how organizations can use this knowledge to position their services vis-à-vis their competition. Finally, we ended the chapter by demonstrating two approaches to developing layouts in manufacturing and service environments.

2.7 EXERCISES

1. Suppose a firm invests in what turns out to be the “wrong” process, given the business strategy. What will happen? Can you think of an example?

2. In general, would you expect to see production lines upstream or downstream of the customization point in a supply chain? What about job shops? Explain.

2.8 SUGGESTED READING

- Operations & Supply Chain Management by Chase, Shankar, Jocaobs
- Operations Management (6th Edition) by Nigel Slack, Stuart Chambers, Robert Johnston
- Theory & Problems in Production & Operations Management- S N Chary, Tata McGraw Hill
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3

FACILITY LOCATION

Unit Structure

3.0 OBJECTIVES

After going through this unit, you will be able to understand:

- Introduction and Meaning
- Need for Selecting a Suitable Location
- Factors Influencing Plant/Facility Location
- Location Theories
- Location Models
- Locational Economics.

3.1 INTRODUCTION AND MEANING

Plant location or the facilities location problem is an important strategic level decision making for an organization. One of the key features of a conversion process (manufacturing system) is the efficiency with which the products (services) are transferred to the customers.

This fact will include the determination of where to place the plant or facility. The selection of location is a key-decision as large investment is made in building plant and machinery. It is not advisable or not possible to change the location very often. So an improper location of plant may lead to waste of all the investments made in building and machinery, equipment. Before a location for a plant is selected, long range forecasts should be made anticipating future needs of the company. The plant location should be based on the company's expansion plan and policy, diversification plan for the products, changing market conditions, the changing sources of raw materials and many other factors that influence the choice of the location decision. The purpose of the location study is to find an optimum location one that will result in the greatest advantage to the organization.

3.2 NEED FOR SELECTING A SUITABLE LOCATION

The need for selecting a suitable location arises because of three situations.

I. When starting a new organization, i.e., location choice for the first time.

II. In case of existing organization.

III. In case of Global Location.

I. In Case of Location Choice for the First Time or New Organizations

Cost economies are always important while selecting a location for the first time, but should keep in mind the cost of long-term business/organizational objectives. The following are the factors to be considered while selecting the location for the new organizations:

1. **Identification of region:** The organizational objectives along with the various long-term considerations about marketing, technology, internal organizational strengths and weaknesses, region specific resources and business environment, legal-governmental environment, social environment and geographical environment suggest a suitable region for locating the operations facility.

2. **Choice of a site within a region:** Once the suitable region is identified, the next step is choosing the best site from an available set. Choice of a site is less dependent on the organization's long-term strategies. Evaluation of alternative sites for their tangible and intangible costs will resolve facilities-location problem.

   The problem of location of a site within the region can be approached with the following cost-oriented non-interactive model, i.e., dimensional analysis.

3. **Dimensional analysis:** If all the costs were tangible and quantifiable, the comparison and selection of a site is easy. The location with the least cost is selected. In most of the cases intangible costs which are expressed in relative terms than in absolute terms. Their relative merits and demerits of sites can also be compared easily. Since both tangible and intangible costs need to be considered for a selection of a site, dimensional analysis is used.

Dimensional analysis consists in computing the relative merits (cost ratio) for each of the cost items for two alternative sites. For each of the ratios an appropriate weightage by means of power is given and multiplying these weighted ratios to come up with a comprehensive figure on the relative merit of two alternative sites, i.e.

$C_1^M, C_2^M, \ldots, C_z^M$ are the different costs associated with a site M on the 'z' different cost items.

$C_1^N, C_2^N, \ldots, C_z^N$ are the different costs associated with a site N and $W_1, W_2, W_3, \ldots, W_z$ are the weightage given to these cost items, then relative merit of the M and site N is given by:

$$\left(C_1^M / C_1^N\right)^{W_1} \times \left(C_2^M / C_2^N\right)^{W_2}, \ldots, \left(C_z^M / C_z^N\right)^{W_z}$$

If this is > 1, site N is superior and vice-versa.

When starting a new factory, plant location decisions are very important because they have direct bearing on factors like, financial, employment and distribution patterns. In the long run, relocation of plant may even benefit the organization. But, the relocation of the plant involves stoppage of production, and also cost for shifting the facilities to a new location. In addition to these things, it will introduce some inconvenience in the normal functioning of the business.

Hence, at the time of starting any industry, one should generate several alternate sites for locating the plant. After a critical analysis, the best site is to be selected for commissioning the plant. Location of warehouses and other facilities are also having direct bearing on the operational performance of organizations.

The existing firms will seek new locations in order to expand the capacity or to place the existing facilities. When the demand for product increases, it will give rise to following decisions:

- Whether to expand the existing capacity and facilities.
- Whether to look for new locations for additional facilities.
- Whether to close down existing facilities to take advantage of some new locations.

II. In Case of Location Choice for Existing Organization

In this case a manufacturing plant has to fit into a multi-plant operations strategy. That is, additional plant location in the same premises and elsewhere under following circumstances:

1. Plant manufacturing distinct products.
2. Manufacturing plant supplying to specific market area.
3. Plant divided on the basis of the process or stages in manufacturing.
4. Plants emphasizing flexibility.

The different operations strategies under the above circumstances could be:

1. **Plants manufacturing distinct products:** Each plant services the entire market area for the organization. This strategy is necessary where the needs of technological and resource inputs are specialized or distinctively different for the different product-lines. For example, a high quality precision product-line should not be located along with other product-line requiring little emphasis on precision. It may not be proper to have too many contradictions such as sophisticated and old equipment, highly skilled and semi-skilled personnel, delicate processes and those that could permit rough handlings, all under one roof and one set of managers. Such a setting leads to much confusion regarding the required emphasis and the management policies.

   Product specialization may be necessary in a highly competitive market. It may be necessary to exploit the special resources of a particular geographical area. The more decentralized these pairs are in terms of the management and in terms of their physical location, the better would be the planning and control and the utilization of the resources.

2. **Manufacturing plants supplying to a specific market area:** Here, each plant manufactures almost all of the company's products. This type of strategy is useful where market proximity consideration dominates the resources and technology considerations. This strategy requires great deal of coordination from the corporate office. An extreme example of this strategy is that of soft drinks bottling plants.

3. **Plants divided on the basis of the process or stages in manufacturing:** Each production process or stage of manufacturing may require distinctively different equipment capabilities, labour skills, technologies, and managerial policies and emphasis. Since the products of one plant feed into the other plant, this strategy requires much centralized coordination of the manufacturing activities from the corporate office that are expected to understand the various technological aspects of all the plants.

4. **Plants emphasizing flexibility:** This requires much coordination between plants to meet the changing needs and at the same time ensure efficient use of the facilities and resources. Frequent changes in the long-term strategy in order to improve be efficiently temporarily, are not healthy for the organization. In any facility location problem the central question is: 'Is this a location at which the company can remain competitive for a long time?'

   For an established organization in order to add on to the capacity, following are the ways:

   (a) Expansion of the facilities at the existing site: This is acceptable when it does not violate the basic business and managerial outlines, i.e., philosophies, purposes, strategies and capabilities. For example, expansion should not compromise quality, delivery, or customer service.

(b) Relocation of the facilities (closing down the existing ones): This is a drastic step which can be called as ‘Uprooting and Transplanting’. Unless there are very compelling reasons, relocation is not done. The reasons will be either bringing radical changes in technology, resource availability or other destabilization.

All these factors are applicable to service organizations, whose objectives, priorities and strategies may differ from those of hardcore manufacturing organizations.

III. In Case of Global Location

Because of globalization, multinational corporations are setting up their organizations in India and Indian companies are extending their operations in other countries. In case of global locations there is scope for virtual proximity and virtual factory.

VIRTUAL PROXIMITY

With the advance in telecommunications technology, a firm can be in virtual proximity to its customers. For a software services firm much of its logistics is through the information/communication pathway. Many firms use the communications highway for conducting a large portion of their business transactions. Logistics is certainly an important factor in deciding on a location—whether in the home country or abroad. Markets have to be reached. Customers have to be contacted. Hence, a market presence in the country of the customers is quite necessary.

VIRTUAL FACTORY

Many firms based in USA and UK in the service sector and in the manufacturing sector often out sources part of their business processes to foreign locations such as India. Thus, instead of one’s own operations, a firm could use its business associates’ operations facilities. The Indian BPO firm is a foreign-based company’s ‘virtual service factory’. So a location could be one’s own or one’s business associates. The location decision need not always necessarily pertain to own operations.

REASONS FOR A GLOBAL/FOREIGN LOCATION

A. Tangible Reasons

The tangible reasons for setting up an operations facility abroad could be as follows:

Reaching the customer: One obvious reason for locating a facility abroad is that of capturing a share of the market expanding worldwide. The phenomenal growth of the GDP of India is a big reason for the multinationals to have their operations facilities in our country. An important reason is that of providing service to the customer promptly and economically which is logistics-dependent. Therefore, cost and case of logistics is a reason for setting up manufacturing facilities abroad. By logistics set of activities closes the gap between production of goods/services and reaching of these intended goods/services to the customer to his satisfaction. Reaching the customer is thus the main objective. The tangible and intangible gains and costs depend upon the company defining for it as to what that 'reaching' means. The tangible costs could be the logistics related costs; the intangible costs may be the risk of operating is a foreign country. The tangible gains are the immediate gains; the intangible gains are an outcome of what the company defines the concepts of reaching and customer for itself.

The other tangible reasons could be as follows:

(a) The host country may offer substantial tax advantages compared to the home country.

(b) The costs of manufacturing and running operations may be substantially less in that foreign country. This may be due to lower labour costs, lower raw material cost, better availability of the inputs like materials, energy, water, ores, metals, key personnel etc.

(c) The company may overcome the tariff barriers by setting up a manufacturing plant in a foreign country rather than exporting the items to that country.

B. Intangible Reasons

The intangible reasons for considering setting up an operations facility abroad could be as follows:

1. Customer-related Reasons

(a) With an operations facility in the foreign country, the firm's customers may feel secure that the firm is more accessible. Accessibility is an important 'service quality' determinant.

(b) The firm may be able to give a personal tough.

(c) The firm may interact more intimately with its customers and may thus understand their requirements better.

(d) It may also discover other potential customers in the foreign location.

2. Organizational Learning-related Reasons

(a) The firm can learn advanced technology. For example, it is possible that cutting-edge technologies can be learning by having operations in an technologically more advanced country. The firm can learn from advanced research laboratories/universities in that country. Such learning may help the entire product-line of the company.

(b) The firm can learn from its customers abroad. A physical location there may be essential towards this goal.

(c) It can also learn from its competitors operating in that country. For this reason, it may have to be physically present where the action is.

(d) The firm may also learn from its suppliers abroad. If the firm has a manufacturing plant there, it will have intensive interaction with the suppliers in that country from whom there may be much to learn in terms of modern and appropriate technology, modern management methods, and new trends in business worldwide.

3. Other Strategic Reasons

(a) The firm by being physically present in the host country may gain some 'local boy' kind of psychological advantage. The firm is no more a 'foreign' company just sending its products across international borders. This may help the firm in lobbying with the government of that country and with the business associations in that country.

(b) The firm may avoid 'political risk' by having operations in multiple countries.

(c) By being in the foreign country, the firm can build alternative sources of supply. The firm could, thus, reduce its supply risks.

(d) The firm could hunt for human capital in different countries by having operations in those countries. Thus, the firm can gather the best of people from across the globe.

(e) Foreign locations in addition to the domestic locations would lower the market risks for the firm. If one market goes slow the other may be doing well, thus lowering the overall risk.

3.3 FACTORS INFLUENCING PLANT / FACILITY LOCATION

Facility location is the process of determining a geographic site for a firm's operations. Managers of both service and manufacturing organizations must weigh many factors when assessing the desirability of a particular site, including proximity to customers and suppliers, labour costs, and transportation costs.

Location conditions are complex and each comprises a different Characteristic of a tangible (i.e. Freight rates, production costs) and non-tangible (i.e. reliability, Frequency security, quality) nature.

Location conditions are hard to measure. Tangible cost based factors such as wages and products costs can be quantified precisely into what makes locations better to compare. On the other hand non-tangible features, which refer to such characteristics as reliability, availability and security, can only be measured along an ordinal or even nominal scale. Other non-tangible features like the percentage of employees that are unionized can be measured as well. To sum this up non-tangible features are very important for business location decisions. It is appropriate to divide the factors, which influence the plant location or facility location on the basis of the nature of the organization as:

1. **General locational factors**, which include controllable and uncontrollable factors for all type of organizations.

2. **Specific locational factors** specifically required for manufacturing and service organizations. Location factors can be further divided into two categories:

Dominant factors are those derived from competitive priorities (cost, quality, time, and flexibility) and have a particularly strong impact on sales or costs. Secondary factors also are important, but management may downplay or even ignore some of them if other factors are more important.

General Locational Factors

Following are the general factors required for location of plant in case of all types of organizations:

- **Controllable Factors**

  1. Proximity to markets
  2. Supply of materials
  3. Transportation facilities
  4. Infrastructure availability
  5. Labour and wages
  6. External economies
  7. Capital.

- **Uncontrollable Factors**

  8. Government policy
  9. Climate conditions
  10. Supporting industries and services
  11. Community and labour attitudes
  12. Community Infrastructure.

Controllable Factors

1. **Proximity to markets:** Every company is expected to serve its customers by providing goods and services at the time needed and at reasonable price organizations may choose to locate facilities close to the market or away from the market depending upon the product. When the buyers for the product are concentrated, it is advisable to locate the facilities close to the market. Locating nearer to the market is preferred if: the products are delicate and susceptible to spoilage, after sales services are promptly required very often,

transportation cost is high and increase the cost significantly and Shelf life of the product is low.

Nearness to the market ensures a consistent supply of goods to customers and reduces the cost of transportation.

2. **Supply of raw material:** It is essential for the organization to get raw material in right qualities and time in order to have an uninterrupted production. This factor becomes very important if the materials are perishable and cost of transportation is very high.

   General guidelines regarding effects of raw materials on plant location are:

   - When a single raw material is used without loss of weight, locate the plant at the raw material source, at the market or at any point in between.
   - When weight loosing raw material is demanded, locate the plant at the raw material source.
   - When raw material is universally available, locate close to the market area.
   - If the raw materials are processed from variety of locations, the plant may be situated so as to minimize total transportation costs.

     Nearness to raw material is important in case of industries such as sugar, cement, jute and cotton textiles.

3. **Transportation facilities:** Speedy transport facilities ensure timely supply of raw materials to the company and finished goods to the customers. The transport facility is a prerequisite for the location of the plant. There are five basic modes of physical transportation, air, road, rail, water and pipeline. Goods that are mainly intended for exports demand a location near to the port or large airport. The choice of transport method and hence the location will depend on relative costs, convenience, and suitability. Thus transportation cost to value added is one of the criteria for plant location.

4. **Infrastructure availability:** The basic infrastructure facilities like power, water and waste disposal, etc., become the prominent factors in deciding the location. Certain types of industries are power hungry e.g., aluminum and steel and they should be located close to the power station or location where uninterrupted power supply is assured throughout the year. The non-availability of power may become a survival problem for such industries. Process industries like paper, chemical, cement, etc., require continuous. Supply of water in large amount and good quality, and mineral content of water becomes an important factor. A waste disposal facility for process industries is an important factor, which influences the plant location.

5. **Labour and wages:** The problem of securing adequate number of labour and with skills specific is a factor to be considered both at territorial as well as at community level during plant location. Importing labour is usually costly and involve administrative problem. The history of labour relations in a prospective community is to be studied. Prospective community is to be studied. Productivity of labour is also an important factor to be considered. Prevailing wage pattern, cost of living and industrial relation and bargaining power of the union forms some of the important considerations.

6. **External economies of scale:** External economies of scale can be described as urbanization and locational economies of scale. It refers to advantages of a company by setting up operations in a large city while the second one refers to the "settling down" among other companies of related Industries. In the case of urbanization economies, firms derive from locating in larger cities rather than in smaller ones in a search of having access to a large pool of labour, transport facilities, and as well to increase their markets for selling their products and have access to a much wider range of business services. Location economies of scale in the manufacturing sector have evolved over time and have mainly increased competition due to production facilities and lower production costs as a result of lower transportation and logistical costs. This led to manufacturing districts where many companies of related industries are located more or less in the same area. As large corporations have realized that inventories and warehouses have become a major cost factor, they have tried reducing inventory costs by launching "Just in Time" production system (the so called Kanban System). This high efficient production system was one main factor in the Japanese car industry for being so successful. Just in time ensures to get spare parts from suppliers within just a few hours after ordering. To fulfill these criteria corporations have to be located in the same area increasing their market and service for large corporations.

7. **Capital:** By looking at capital as a location condition, it is important to distinguish the physiology of fixed capital in buildings and equipment from financial capital. Fixed capital costs as building and construction costs vary from region to region. But on the other hand buildings can also be rented and existing plants can be expanded. Financial capital is highly mobile and does not very much influence decisions. For example, large Multinational Corporations such as Coca-Cola operate in many different countries and can raise capital where interest rates are lowest and conditions are most suitable. Capital becomes a main factor when it comes to venture capital. In that case young, fast growing (or not) high tech firms are concerned which usually have not many fixed assets. These firms particularly need access to financial capital and also skilled educated employees.

Uncontrollable Factors

8. **Government policy:** The policies of the state governments and local bodies concerning labour laws, building codes, safety, etc., are the factors that demand attention. In order to have a balanced regional growth of industries, both central and state governments in our country offer the package of incentives to entrepreneurs in particular locations. The incentive package may be in the form of exemption from sales tax and excise duties for a specific period, soft loan from financial institutions, subsidy in electricity charges and investment subsidy. Some of these incentives may tempt to locate the plant to avail these facilities offered.

9. **Climatic conditions:** The geology of the area needs to be considered together with climatic conditions (humidity, temperature). Climates greatly influence human efficiency and behaviour. Some industries require specific climatic conditions e.g., textile mill will require humidity.

10. **Supporting industries and services:** Now a day the manufacturing organization will not make all the components and parts by itself and it subcontracts the work to vendors. So, the source of supply of component parts will be the one of the factors that influences the location. The various services like communications, banking services professional consultancy services and other civil amenities services will play a vital role in selection of a location.

11. **Community and labour attitudes:** Community attitude towards their work and towards the prospective industries can make or mar the industry. Community attitudes towards supporting trade union activities are important criteria. Facility location in specific location is not desirable even though all factors are favoring because of labour attitude towards management, which brings very often the strikes and lockouts.

12. **Community infrastructure and amenity:** All manufacturing activities require access to a community infrastructure, most notably economic overhead capital, such as roads, railways, port facilities, power lines and service facilities and social overhead capital like schools, universities and hospitals. These factors are also needed to be considered by location decisions as infrastructure is enormously expensive to build and for most manufacturing activities the existing stock of infrastructure provides physical restrictions on location possibilities.

Specific Locational Factors for Manufacturing Organization

Dominant Factors

Factors dominating location decisions for new manufacturing plants can be broadly classified in six groups. They are listed in the order of their importance as follows:

1. Favourable labour climate
2. Proximity to markets
3. Quality of life
4. Proximity to suppliers and resources
5. Utilities, taxes, and real estate costs

1. **Favourable labour climate:** A favorable labour climate may be the most important factor in location decisions for labour-intensive firms in industries such as textiles furniture and consumer electronics. Labour climate includes wage rates, training requirements attitudes toward work, worker productivity and union strength. Many executives consider weak unions or al low probability of union organizing efforts as a distinct advantage.

2. **Proximity to markets:** After determining where the demand for goods and services is greatest, management must select a location for the facility that will supply that demand. Locating near markets is particularly important when the final goods are bulky or heavy and outbound transportation rates are high. For example, manufacturers of products such as plastic pipe and heavy metals all emphasize proximity to their markets.

3. **Quality of life:** Good schools, recreational facilities, cultural events, and an attractive lifestyle contribute to quality of life. This factor is relatively unimportant on its own, but it can make the difference in location decisions.

4. **Proximity to suppliers and resources:** In many companies, plants supply parts to other facilities or rely on other facilities for management and staff support. These require frequent coordination and communication, which can become more difficult as distance increases.

5. **Utilities, taxes, and real estate costs:** Other important factors that may emerge include utility costs (telephone, energy, and water), local and state taxes, financing incentives offered by local or state governments, relocation costs, and land costs.

Secondary Factors

There are some other factors needed to be considered, including room for expansion, construction costs, accessibility to multiple modes of transportation, the cost of shuffling people and materials between plants, competition from other firms for the workforce, community attitudes, and many others. For global operations, firms are emphasizing local employee skills and education and the local infrastructure.

Specific Locational Factors for Service Organization

Dominant Factors

The factors considered for manufacturers are also applied to service providers, with one important addition — the impact of location on sales and customer satisfaction. Customers usually look about how close a service facility is, particularly if the process requires considerable customer contact.

Proximity to Customers

Location is a key factor in determining how conveniently customers can carry on business with a firm. For example, few people would like to go to remotely located dry cleaner or supermarket if another is more convenient. Thus the influence of location on revenues tends to be the dominant factor.

Transportation Costs and Proximity to Markets

For warehousing and distribution operations, transportation costs and proximity to markets are extremely important. With a warehouse nearby, many firms can hold inventory closer to the customer, thus reducing delivery time and promoting sales.

Location of Competitors

One complication in estimating the sales potential at different location is the impact of competitors. Management must not only consider the current location of competitors but also try to anticipate their reaction to the firm's new location. Avoiding areas where competitors are already well established often pays. However, in some industries, such as new-car sales showrooms and fast food chains, locating near competitors is actually advantageous. The strategy is to create a critical mass, whereby several competing firms clustered in one location attract more customers than the total number who would shop at the same stores at scattered locations. Recognizing this effect, some firms use a follow –the leader strategy when selecting new sites.

Secondary Factors

Retailers also must consider the level of retail activity, residential density, traffic flow, and site visibility. Retail activity in the area is important, as shoppers often decide on impulse to go shopping or to eat in a restaurant. Traffic flows and visibility are important because businesses customers arrive in cars. Visibility involves distance from the street and size of nearby buildings and signs. High residential density ensures night time and weekend business when the population in the area fits the firm's competitive priorities and target market segment.

3.4 LOCATION THEORIES

Location Theories

Alfred Weber's Theory of the Location of Industries

Alfred Weber (1868–1958), with the publication of Theory of the Location of Industries in 1909, put forth the first developed general theory of industrial location. His model took into account several spatial factors for finding the optimal location and minimal cost for manufacturing plants.

The point for locating an industry that minimizes costs of transportation and labour requires analysis of three factors:

1. The point of optimal transportation based on the costs of distance to the 'material index'—the ratio of weight to intermediate products (raw materials) to finished product.
2. The labour distortion, in which more favourable sources of lower cost of labour may justify greater transport distances.
3. Agglomeration and degglomerating.

Agglomeration or concentration of firms in a locale occurs when there is sufficient demand for support services for the company and labour force, including new investments in schools and hospitals. Also supporting companies; such as facilities that build and service machines and financial services; prefer closer contact with their customers.

Degglommeration occurs when companies and services leave because of over concentration of industries or of the wrong types of industries, or shortages of labour, capital, affordable land, etc. Weber also examined factors leading to the diversification of an industry in the horizontal relations between processes within the plant. The issue of industry location is increasingly relevant to today's global markets and transnational corporations. Focusing only on the mechanics of the Weberian model could justify greater transport distances for cheap labour and unexploited raw materials. When resources are exhausted or workers revolt, industries move to different countries.

3.5 LOCATION MODELS

Various models are available which help to identify the ideal location. Some of the popular models are:

1. Factor rating method
2. Weighted factor rating method
3. Load-distance method
4. Centre of gravity method
5. Break-even analysis.

Factor Rating Method

The process of selecting a new facility location involves a series of following steps:

1. Identify the important location factors.

2. Rate each factor according to its relative importance, i.e., higher the ratings is indicative of prominent factor.

3. Assign each location according to the merits of the location for each factor.

4. Calculate the rating for each location by multiplying factor assigned to each location with basic factors considered.

5. Find the sum of product calculated for each factor and select best location having highest total score.

Illustration 1: Let us assume that a new medical facility, Health-care, is to be located in Delhi. The location factors, factor rating and scores for two potential sites are shown in the following table. Which is the best location based on factor rating method?

S.No	Location Factor	Factor Rating	Rating	
			Location 1	Location 2
1	Facility Location	8	3	5
2	Total patient per month	5	4	3
3	Average time per emergency trip	6	4	5
4	Land and construction costs	3	1	2
5	Employee preferences	5	5	3

Solution:

S.No	Location Factor	Factor Rating (1)	Location 1		Location 2	
			(Rating) (2)	Total= (1).(2)	(Rating) (3)	Total= (1).(3)
1	Facility Location	8	3	24	5	40
2	Total patient	5	4	20	3	15

	per month					
3	Average time per emergency trip	6	4	24	5	30
4	Land and construction costs	3	1	3	2	6
5	Employee preferences	5	5	25	3	15
			Total	**96**	**Total**	**106**

The total score for location 2 is higher than that of location 1. Hence location 2, is the best choice.

Weighted Factor Rating Method

In this method to merge quantitative and qualitative factors, factors are assigned weights based on relative importance and weightage score for each site using a preference matrix is calculated. The site with the highest weighted score is selected as the best choice.

Illustration 2: Let us assume that a new medical facility, Health-care, is to be located in Delhi. The location factors, weights, and scores (1 = poor, 5 = excellent) for two potential sites are shown in the following table. What is the weighted score for these sites? Which is the best location?

S.No	**Location Factor**	**Weight**	**Scores**	
			Location 1	Location 2
1	Facility Location	25	3	5
2	Total patient per month	25	4	3
3	Average time per emergency trip	25	3	3
4	Land and construction costs	15	1	2
5	Employee preferences	10	5	3

Solution: The weighted score for this particular site is calculated by multiplying each factor's weight by its score and adding the results:

Weighted score location 1

= 25 × 3 + 25 × 4 + 25 × 3 + 15 × 1 + 10 × 5

= 75 + 100 + 75 + 15 + 50 = 315

Weighted score location 2

= 25 × 5 + 25 × 3 + 25 × 3 + 15 × 2 + 10 × 3

= 125 + 75 + 75 + 30 + 30 = 335

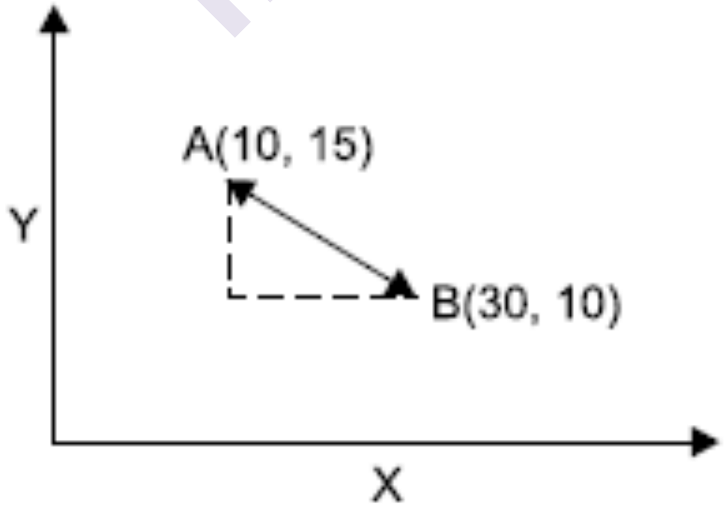
Location 2 is the best site based on total weighted scores.

Load-distance Method

The load-distance method is a mathematical model used to evaluate locations based on proximity factors. The objective is to select a location that minimizes the total weighted loads moving into and out of the facility. The distance between two points is expressed by assigning the points to grid coordinates on a map. An alternative approach is to use time rather than distance.

Distance Measures

Suppose that a new warehouse is to be located to serve Delhi. It will receive inbound shipments from several suppliers, including one in Ghaziabad. If the new warehouse were located at Gurgaon, what would be the distance between the two facilities? If shipments travel by truck, the distance depends on the highway system and the specific route taken. Computer software is available for calculating the actual mileage between any two locations in the same county. However, for load-distance method, a rough calculation that is either Euclidean or rectilinear distance measure may be used. Euclidean distance is the straight-line distance, or shortest possible path, between two points.



Distance between point A and point B

The point A on the grid represents the supplier's location in Ghaziabad, and the point B represents the possible warehouse location at Gurgaon. The distance between points A and B is the length of the hypotenuse of a right triangle, or

$dAB = \text{Sqrt}((XA - XB)^2 + (YA - YB)^2)$

where dAB = distance between points A and B

XA = x-coordinate of point A

YA = y-coordinate of point A

XB = x-coordinate of point B

YB = y-coordinate of point B

Rectilinear distance measures distance between two points with a series of 90° turns as city blocks. Essentially, this distance is the sum of the two dashed lines representing the base and side of the triangle in figure. The distance travelled in the x-direction is the absolute value of the difference in x-coordinates. Adding this result to the absolute value of the difference in the y-coordinates gives

$DAB = |XA - XB| + |YA - YB|$

Calculating a Load-Distance Score

Suppose that a firm planning a new location wants to select a site that minimizes the distances that loads, particularly the larger ones, must travel to and from the site. Depending on the industry, a load may be shipments from suppliers, between plants, or to customers, or it may be customers or employees travelling to or from the facility. The firm seeks to minimize its load distance, generally by choosing a location so that large loads go short distances.

To calculate a load-distance for any potential location, we use either of the distance measures and simply multiply the loads flowing to and from the facility by the distances travelled. These loads may be expressed as tones or number of trips per week. This calls for a practical example to appreciate the relevance of the concept. Let us visit a new Health-care facility, once again.

Illustration 3: The new Health-care facility is targeted to serve seven census tracts in Delhi. The table given below shows the coordinates for the centre of each census tract, along with the projected populations, measured in thousands. Customers will travel from the seven census tract centres to the new facility when they need health-care. Two locations being considered for the new facility are at (5.5, 4.5) and (7, 2), which are the centres of census tracts C and F. Details of seven census tract centres, co-ordinate distances along with the population for each centre are given below. If we use the population as the loads and use rectilinear distance, which location is better in terms of its total load-distance score?

Sr. No.	Census Tract	(x,y)	Population (l)
1	A	(2.5, 4.5)	2
2	B	(2.5, 2.5)	5
3	C	(5.5, 4.5)	10
4	D	(5, 2)	7
5	E	(8, 5)	10
6	F	(7, 2)	20
7	G	(9, 2.5)	14

Solution: Calculate the load-distance score for each location. Using the coordinates from the above table. Calculate the load-distance score for each tract.

Using the formula DAB = |XA – XB| + |YA – YB|

Sr. No.	(x,y)	Population (l)	Locate at (5.5, 4.5)		Locate at (7, 2)	
			Distance (d)	Load-Distance	Distance (d)	Load-Distance
1	(2.5, 4.5)	2	3 + 0 = 3	6	4.5 + 2.5 = 7	14
2	(2.5, 2.5)	5	3 + 2 = 5	25	4.5 + 0.5 = 5	25
3	(5.5, 4.5)	10	0 + 0 = 0	0	1.5 + 2.5 = 4	40
4	(5, 2)	7	0.5 + 2.5 = 3	21	2 + 0 = 2	14
5	(8, 5)	10	2.5 + 0.5 = 3	30	1 + 3 = 4	40
6	(7, 2)	20	1.5 + 2.5 = 4	80	0 + 0 = 0	0
7	(9, 2.5)	14	3.5 + 2 = 5.5	77	2 + 0.5 = 2.5	35
			Total	**239**	**Total**	**168**

Summing the scores for all tracts gives a total load-distance score of 239 when the facility is located at (5.5, 4.5) versus a load-distance score of 168 at location (7, 2). Therefore, the location in census tract F is a better location.

Centre of Gravity

Centre of gravity is based primarily on cost considerations. This method can be used to assist managers in balancing cost and service objectives. The centre of gravity method takes into account the locations of plants and markets, the volume of goods moved, and transportation costs in arriving at the best location for a single intermediate warehouse.

The centre of gravity is defined to be the location that minimizes the weighted distance between the warehouse and its supply and distribution points, where the distance is weighted by the number of tones supplied or consumed. The first step in this procedure is to place the locations on a coordinate system. The origin of the coordinate system and scale used are arbitrary, just as long as the relative distances are correctly represented. This can be easily done by placing a grid over an ordinary map. The centre of gravity is determined by the formula.

$$C_X = \frac{\sum D_{ix}.W_i}{\sum W_i} \qquad C_Y = \frac{\sum D_{iy}.W_i}{\sum W_i}$$

where Cx = x-coordinate of the centre of gravity

Cy = y-coordinate of the centre of gravity

Dix = x-coordinate of location i

Diy = y-coordinate of location i

Illustration 4: The new Health-care facility is targeted to serve seven census tracts in Delhi. The table given below shows the coordinates for the centre of each census tract, along with the projected populations, measured in thousands. Customers will travel from the seven census tract centres to the new facility when they need health-care. Two locations being considered for the new facility are at (5.5, 4.5) and (7, 2), which are the centres of census tracts C and F. Details of seven census tract centres, coordinate distances along with the population for each centre are given below. Find the target area's centre of gravity for the Health-care medical facility.

Sr. No.	Census Tract	(x,y)	Population (l)
1	A	(2.5, 4.5)	2
2	B	(2.5, 2.5)	5
3	C	(5.5, 4.5)	10
4	D	(5, 2)	7
5	E	(8, 5)	10
6	F	(7, 2)	20
7	G	(9, 2.5)	14

Solution: To calculate the centre of gravity, start with the following information, where population is given in thousands.

Sr. No.	**Census Tract**	**(x,y)**	**Population (l)**	**Lx**	**Ly**
1	A	(2.5, 4.5)	2	5	9
2	B	(2.5, 2.5)	5	12.5	12.5
3	C	(5.5, 4.5)	10	55	45
4	D	(5, 2)	7	35	14
5	E	(8, 5)	10	80	50
6	F	(7, 2)	20	140	40
7	G	(9, 2.5)	14	126	35
		Total	98	453.50	205.50

Next we find Cx and Cy.

Cx = 453.5/68 = 6.67

Cy = 205.5/68 = 3.02

The centre of gravity is (6.67, 3.02). Using the centre of gravity as starting point, managers can now search in its vicinity for the optimal location.

Break-even Analysis

Break even analysis implies that at some point in the operations, total revenue equals total cost. Break even analysis is concerned with finding the point at which revenues and costs agree exactly. It is called 'Break-even Point'. The Fig. portrays the Break Even Chart. Break even point is the volume of output at which neither a profit is made nor a loss is incurred.

The Break Even Point (BEP) in units can be calculated by using the relation:

$$\text{BEP} = \frac{\text{Fixed Cost}}{\text{Contribution per unit}} = \frac{\text{Fixed Cost}}{\text{Selling Price} - \text{Variable Cost per unit}} = \frac{F}{S-V} \text{ units}$$

The Break Even Point (BEP) in Rs. can be calculated by using the relation:

$$\text{BEP} = \frac{\text{Fixed Cost}}{\text{PV Ratio}} = \frac{\text{Fixed Cost}}{\left\{\dfrac{\text{Sales} - \text{Variable Cost}}{\text{Sales}}\right\}} = \frac{F}{\phi} \text{ Rs.}$$

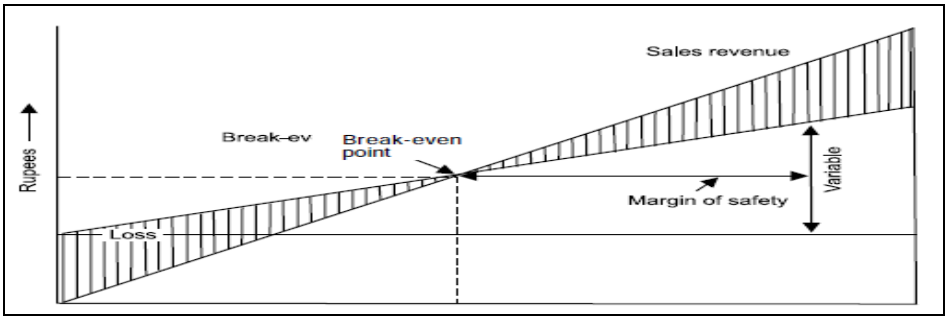


Fig. Units of output or percentage of capacity

Plotting the break even chart for each location can make economic comparisons of locations.

This will be helpful in identifying the range of production volume over which location can be selected.

Illustration 5: Potential locations X, Y and Z have the cost structures shown below. The ABC company has a demand of 1,30,000 units of a new product. Three potential locations X, Y and Z having following cost structures shown are available. Select which location is to be selected and also identify the volume ranges where each location is suited?

	Location X	Location Y	Location Z
Fixed Costs	Rs. 150,000	Rs. 350,000	Rs. 950,000
Variable Costs	Rs. 10	Rs. 8	Rs. 6

Solution: Solve for the crossover between X and Y:

10X + 150,000 = 8X + 350,000

2X = 200,000

X = 100,000 units

Solve for the crossover between Y and Z:

8X + 350,000 = 6X + 950,000

2X = 600,000

X = 300,000 units

Therefore, at a volume of 1,30,000 units, Y is the appropriate strategy.

From the graph below we can interpret that location X is suitable up to 100,000 units, location Y is suitable up to between 100,000 to 300,000 units and location Z is suitable if the demand is more than 300,000 units.

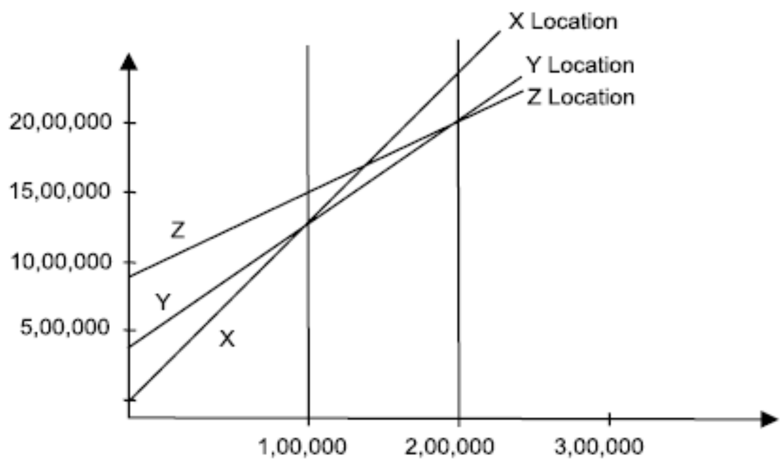


Fig. BEP chart

3.6 LOCATIONAL ECONOMICS

An ideal location is one which results in lowest production cost and least distribution cost per unit. These costs are influenced by a number of factors as discussed earlier. The various costs which decide locational economy are those of land, building, equipment, labour, material, etc. Other factors like community attitude, community facilities and housing facilities will also influence the selection of best location. Economic analysis is carried out to decide as to which locate best location. The following illustration will clarify the method of evaluation of best layout selection.

Illustration 6: From the following data select the most advantageous location for setting a plant for making transistor radios.

	Site X –Rs.	**Site Y –Rs.**	**Site Z –Rs.**
(i) Total initial investment	2,00,000	2,00,000	2,00,000
(ii) Total expected sales	2,50,000	3,00,000	2,50,000
(iii) Distribution expenses	40,000	40,000	75,000
(iv) Raw material expenses	70,000	80,000	90,000
(v) Power and water supply expenses	40,000	30,000	20,000
(vi) Wages and salaries	20,000	25,000	20,000
(vii) Other expenses	25,000	40,000	30,000
(viii) Community attitude	Indifferent t	Want business	Indifferent
(ix) Employee housing facilities	Poor	Excellent	Good

Solution

Total expenses	Site X –Rs.	Site Y –Rs.	Site Z –Rs.
([Add (iii) (iv) (v) (vi) and (vii)]	1,95,000	2,15,000	2,35,000

$$\text{Rate of return (RoR), \%} = \frac{\text{Total sales} - \text{Total expenses}}{\text{Total investment}} \times 100$$

$$\text{RoR for Site X} = \frac{2{,}50{,}000 - 1{,}95{,}000}{2{,}00{,}000} \times 100$$

$$= \mathbf{27.5\%}$$

$$\text{RoR for Site Y} = \frac{3{,}00{,}000 - 2{,}15{,}000}{2{,}00{,}000} \times 100$$

$$= \mathbf{42.5\%}$$

$$\text{RoR for Site Z} = \frac{2{,}50{,}000 - 2{,}35{,}000}{2{,}00{,}000} \times 100$$

$$= \mathbf{7.5\%}$$

Location Y can be selected because of higher rate of return.

3.7 LET US SUM UP

Facility or Plant location may be understood as the function of determining where the plant should be located for maximum operating economy and effectiveness. The selection of a place for locating a plant is one of the problems, perhaps the most important, which is faced by an entrepreneur while launching a new enterprise. A selection on pure economic considerations will ensure an easy and regular supply of raw materials, labour force, efficient plant layout, proper utilization of production capacity and reduced cost of production. An ideal location may not, by itself, guarantee success; but it certainly contributes to the smooth and efficient working of an organization. A bad location, on the other hand, is a severe handicap for any enterprise and it finally bankrupts it. It is, therefore, very essential that utmost care should be exercised in the initial stages to select a proper place. Once a mistake is made in locating a plant it becomes extremely difficult and costly to correct it. There are different location theories and location models that help the organization about the selection or location of a site.

3.8 EXERCISES

1. What do you mean by plant location?
2. What is virtual proximity?
3. What is virtual factory?
4. What is agglomeration?
5. What is degglomerating?

6. Explain different operations strategies in case of location choice for existing organization.
7. Explain the factors to be considered while selecting the location for the new organization
8. Explain the reasons for global or foreign location.
9. Explain the Alfred Weber's theory of the location of industries.
10. Explain the factors influencing plant location.

3.9 SUGGESTED READING

- Operations & Supply Chain Management by Chase, Shankar, Jocaobs
- Operations Management (6th Edition) by Nigel Slack, Stuart Chambers, Robert Johnston
- Theory & Problems in Production & Operations Management- S N Chary, Tata McGraw Hill
- Production & Operations Management -Kanishka Bedi , Oxford University Press
- Operations Management for competitive advantage-Chase & Jacob, McGraw-Hill/Irwin
- Production and Operations Management- Chunawalla & Patel, Himalaya Publishing

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4

FACILITY LAYOUT

Unit Structure

4.0 OBJECTIVES

After going through this unit, you will be able to understand:

- Plant Layout
- Classification of Layout
- Design of Product Layout
- Design of Process Layout
- Service Layout
- Organization of Physical Facilities

4.1 PLANT LAYOUT

Plant layout refers to the physical arrangement of production facilities. It is the configuration of departments, work centers and equipment in the conversion process. It is a floor plan of the physical facilities, which are used in production. According to Moore "Plant layout is a plan of an optimum arrangement of facilities including personnel, operating equipment, storage space, material handling equipment and all other supporting services along with the design of best structure to contain all these facilities".

Objectives of Plant Layout

The primary goal of the plant layout is to maximize the profit by arrangement of all the plant facilities to the best advantage of total manufacturing of the product.

The objectives of plant layout are:

- Streamline the flow of materials through the plant.
- Facilitate the manufacturing process.
- Maintain high turnover of in-process inventory.
- Minimize materials handling and cost.
- Effective utilization of men, equipment and space.
- Make effective utilization of cubic space.
- Flexibility of manufacturing operations and arrangements.
- Provide for employee convenience, safety and comfort.
- Minimize investment in equipment.
- Minimize overall production time.
- Maintain flexibility of arrangement and operation.
- Facilitate the organizational structure.

Principles of Plant Layout

1. **Principle of integration:** A good layout is one that integrates men, materials, machines and supporting services and others in order to get the optimum utilization of resources and maximum effectiveness.

2. **Principle of minimum distance:** This principle is concerned with the minimum travel (or movement) of man and materials. The facilities should be arranged such that, the total distance travelled by the men and materials should be minimum and as far as possible straight line movement should be preferred.

3. **Principle of cubic space utilization:** The good layout is one that utilizes both horizontal and vertical space. It is not only enough if only the floor space is utilized optimally but the third dimension, i.e., the height is also to be utilized effectively.

4. **Principle of flow:** A good layout is one that makes the materials to move in forward direction towards the completion stage, i.e., there should not be any backtracking.

5. **Principle of maximum flexibility**: The good layout is one that can be altered without much cost and time, i.e., future requirements should be taken into account while designing the present layout.

6. **Principle of safety, security and satisfaction:** A good layout is one that gives due consideration to workers safety and satisfaction and safeguards the plant and machinery against fire, theft, etc.

7. **Principle of minimum handling:** A good layout is one that reduces the material handling to the minimum.

4.2 CLASSIFICATION OF LAYOUT

Layouts can be classified into the following five categories:

- Process layout
- Product layout
- Combination layout
- Fixed position layout
- Group layout.

Process Layout

Process layout is recommended for batch production. All machines performing similar type of operations are grouped at one location in the process layout e.g., all lathes, milling machines, etc. are grouped in the shop will be clustered in like groups. Thus, in process layout the arrangement of facilities are grouped together according to their functions. A typical process layout is shown in Fig. The flow paths of material through the facilities from one functional area to another vary from product to product. Usually the paths are long and there will be possibility of backtracking. Process layout is normally used when the production volume is not sufficient to justify a product layout. Typically, job shops employ process layouts due to the variety of products manufactured and their low production volumes.

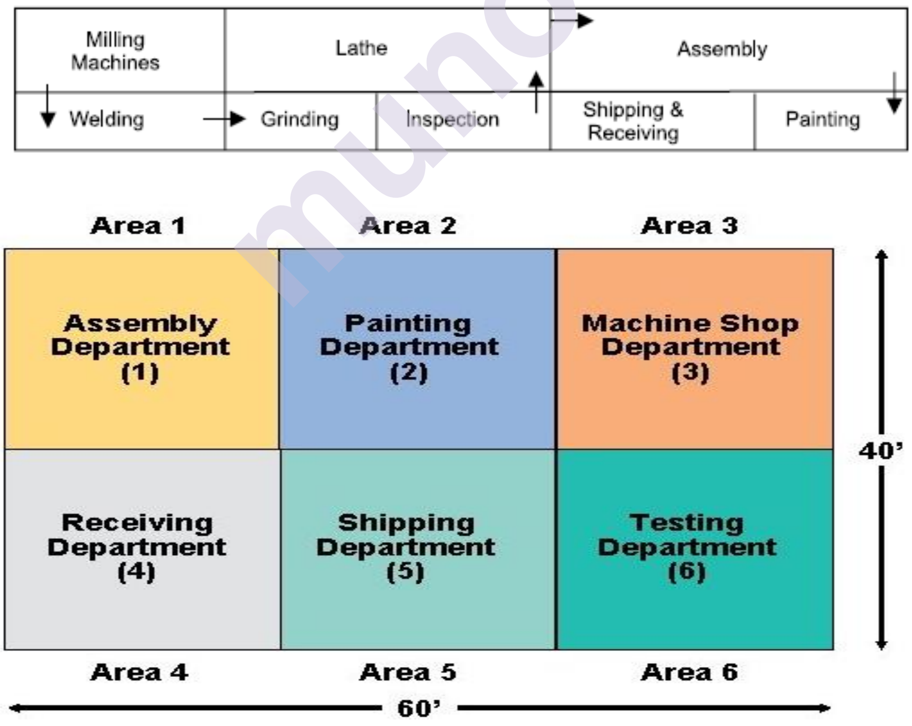


Fig. Process layout

Advantages

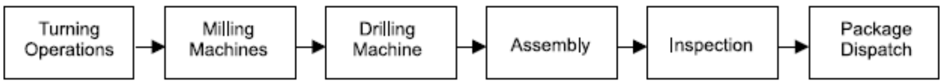
- In process layout machines are better utilized and fewer machines are required.
- Flexibility of equipment and personnel is possible in process layout.
- Lower investment on account of comparatively less number of machines and lower cost of general purpose machines.
- Higher utilization of production facilities.
- A high degree of flexibility with regards to work distribution to machineries and workers.
- The diversity of tasks and variety of job makes the job challenging and interesting.
- Supervisors will become highly knowledgeable about the functions under their department.

Limitations

- Backtracking and long movements may occur in the handling of materials thus, reducing material handling efficiency.
- Material handling cannot be mechanized which adds to cost.
- Process time is prolonged which reduce the inventory turnover and increases the in process inventory.
- Lowered productivity due to number of set-ups.
- Throughput (time gap between in and out in the process) time is longer.
- Space and capital are tied up by work-in-process.

Product Layout

In this type of layout, machines and auxiliary services are located according to the processing sequence of the product. If the volume of production of one or more products is large, the facilities can be arranged to achieve efficient flow of materials and lower cost per unit. Special purpose machines are used which perform the required function quickly and reliably. The product layout is selected when the volume of production of a product is high such that a separate production line to manufacture it can be justified. In a strict product layout, machines are not shared by different products. Therefore, the production volume must be sufficient to achieve satisfactory utilization of the equipment. A typical product layout is shown in Fig.



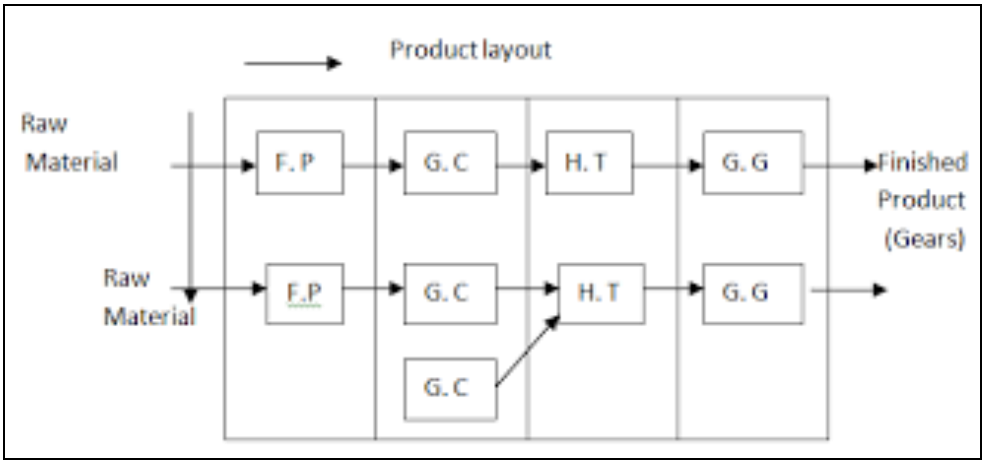


Fig. Product layout

Advantages

- The flow of product will be smooth and logical in flow lines.
- In-process inventory is less.
- Throughput time is less.
- Minimum material handling cost.
- Simplified production, planning and control systems are possible.
- Less space is occupied by work transit and for temporary storage.
- Reduced material handling cost due to mechanized handling systems and straight flow.
- Perfect line balancing which eliminates bottlenecks and idle capacity.
- Manufacturing cycle is short due to uninterrupted flow of materials.
- Small amount of work-in-process inventory.
- Unskilled workers can learn and manage the production.

Limitations

- A breakdown of one machine in a product line may cause stoppages of machines in the downstream of the line.
- A change in product design may require major alterations in the layout.
- The line output is decided by the bottleneck machine.
- Comparatively high investment in equipment is required.
- Lack of flexibility. A change in product may require the facility modification.

Combination Layout

A combination of process and product layouts combines the advantages of both types of layouts. A combination layout is possible where an item is being made in different types and sizes. Here machinery is arranged in a process layout but the process grouping is then arranged in a sequence to manufacture various types and sizes of products. It is to be noted that the sequence of operations remains same with the variety of products and sizes. Figure shows a combination type of layout for manufacturing different sized gears.

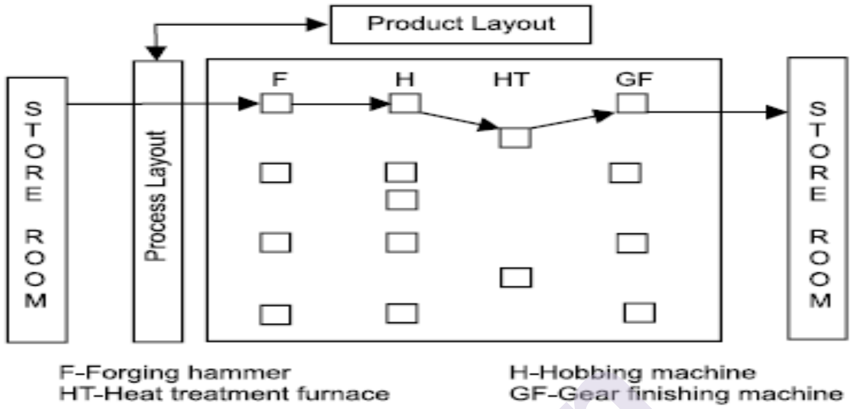


Fig. Combination layout for making different types and sizes of gears

Fixed Position Layout

This is also called the **project type** of layout. In this type of layout, the material, or major components remain in a fixed location and tools, machinery, men and other materials are brought to this location. This type of layout is suitable when one or a few pieces of identical heavy products are to be manufactured and when the assembly consists of large number of heavy parts, the cost of transportation of these parts is very high.

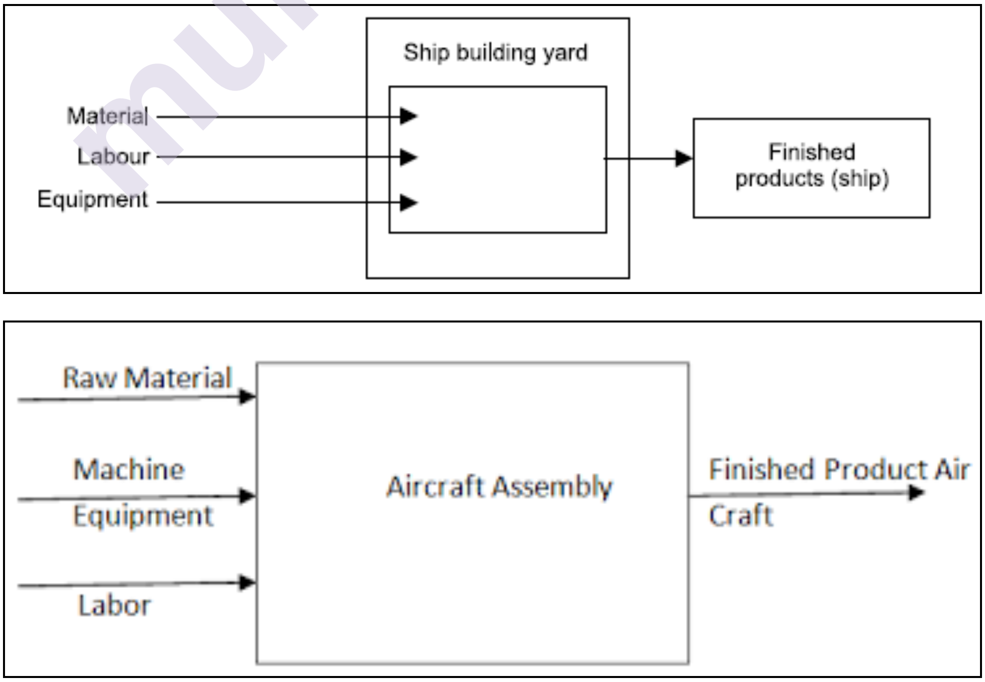


Fig. Fixed position layout

Advantages

The major advantages of this type of layout are:

- Helps in job enlargement and upgrades the skills of the operators.
- The workers identify themselves with a product in which they take interest and pride in doing the job.
- Greater flexibility with this type of layout.
- Layout capital investment is lower.

Group Layout (or Cellular Layout)

There is a trend now to bring an element of flexibility into manufacturing system as regards to variation in batch sizes and sequence of operations. A grouping of equipment for performing a sequence of operations on family of similar components or products has become all the important. Group Technology (GT) is the analysis and comparisons of items to group them into families with similar characteristics. GT can be used to develop a hybrid between pure process layout and pure flow line (product) layout. This technique is very useful for companies that produce variety of parts in small batches to enable them to take advantage and economics of flow line layout. The application of group technology involves two basic steps; first step is to determine component families or groups. The second step in applying group technology is to arrange the plants equipment used to process a particular family of components. This represents small plants within the plants. The group technology reduces production planning time for jobs. It reduces the set-up time.

Thus **group layout** is a combination of the product layout and process layout. It combines the advantages of both layout systems. If there are m-machines and n-components, in a group layout (Group-Technology Layout), the m-machines and n-components will be divided into distinct number of machine-component cells (group) such that all the components assigned to a cell are almost processed within that cell itself. Here, the objective is to minimize the intercell movements.

The basic aim of a group technology layout is to identify families of components that require similar of satisfying all the requirements of the machines are grouped into cells. Each cell is capable of satisfying all the requirements of the component family assigned to it. The layout design process considers mostly a single objective while designing layouts. In process layout, the objective is to minimize the total cost of materials handling. Because of the nature of the layout, the cost of equipment will be the minimum in this type of layout. In product layout, the cost of materials handling will be at the absolute minimum. But the cost of equipment would not be at the minimum if the equipment is not fully utilized. In-group technology layout, the objective is to minimize the sum of the cost of transportation and the cost of equipment. So, this is called as multi-objective layout. A typical process layout is shown in Fig.

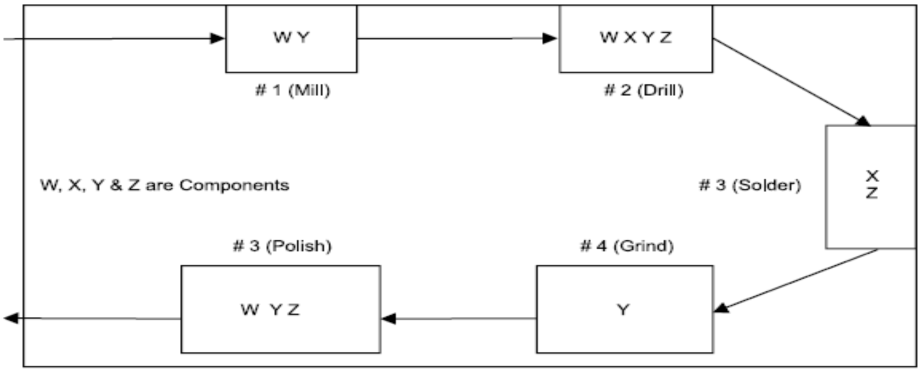


Fig. Group layout or Cellular layout

Advantages of Group Technology Layout

Group Technology layout can increase:

- Component standardization and rationalization.
- Reliability of estimates.
- Effective machine operation and productivity.
- Customer service.
- It can decrease the—
- Paper work and overall production time.
- Work-in-progress and work movement.
- Overall cost.

Limitations of Group Technology Layout

This type of layout may not be feasible for all situations. If the product mix is completely dissimilar, then we may not have meaningful cell formation.

4.3 DESIGN OF PRODUCT LAYOUT

In product layout, equipment or departments are dedicated to a particular product line, duplicate equipment is employed to avoid backtracking, and a straight-line flow of material movement is achievable. Adopting a product layout makes sense when the batch size of a given product or part is large relative to the number of different products or parts produced.

Assembly lines are a special case of product layout. In a general sense, the term assembly line refers to progressive assembly linked by some material-handling device. The usual assumption is that some form of pacing is present and the allowable processing time is equivalent for all workstations. Within this broad definition, there are important differences among line types. A few of these are material handling devices (belt or roller conveyor, overhead crane); line configuration (U-shape, straight, branching); pacing (mechanical, human); product mix (one product or multiple products); workstation characteristics (workers may sit, stand, walk with the line, or ride the line); and length of the line (few or many workers). The range of products partially or completely assembled on lines includes toys, appliances, autos, clothing and a wide variety of electronic components. In fact, virtually any product that has multiple parts and is produced in large volume uses assembly lines to some degree.

A more-challenging problem is the determination of the optimum configuration of operators and buffers in a production flow process. A major design consideration in production lines is the assignment of operation so that all stages are more or less equally loaded. Consider the case of traditional assembly lines illustrated in Fig.

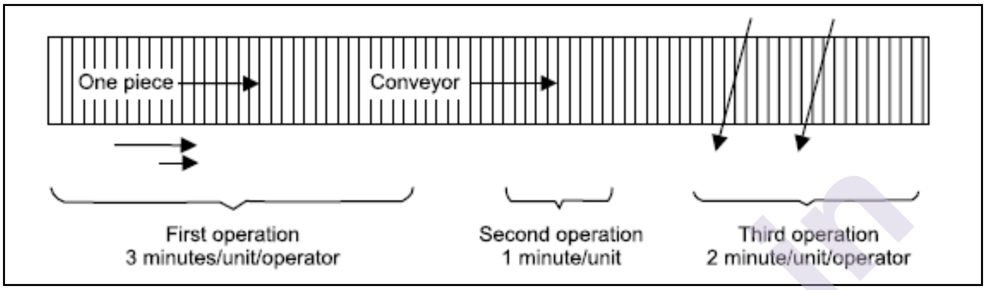


Fig. Traditional assembly line

In this example, parts move along a conveyor at a rate of one part per minute to three groups of workstations. The first operation requires 3 minutes per unit; the second operation requires 1 minute per unit; and the third requires 2 minutes per unit. The first workstation consists of three operators; the second, one operator; and the third, two operators. An operator removes a part from the conveyor and performs some assembly task at his or her workstation. The completed part is returned to the conveyor and transported to the next operation. The number of operators at each workstation was chosen so that the line is balanced. Since three operators work simultaneously at the first workstation, on the average one part will be completed each minute. This is also true for other two stations. Since the parts arrive at a rate of one per minute, parts are also completed at this rate.

Assembly-line systems work well when there is a low variance in the times required to perform the individual subassemblies. If the tasks are somewhat complex, thus resulting in a higher assembly-time variance, operators down the line may not be able to keep up with the flow of parts from the preceding workstation or may experience excessive idle time. An alternative to a conveyor-paced assembly-line is a sequence of workstations linked by gravity conveyors, which act as buffers between successive operations.

Line Balancing

Assembly-line balancing often has implications for layout. This would occur when, for balance purposes, workstation size or the number used would have to be physically modified. The most common assembly-line is a moving conveyor that passes a series of workstations in a uniform time interval called the **workstation cycle time** (which is also the time between successive units coming off the end of the line). At each workstation, work is performed on a product either by adding parts or by completing assembly operations. The work performed at each station is made up of many bits of work, termed tasks, elements, and work units. Such tasks are described by motion-time analysis. Generally, they are grouping that cannot be subdivided on the assembly-line without paying a penalty in extra motions. The total work to be performed at a workstation is equal to the sum of the tasks assigned to that workstation. The line-balancing problem is one of assigning all tasks to a series of workstations so that each workstation has no more than can be done in the workstation cycle time, and so that the unassigned (idle) time across all workstations is minimized. The problem is complicated by the relationships among tasks imposed by product design and process technologies. This is called the precedence relationship, which specifies the order in which tasks must be performed in the assembly process.

The steps in balancing an assembly line are:

1. Specify the sequential relationships among tasks using a precedence diagram.
2. Determine the required workstation cycle time C, using the formula

   C = (Production time per day / Required output per day (in units))
3. Determine the theoretical minimum number of workstations (Nt) required to satisfy the workstation cycle time constraint using the formula

   Nt = (Sum of task times (T)) / (Cycle time (C))
4. Select a primary rule by which tasks are to be assigned to workstations, and a secondary rule to break ties.
5. Assign tasks, once at a time, to the first workstation until the sum of the task times is equal to the workstation cycle time, or no other tasks are feasible because of time or sequence restrictions. Repeat the process for workstation 2, workstation 3, and so on until all tasks are assigned.
6. Evaluate the efficiency of the balance derived using the formula

   Efficiency =

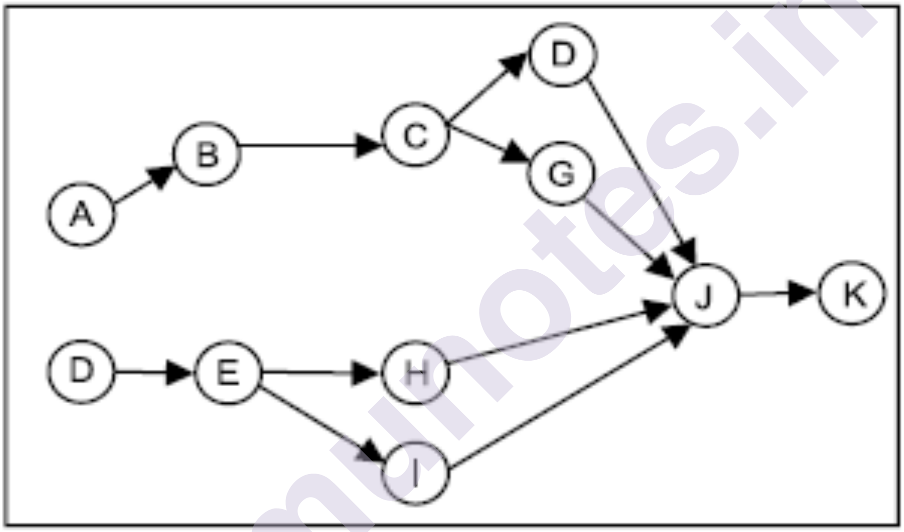
   [Sum of task times (T)] / [Actual number of workstations (Na) × Workstations cycle time (C)]
7. If efficiency is unsatisfactory, rebalance using a different decision rule.

Illustration 1: The MS 800 car is to be assembled on a conveyor belt. Five hundred cars are required per day. Production time per day is 420 minutes, and the assembly steps and times for the wagon are given below. Find the balance that minimizes the number of workstations, subject to cycle time and precedence constraints.

Task	Task time (in seconds)	Description	Tasks that must precede
A	45	Position rear axle support and hand fasten	-
B	11	Four screws to nuts	A
C	9	Insert rear axle	B
D	50	Tighten rear axle support screws to nuts	-
E	15	Position front axle assembly and hand	D
F	12	Fasten with four screws to nuts	C
G	12	Tighten front axle assembly screws	C
H	12	Position rear wheel 1 and fasten hubcap	E
I	12	Position rear wheel 2 and fasten hubcap	E
J	8	Position front wheel 1 and fasten hubcap	F, G, H, I
K	9	Position front wheel 2 and fasten hubcap	J

Solution

1. Draw a precedence diagram as follows:



2. Determine workstation cycle time. Here we have to convert production time to seconds because our task times are in seconds

$$C = \frac{\text{Production time per day}}{\text{Required output per day in units}}$$

$$= \frac{420 \text{ min X } 60 \text{ sec}}{500 \text{ cars}}$$

$$= \frac{25200}{500} = 50.4 \text{ secs}$$

3. Determine the theoretical minimum number of workstations required (the actual number may be greater)

Nt = T / C = 195 seconds / 50.4 seconds = 3.87 = 4

4. Select assignment rules.

(a) Prioritize tasks in order of the largest number of following tasks:

Task	Number of following tasks
A	6
B or D	5
C or E	4
F, G, H, or I	2
J	1
K	0

Our secondary rule, to be invoked where ties exist from our primary rule, is (b) Prioritize tasks in order of longest task time. Note that D should be assigned before B, and E assigned before C due to this tie-breaking rule.

5. Make task assignments to form workstation 1, workstation 2, and so forth until all tasks are assigned. It is important to meet precedence and cycle time requirements as the assignments are made.

Station	Task	Task time (in sec)	Remaining unassigned time (in sec)	Feasible remaining tasks	Task with most followers	Task with longest operation time
Station 1	A	45	5.4	Idle	None	
Station 2	D	50	0.4	Idle	None	
Station 3	B	11	39.4	C, E	C, E	E
	E	15	24.4	C, H, I	C	
	C	9	15.4	F, G, H, I	F, G, H, I	F, G, H, I
	F	12	3.4 idle	None		
Station 4	G	12	38.4	H, I	H, I	H, I
	H	12	26.4	I		
	I	12	14.4	J		
	J	8	6.4 idle	None		
Station 5	K	9	41.4 idle	None		

6. Calculate the efficiency.

Efficiency = T / NaC = [195 / (5 X 50.4)] = 0.77 or 77%

7. Evaluate the solution. An efficiency of 77 per cent indicates an imbalance or idle time of 23 per cent (1.0 – 0.77) across the entire line.

In addition to balancing a line for a given cycle time, managers must also consider four other options: pacing, behavioural factors, number of models produced, and cycle times.

Pacing is the movement of product from one station to the next after the cycle time has elapsed. Paced lines have no buffer inventory. Unpaced lines require inventory storage areas to be placed between stations.

Behavioural Factors

The most controversial aspect of product layout is behavioural response. Studies have shown that paced production and high specialization lower job satisfaction. One study has shown that productivity increased on unpaced lines. Many companies are exploring job enlargement and rotation to increase job variety and reduce excessive specialization. For example, New York Life has redesigned the jobs of workers who process and evaluate claims applications. Instead of using a production line approach with several workers doing specialized tasks, New York Life has made each worker solely responsible for an entire application. This approach increased worker responsibility and raised morale. In manufacturing, at its plant in Kohda, Japan, Sony Corporation dismantled the conveyor belts on which as many as 50 people assembled camcorders.

It set up tables for workers to assemble an entire camera themselves, doing everything from soldering to testing. Output per worker is up 10 per cent, because the approach frees efficient assemblers to make more products instead of limiting them to conveyor belt's speed. And if something goes wrong, only a small section of the plant is affected. This approach also allows the line to match actual demand better and avoid frequent shutdown because of inventory buildups.

Number of Models Produced

A mixed-model line produces several items belonging to the same family. A single-model line produces one model with no variations. Mixed model production enables a plant to achieve both high-volume production and product variety. However, it complicates scheduling and increases the need for good communication about the specific parts to be produced at each station.

Cycle Times

A line's cycle time depends on the desired output rate (or sometimes on the maximum number of workstations allowed). In turn, the maximum line efficiency varies considerably with the cycle time selected. Thus, exploring a range of cycle times makes sense. A manager might go with a particularly efficient solution even if it does not match the output rate. The manager can compensate for the mismatch by varying the number of hours the line operates through overtime, extending shifts, or adding shifts. Multiple lines might even be the answer.

4.4 DESIGN OF PROCESS LAYOUT

The analysis involved in the design of production lines and assembly lines relates primarily to timing, coordination, and balance among individual stages in the process.

For process layouts, the relative arrangement of departments and machines is the critical factor because of the large amount of transportation and handling involved.

Procedure for Designing Process Layouts

Process layout design determines the best relative locations of functional work centres. Work centres that interact frequently, with movement of material or people, should be located close together, whereas those that have little interaction can be spatially separated.

One approach of designing an efficient functional layout is described below.

- List and describe each functional work centre.
- Obtain a drawing and description of the facility being designed.
- Identify and estimate the amount of material and personnel flow among work centres
- Use structured analytical methods to obtain a good general layout.
- Evaluate and modify the layout, incorporating details such as machine orientation, storage area location, and equipment access.

The first step in the layout process is to identify and describe each work centre. The description should include the primary function of the work centre; drilling, new accounts, or cashier; its major components, including equipment and number of personnel; and the space required. The description should also include any special access needs (such as access to running water or an elevator) or restrictions (it must be in a clean area or away from heat).

For a new facility, the spatial configuration of the work centres and the size and shape of the facility are determined simultaneously. Determining the locations of special structures and fixtures such as elevators, loading docks, and bathrooms becomes part of the layout process.

However, in many cases the facility and its characteristics are given. In these situations, it is necessary to obtain a drawing of the facility being designed, including shape and dimensions, locations of fixed structures, and restrictions on activities, such as weight limits on certain parts of a floor or foundation.

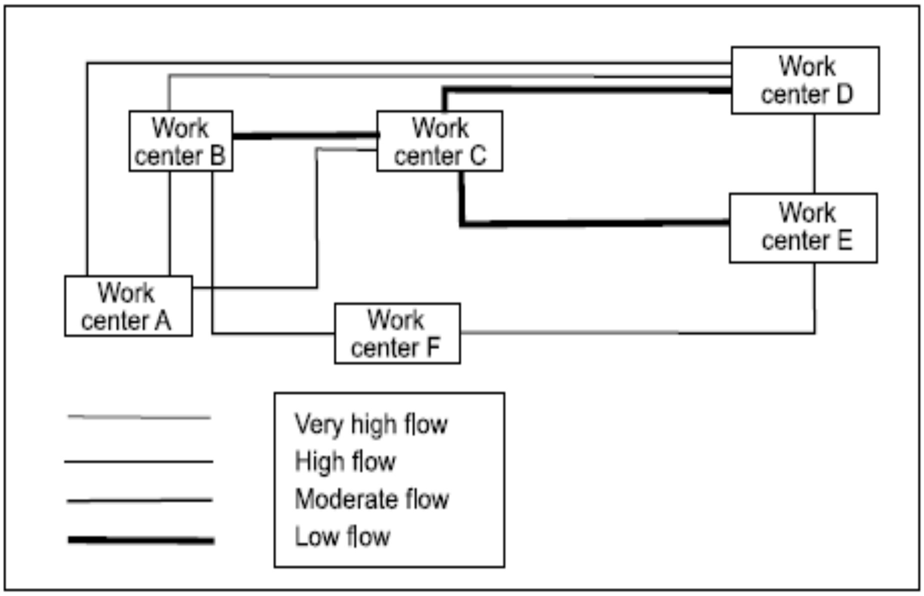


Fig. Relationship flow diagram

To minimize transport times and material-handling costs, we would like to place close together those work centres that have the greatest flow of materials and people between them.

To estimate the flows between work centres, it is helpful to begin by drawing relationship diagram as shown in Fig.

For manufacturing systems, material flows and transporting costs can be estimated reasonably well using historical routings for products or through work sampling techniques applied to workers or jobs. The flow of people, especially in a service system such as a business office or a university administration building, may be difficult to estimate precisely, although work sampling can be used to obtain rough estimates.

The amounts and/or costs of flows among work centres are usually presented using a flow matrix, a flow-cost matrix, or a proximity chart.

Flow Matrix

A flow matrix is a matrix of the estimated amounts of flow between each pair of work centres. The flow may be materials (expressed as the number of loads transported) or people who move between centres. Each work centre corresponds to one row and one column, and the element fij designates the amount of flow from work centre (row) i to work centre (column) j.

Normally, the direction of flow between work centres is not important, only the total amount, so fij and fji can be combined and the flows represented using only the upper right half of a matrix.

Flow Matrix Table

Work centre										
	A	B	C	D	E	F	G	H	I	
A	-	25	32	0	80	0	30	5	15	
B	-	-	20	10	30	75	0	7	10	Daily flows
C	-	-	-	0	10	50	45	60	0	between
D	-	-	-	-	35	0	25	90	120	work
E	-	-	-	-	-	20	80	0	70	centres
F	-	-	-	-	-	-	0	150	20	
G	-	-	-	-	-	-	-	50	45	
H	-	-	-	-	-	-	-	-	80	
I	-	-	-	-	-	-	-	-	-	

Flow-cost Matrix

A basic assumption of facility layout is that the cost of moving materials or people between work centers is a function of distance travelled. Although more complicated cost functions can be accommodated, often we assume that the per unit cost of material and personnel flows between work centres is proportional to the distance between the centres. So for each type of flow between each pair of departments, i and j, we estimate the cost per unit per unit distance, cij.

Flow-cost Matrix

Work centre										
	A	B	C	D	E	F	G	H	I	
A	-	25	32	0	80	0	30	5	15	
B	-	-	40	10	90	75	0	7	10	Daily cost
C	-	-	-	0	10	50	45	60	0	for flows
D	-	-	-	-	35	0	50	90	240	between
E	-	-	-	-	-	20	80	0	70	work centres
F	-	-	-	-	-	-	0	150	20	(Rs. per day
G	-	-	-	-	-	-	-	150	45	per 100 ft)
H	-	-	-	-	-	-	-	-	80	
I	-	-	-	-	-	-	-	-	-	

Proximity Chart

Proximity charts (relationship charts) are distinguished from flow and flow-cost matrices by the fact that they describe qualitatively the desirability or need for work centres to be close together, rather than providing quantitative measures of flow and cost. These charts are used when it is difficult to measure or estimate precise amounts or costs of flow among work centres. This is common when the primary flows involve people and do not have a direct cost but rather an indirect cost, such as when employees in a corporate headquarters move among departments (payroll, printing, information systems) to carry out their work.

4.5 SERVICE LAYOUT

The major factors considered for service providers, is an impact of location on sales and customer satisfaction. Customers usually look about how close a service facility is, particularly if the process requires considerable customer contact. Hence, service facility layouts should provide for easy entrance to these facilities from the freeways. Well-organized packing areas, easily accessible facilities, well designed walkways and parking areas are some of the requirements of service facility layout.

Service facility layout will be designed based on degree of customer contact and the service needed by a customer. These service layouts follow conventional layouts as required. For example, for car service station, product layout is adopted, where the activities for servicing a car follows a sequence of operation irrespective of the type of car. Hospital service is the best example for adaptation of process layout. Here, the service required for a customer will follow an independent path. The layout of car servicing and hospital is shown in Figs.

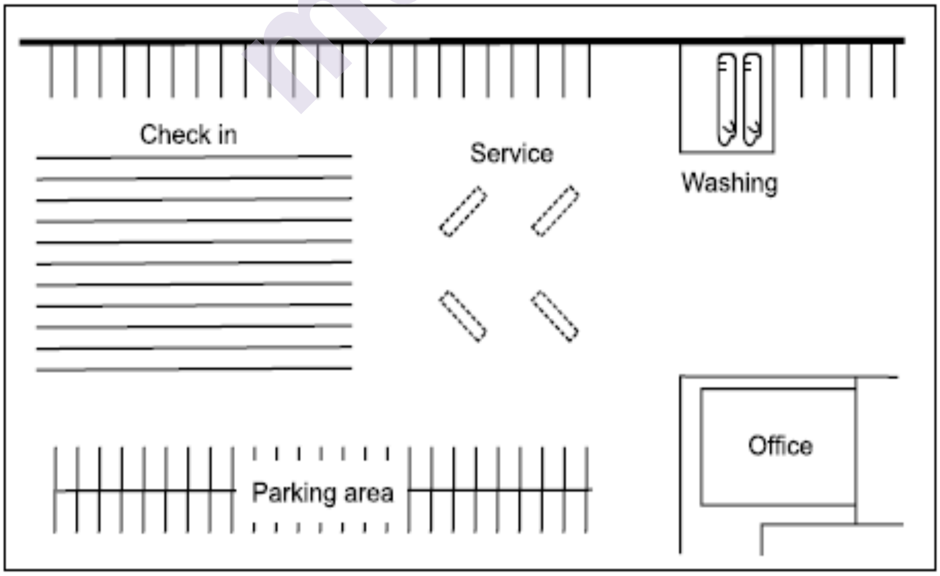


Fig. Service layout for car servicing

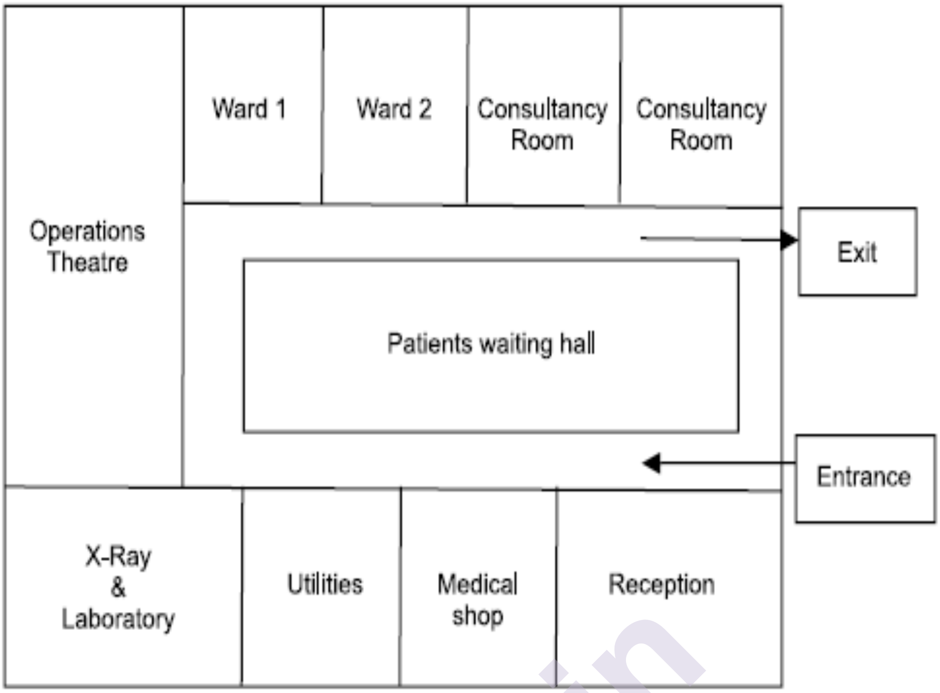


Fig. Layout for hospitality service

4.6 ORGANIZATION OF PHYSICAL FACILITIES

The following are the most important physical facilities to be organized:

- Factory building
- Lighting
- Climatic conditions
- Ventilation
- Work-related welfare facilities.

Factory Building

Factory building is a factor which is the most important consideration for every industrial enterprise. A modem factory building is required to provide protection for men, machines, materials, products or even the company's secrets. It has to serve as a part of the production facilities and as a factor to maximize economy and efficiency in plant operations. It should offer a pleasant and comfortable working environment and project the management's image and prestige. Factory building is like skin and bones of a living body for an organization. It is for these reasons that the factory building acquires great importance.

Following factors are considered for an Industrial Building:

A. Design of the building.

B. Types of buildings.

A. Design of the Building

The building should designed so as to provide a number of facilities—such as lunch rooms, cafeteria, locker rooms, crèches, libraries, first-aid and ambulance rooms, materials handling facilities, heating, ventilation, air-conditioning, etc. Following factors are considerations in the designing of a factory building:

1. **Flexibility:** Flexibility is one of the important considerations because the building is likely to become obsolete and provides greater operating efficiency even when processes and technology change. Flexibility is necessary because it is not always feasible and economical to build a new plant, every time a new firm is organized or the layout is changed. With minor alternations, the building should be able to accommodate different types of operations.

2. **Product and equipment:** The type of product that is to be manufactured, determines column-spacing, type of floor, ceiling, heating and air-conditioning. A product of a temporary nature may call for a less expensive building and that would be a product of a more permanent nature. Similarly, a heavy product demands a far more different building than a product which is light in weight.

3. **Expansibility:** Growth and expansion are natural to any manufacturing enterprises. They are the indicators of the prosperity of a business. The following factors should be borne in mind if the future expansion of the concern is to be provided for:

   (i) The area of the land which is to be acquired should be large enough to provide for the future expansion needs of the firm and accommodate current needs.

   (ii) The design of the building should be in a rectangular shape. Rectangular shapes facilitate expansion on any side.

   (iii) If vertical expansion is expected, strong foundations, supporters and columns must be provided.

   (iv) If horizontal expansion is expected, the side walls must be made non-load-bearing to provide for easy removal.

4. **Employee facilities and service area:** Employee facilities must find a proper place in the building design because they profoundly affect the morale, comfort and productivity. The building plan should include facilities for lunch rooms, cafeteria, water coolers, parking area and the like. The provision of some of these facilities is a legal requirement.

Others make good working conditions possible. And a good working condition is good business.

Service areas, such as the tool room, the supervisor's office, and the maintenance room, receiving and dispatching stations, the stock room and facilities for scrap disposal, should also be included in the building design.

B. Types of Buildings

Industrial buildings may be grouped under two types:

1. Single-storey buildings,

2. Multi-storey buildings.

The decision on choosing a suitable type for a particular firm depends on the manufacturing process and the area of land and the cost of construction.

1. Single-Storey Buildings

Most of the industrial buildings manufacturing which are now designed and constructed are single storeyed, particularly where lands are available at reasonable rates. Single-storey buildings offer several operating advantages. A single-storey construction is preferable when materials handling is difficult because the product is big or heavy, natural lighting is desired, heavy floor loads are required and frequent changes in layout are anticipated.

Advantages

Advantages of single-storey building are:

- There is a greater flexibility in layout and production routing.
- The maintenance cost resulting from the vibration of machinery is reduced considerably because of the housing of the machinery on the ground.
- Expansion is easily ensured by the removal of walls.
- The cost of transportation of materials is reduced because of the absence of materials handling equipment between floors.
- All the equipment is on the same level, making for an easier and more effective layout supervision and control.
- Greater floor load-bearing capacity for heavy equipment is ensured.
- The danger of fire hazards is reduced because of the lateral spread of the building.

Limitations

Single-storey buildings suffer from some limitations. These are:

- High cost of land, particularly in the city.
- High cost of heating, ventilating and cleaning of windows.
- High cost of transportation for moving men and materials to the factory which is generally located far from the city.

2. Multi-Storey Buildings

Schools, colleges, shopping complexes, and residences, and for service industries like Software, BPO etc. multi-storey structures are generally popular, particularly in cities. Multi-storey buildings are useful in manufacture of light products, when the acquisition of land becomes difficult and expensive and when the floor load is less.

Advantages

When constructed for industrial use, multi-storey buildings offer the following advantages:

- Maximum operating floor space (per sq. ft. of land). This is best suited in areas where land is very costly.
- Lower cost of heating and ventilation.
- Reduced cost of materials handling because the advantage of the use of gravity for the flow of materials.

Limitations

Following are the disadvantages of multi-storey building:

- Materials handling becomes very complicated. A lot of time is wasted in moving them between floors.
- A lot of floor space is wasted on elevators, stairways and fire escapes.
- Floor load-bearing capacity is limited, unless special construction is used, which is very expensive.
- Natural lighting is poor in the centres of the shop, particularly when the width of the building is somewhat great.
- Layout changes cannot be effected easily and quickly.
- Generally speaking, textile mills, food industries, detergent plants, chemical industries and software industry use these types of buildings.

II. Lighting

It is estimated that 80 per cent of the information required in doing job is perceived visually. Good visibility of the equipment, the product and the data involved in the work process is an essential factor in accelerating production, reducing the number of defective products, cutting down waste and preventing visual fatigue and headaches among the workers. It may also be added that both inadequate visibility and glare are frequently causes accidents.

In principle, lighting should be adapted to the type of work. However, the level of illumination, measured in should be increased not only in relation to the degree of precision or miniaturization of the work but also in relation to the worker's age. The accumulation of dust and the wear of the light sources cut down the level of illumination by 10–50 per cent of the original level. This gradual drop in the level should therefore be compensated for when designing the lighting system.

Regular cleaning of lighting fixture is obviously essential. Excessive contrasts in lighting levels between the worker's task and the general surroundings should also be avoided. The use of natural light should be encouraged. This can be achieved by installing windows that open, which are recommended to have an area equal to the time of day, the distance of workstations from the windows and the presence or absence of blinds. For this reason it is essential to have artificial lighting, will enable people to maintain proper vision and will ensure that the lighting intensity ratios between the task, the surrounding objects and the general environment are maintained.

Control of Lighting

In order to make the best use of lighting in the work place, the following points should be taken into account:

1. For uniform light distribution, install an independent switch for the row of lighting fixtures closest to the windows. This allows the lights to be switched on and off depending on whether or not natural light is sufficient.
2. To prevent glare, avoid using highly shiny, glossy work surfaces.
3. Use localized lighting in order to achieve the desired level for a particular fine job.
4. Clean light fixtures regularly and follow a maintenance schedule so as to prevent flickering of old bulbs and electrical hazards due to worn out cables.
5. Avoid direct eye contact with the light sources. This is usually achieved by positioning them properly. The use of diffusers is also quite effective.

III. Climatic Conditions

Control of the climatic conditions at the workplace is paramount importance to the workers' health and comfort and to the maintenance of higher productivity. With excess heat or cold, workers may feel very uncomfortable, and their efficiency drops. In addition, this can lead to accidents. This human body functions in such a way as to keep the central nervous system and the internal organs at a constant temperature. It maintains the necessary thermal balance by continuous heat exchange with the environment. It is essential to avoid excessive heat or cold, and wherever possible to keep the climatic conditions optimal so that the body can maintain a thermal balance.

Working in a Hot Environment

Hot working environments are found almost everywhere. Work premise in tropical countries may, on account of general climatic conditions, be naturally hot. When source of heat such as furnaces, kilns or hot processes are present, or when the physical workload is heavy, the human body may also have to deal with excess heat. It should be noted that in such hot working environments sweating is almost the only way in which the body can lose heat. As the sweat evaporates, the body cools. There is a relationship between the amount and speed of evaporation and a feeling of comfort. The more intense the evaporation, the quicker the body will cool and feel refreshed. Evaporation increases with adequate ventilation.

Working in a Cold Environment

Working in cold environments was once restricted to non-tropical or highly elevated regions. Now as a result of modern refrigeration, various groups of workers, even in tropical countries, are exposed to a cold environment. Exposure to cold for short periods of time can produce serious effects, especially when workers are exposed to temperatures below 10°C. The loss of body heat is uncomfortable and quickly affects work efficiency. Workers in cold climates and refrigerated premises should be well protected against the cold by wearing suitable clothes, including footwear, gloves and, most importantly, a hat. Normally, dressing in layers traps dead air and serves as an insulation layer, thus keeping the worker warmer.

Control of the Thermal Environment

There are many ways of controlling the thermal environment. It is relatively easy to assess the effects of thermal conditions, especially when excessive heat or cold is an obvious problem. To solve the problem, however, consistent efforts using a variety of available measures are usually necessary. This is because the problem is linked with the general climate, which greatly affects the workplace climate, production technology, which is often the source of heat or cold and varying conditions of the work premises as well as work methods and schedules. Personal factors such as clothing, nutrition, personal habits, and age and individual differences in response to the given thermal conditions also need to be taken into account in the attempt to attain the thermal comfort of workers.

In controlling the thermal environment, one or more of the following **principles** may be applied:

- Regulating workroom temperature by preventing outside heat or cold from entering (improved design of the roof, insulation material or installing an air-conditioned workroom.
- Air-conditioning is costly, especially in factories. But it is sometimes a worthwhile investment if an appropriate type is chosen);
- provision of ventilation in hot workplaces by increasing natural ventilating through openings or installing ventilation devices;
- separation of heat sources from the working area, insulation of hot surfaces and pipes, or placement of barriers between the heat sources and the workers;
- control of humidity with a view to keeping it at low levels, for example by preventing the escape of steam from pipes and equipment;
- Provision of adequate personal protective clothing and equipment for workers exposed to excessive radiant heat or excessive cold (heat-protective clothing with high insulation value may not be recommended for jobs with long exposure to moderate or heavy work as it prevents evaporative heat loss);
- Reduction of exposure time, for example, by mechanization, remote control or alternating work schedules;
- Insertion of rest pauses between work periods, with comfortable, if possible air-conditioned, resting facilities;
- Ensuring a supply of cold drinking-water for workers in a hot environment and of hot drinks for those exposed to a cold environment.

IV. Ventilation

Ventilation is the dynamic parameter that complements the concept of air space. For a given number of workers, the smaller the work premises the more should be the ventilation. Ventilation differs from air circulation. Ventilation replaces contaminated air by fresh air, whereas as the air-circulation merely moves the air without renewing it. Where the air temperature and humidity are high, merely to circulate the air is not only ineffective but also increases heat absorption. Ventilation disperses the heat generated by machines and people at work. Adequate ventilation should be looked upon as an important factor in maintaining the worker's health and productivity.

Except for confined spaces, all working premises have some minimum ventilation. However, to ensure the necessary air flow (which should not be lower than 50 cubic metres of air per hour per worker), air usually needs to be changed between four to eight times per hour in offices or for sedentary workers, between eight and 12 times per hour in workshops and as much as 15 to 30 or more times per hour for public premises and where there are high levels of atmospheric pollution or humidity. The air speed used for workplace ventilation should be adapted to the air temperature and the energy expenditure: for sedentary work it should exceed 0.2 metre per second, but for a hot environment the optimum speed is between 0.5 and 1 metre per second. For hazardous work it may be even higher. Certain types of hot work can be made tolerable by directing a stream of cold air at the workers.

Natural ventilation, obtained by opening windows or wall or roof airvents, may produce significant air flows but can normally be used only in relatively mild climates. The effectiveness of this type of ventilation depends largely on external conditions. Where natural ventilation is inadequate, artificial ventilation should be used. A choice may be made between a blown-air system, an exhaust air system or a combination of both ('push-pull' ventilation). Only 'push-pull' ventilation systems allow for better regulation of air movement.

V. Work-related Welfare Facilities

Work-related welfare facilities offered at or through the workplace can be important factors. Some facilities are very basic, but often ignored, such as drinking-water and toilets. Others may seem less necessary, but usually have an importance to workers far greater than their cost to the enterprise.

1. Drinking Water

Safe, cool drinking water is essential for all types of work, especially in a hot environment. Without it fatigue increases rapidly and productivity falls. Adequate drinking water should be provided and maintained at convenient points, and clearly marked as "Safe drinking water". Where possible it should be kept in suitable vessels, renewed at least daily and all practical steps taken to preserve the water and the vessels from contamination.

2. Sanitary Facilities

Hygienic sanitary facilities should exist in all workplaces. They are particularly important where chemicals or other dangerous substances are used. Sufficient toilet facilities, with separate facilities for men and women workers, should be installed and conveniently located. Changing rooms and cloakrooms should be provided. Washing facilities, such as washbasins with soap and towels, or showers, should be placed either within changing-rooms or close by.

3. **First-aid and Medical Facilities**

Facilities for rendering first-aid and medical care at the workplace in case of accidents or unforeseen sickness are directly related to the health and safety of the workers. First-aid boxes should be clearly marked and conveniently located. They should contain only first-aid requisites of a prescribed standard and should be in the charge of qualified person. Apart from first-aid boxes, it is also desirable to have a stretcher and suitable means to transport injured persons to a centre where medical care can be provided.

4. **Rest Facilities**

Rest facilities can include seat, rest-rooms, waiting rooms and shelters. They help workers to recover from fatigue and to get away from a noisy, polluted or isolated workstation. A sufficient number of suitable chairs or benches with backrests should be provided and maintained, including seats for occasional rest of workers who are obliged to work standing up. Rest-rooms enable workers to recover during meal and rest breaks.

5. **Feeding Facilities**

It is now well recognized that the health and work capacity of workers to have light refreshments are needed. A full meal at the workplace in necessary, when the workers live some distance away and when the hours of work are so organized that the meal breaks are short. A snack bar, buffet or mobile trolleys can provide tea, coffee and soft drinks, as well as light refreshments. Canteens or a restaurant can allow workers to purchase a cheap, well-cooked and nutritious meal for a reasonable price and eat in a clean, comfortable place, away from the workstation.

6. **Child-care Facilities**

Many employers find that working mothers are especially loyal and effective workers, but they often face the special problems of carrying for children. It is for this reason that child-care facilities, including crèches and day-care centres, should be provided. These should be in secure, airy, clean and well lit premises. Children should be looked after properly by qualified staff and offered food, drink education and play at very low cost.

7. **Recreational Facilities**

Recreational facilities offer workers the opportunity to spend their leisure time in activities likely to increase physical and mental well-being. They may also help to improve social relations within the enterprise. Such facilities can include halls for recreation and for indoor and outdoor sports, reading-rooms and libraries, clubs for hobbies, picnics and cinemas. Special educational and vocational training courses can also be organized.

4.7 LET US SUM UP

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

4.8 EXERCISES

1. What is plant layout?
2. Mention any four objectives of plant layout.
3. Explain the objectives of plant layout.
4. Explain the main principles of plant layout.
5. Explain the factors considered for an industrial building
6. Explain the different types of layouts.
7. Explain the physical facilities required in an organization/factory.

4.9 SUGGESTED READING

- Operations & Supply Chain Management by Chase, Shankar, Jocaobs
- Operations Management (6th Edition) by Nigel Slack, Stuart Chambers, Robert Johnston
- Theory & Problems in Production & Operations Management- S N Chary, Tata McGraw Hill
- Production & Operations Management -Kanishka Bedi , Oxford University Press
- Operations Management for competitive advantage-Chase & Jacob, McGraw-Hill/Irwin
- Production and Operations Management- Chunawalla & Patel, Himalaya Publishing

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5

INVENTORY MANAGEMENT, EOQ, ABC ANALYSIS, DISCOUNT POLICY

Unit Structure

5.0 OBJECTIVES

After going through this you will be able to understand the following concepts:

- Meaning of Inventory
- Reasons for Keeping Inventories
- Meaning of Inventory Control
- Objectives of Inventory Control
- Benefits of Inventory Control
- Techniques of Inventory Control
- Inventory Model.

5.1 MEANING OF INVENTORY

Inventory generally refers to the materials in stock. It is also called the idle resource of an enterprise. Inventories represent those items which are either stocked for sale or they are in the process of manufacturing or they are in the form of materials, which are yet to be utilised. The interval between receiving the purchased parts and transforming them into final products varies from industries to industries depending upon the cycle time of manufacture. It is, therefore, necessary to hold inventories of various kinds to act as a buffer between supply and demand for efficient operation of the system. Thus, an effective control on inventory is a must for smooth and efficient running of the production cycle with least interruptions.

5.2 REASONS FOR KEEPING INVENTORIES

You should visualize inventory as stacks of money sitting on forklifts, on shelves, and in trucks and planes while in transit. That's what inventory is—money. For many businesses, inventory is the largest asset on the balance sheet at any given time, even though it is often not very liquid. It is a good idea to try to get your inventory down as far as possible. The considerations or reasons for keepting the inventory are as under:

- **To stabilize production:** The demand for an item fluctuates because of the number of factors, e.g., seasonality, production schedule etc. The inventories (raw materials and components) should be made available to the production as per the demand failing which results in stock out and the production stoppage takes place for want of materials. Hence, the inventory is kept to take care of this fluctuation so that the production is smooth.

- **To take advantage of price discounts:** Usually the manufacturers offer discount for bulk buying and to gain this price advantage the materials are bought in bulk even though it is not required immediately. Thus, inventory is maintained to gain economy in purchasing.

- **To meet the demand during the replenishment period:** The lead time for procurement of materials depends upon many factors like location of the source, demand supply condition, etc. So inventory is maintained to meet the demand during the procurement (replenishment) period.

- **To prevent loss of orders (sales):** In this competitive scenario, one has to meet the delivery schedules at 100 per cent service level, means they cannot afford to miss the delivery schedule which may result in loss of sales. To avoid the organizations have to maintain inventory.

- **To keep pace with changing market conditions:** The organizations have to anticipate the changing market sentiments and they have to stock materials in anticipation of non-availability of materials or sudden increase in prices.

Sometimes the organizations have to stock materials due to other reasons like suppliers minimum quantity condition, seasonal availability of materials or sudden increase in prices.

5.3 MEANING OF INVENTORY CONTROL

Inventory control is a planned approach of determining what to order, when to order and how much to order and how much to stock so that costs associated with buying and storing are optimal without interrupting production and sales. Inventory control basically deals with two problems: (i) When should an order be placed? (Order level), and (ii) How much should be ordered (Order quantity)?

These questions are answered by the use of inventory models. The scientific inventory control system strikes the balance between the loss due to non-availability of an item and cost of carrying the stock of an item. Scientific inventory control aims at maintaining optimum level of stock of goods required by the company at minimum cost to the company.

5.4 OBJECTIVES OF INVENTORY CONTROL

- To ensure adequate supply of products to customer and avoid shortages as far as possible.
- To make sure that the financial investment in inventories is minimum (i.e., to see that the working capital is blocked to the minimum possible extent).
- Efficient purchasing, storing, consumption and accounting for materials is an important objective.
- To maintain timely record of inventories of all the items and to maintain the stock within the desired limits
- To ensure timely action for replenishment.
- To provide a reserve stock for variations in lead times of delivery of materials.
- To provide a scientific base for both short-term and long-term planning of materials.

5.5 BENEFITS OF INVENTORY CONTROL

It is an established fact that through the practice of scientific inventory control, following are the benefits of inventory control:

- Improvement in customer's relationship because of the timely delivery of goods and service.
- Smooth and uninterrupted production and, hence, no stock out.
- Efficient utilization of working capital. Helps in minimizing loss due to deterioration, obsolescence damage and pilferage.
- Economy in purchasing.
- Eliminates the possibility of duplicate ordering.

5.6 TECHNIQUES OF INVENTORY CONTROL

In any organization, depending on the type of business, inventory is maintained. When the number of items in inventory is large and then large amount of money is needed to create such inventory, it becomes the concern of the management to have a proper control over its ordering, procurement, maintenance and consumption. The control can be for order quality and order frequency.

The different techniques of inventory control are: (1) ABC analysis, (2) HML analysis, (3) VED analysis, (4) FSN analysis, (5) SDE analysis, (6) GOLF analysis and (7) SOS analysis.

The most widely used method of inventory control is known as ABC analysis. In this technique, the total inventory is categorized into three sub-heads and then proper exercise is exercised for each sub-heads.

1. **ABC analysis:** In this analysis, the classification of existing inventory is based on annual consumption and the annual value of the items. Hence we obtain the quantity of inventory item consumed during the year and multiply it by unit cost to obtain annual usage cost. The items are then arranged in the descending order of such annual usage cost. The analysis is carried out by drawing a graph based on the cumulative number of items and cumulative usage of consumption cost. Classification is done as follows:

Category	Percentage of items	Percentage of annual consumption value
A	10–20	70–80
B	20–30	10–25
C	60–70	5–15

The classification of ABC analysis is shown by the graph given as follows:

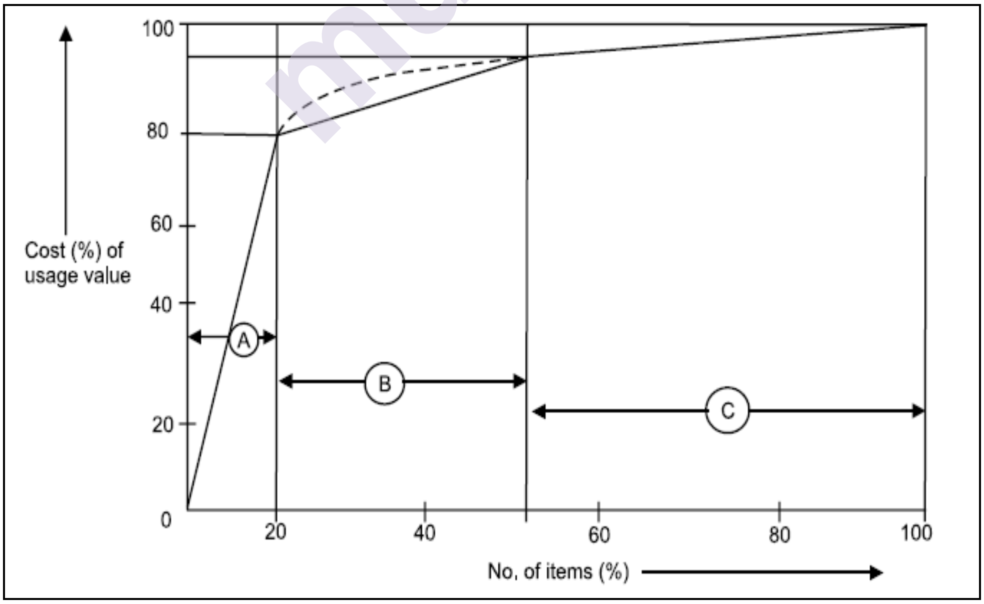


Fig. ABC classification

Once ABC classification has been achieved, the policy control can be formulated as follows:

(a) **A-Item:** Very tight control, the items being of high value. The control need be exercised at higher level of authority.

(b) **B-Item:** Moderate control, the items being of moderate value. The control need be exercised at middle level of authority.

(c) **C-Item:** The items being of low value, the control can be exercised at gross root level of authority, i.e., by respective user department managers.

2. **HML analysis**: In this analysis, the classification of existing inventory is based on unit price of the items. They are classified as high price, medium price and low cost items.

3. **VED analysis:** In this analysis, the classification of existing inventory is based on criticality of the items. They are classified as vital, essential and desirable items. It is mainly used in spare parts inventory.

4. **FSN analysis:** In this analysis, the classification of existing inventory is based consumption of the items. They are classified as fast moving, slow moving and non-moving items.

5. **SDE analysis:** In this analysis, the classification of existing inventory is based on the items.

6. **GOLF analysis:** In this analysis, the classification of existing inventory is based sources of the items. They are classified as Government supply, ordinarily available, local availability and foreign source of supply items.

7. **SOS analysis:** In this analysis, the classification of existing inventory is based nature of supply of items. They are classified as seasonal and off-seasonal items.

For effective inventory control, combination of the techniques of ABC with VED or ABC with HML or VED with HML analysis is practically used.

5.7 INVENTORY MODEL

Economic Order Quantity (EOQ)

Inventory models deal with idle resources like men, machines, money and materials. These models are concerned with two decisions: how much to order (purchase or produce) and when to order so as to minimize the total cost.

For the first decision—how much to order, there are two basic costs are considered namely, inventory carrying costs and the ordering or acquisition costs. As the quantity ordered is increased, the inventory carrying cost increases while the ordering cost decreases. The 'order quantity' means the quantity produced or procured during one production cycle. Economic order quantity is calculated by balancing the two costs. Economic Order Quantity (EOQ) is that size of order which minimizes total costs of carrying and cost of ordering. i.e., Minimum Total Cost occurs when Inventory Carrying Cost = Ordering Cost.

Economic order quantity can be determined by two methods:

1. Tabulation method. 2. Algebraic method.

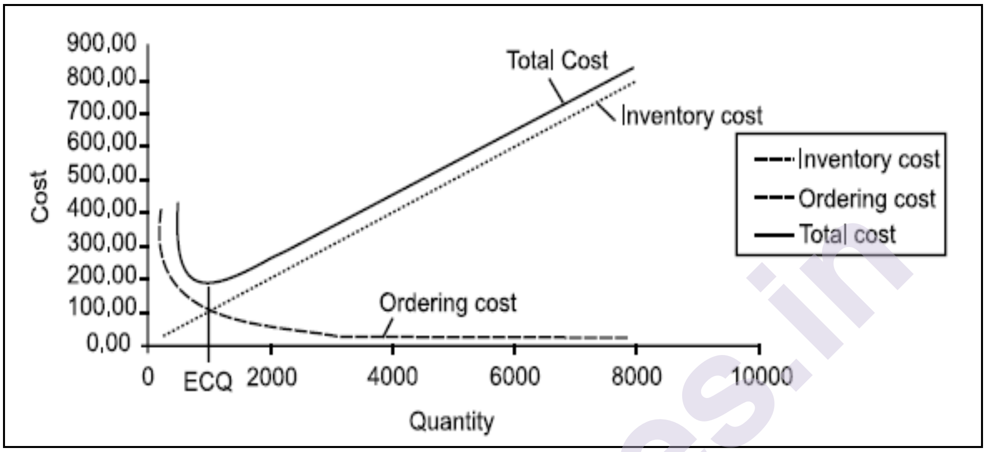


Fig. Inventory cost curve

1. **Determination of EOQ by tabulation (Trial & Error) method**

   This method involves the following steps:

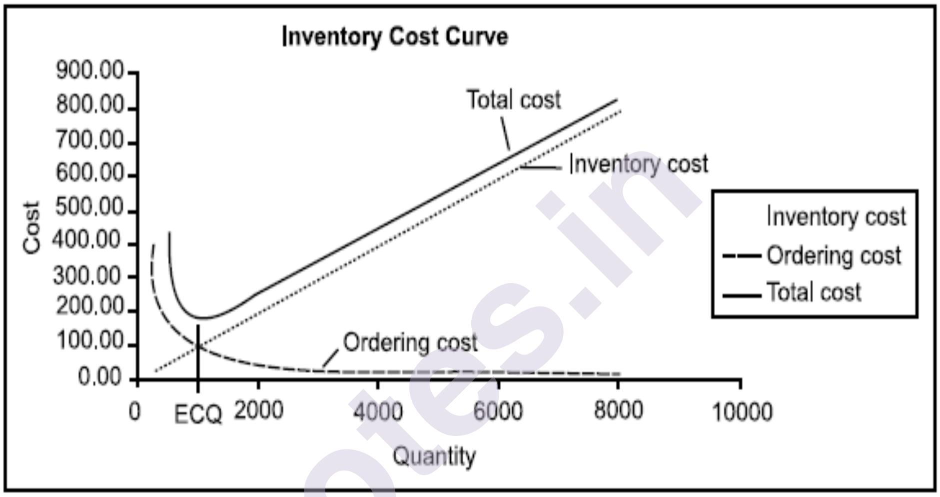
   - Select the number of possible lot sizes to purchase.
   - Determine average inventory carrying cost for the lot purchased.
     - (a) Determine the total ordering cost for the orders placed.
     - (b) Determine the total cost for each lot size chosen which is the summation of inventory carrying cost and ordering cost.
     - (c) Select the ordering quantity, which minimizes the total cost.

The data calculated in a tabular column can plotted showing the nature of total cost, inventory cost and ordering cost curve against the quantity ordered as in Fig. above.

Illustration 1: The XYZ Ltd. carries a wide assortment of items for its customers. One of its popular items has annual demand of 8000 units. Ordering cost per order is found to be Rs. 12.5. The carrying cost of average inventory is 20% per year and the cost per unit is Re. 1.00.

Determine the optimal economic quantity and make your recommendations.

No. of orders/ year (1)	Lot size (2)	Average inventory (3)	Carrying cost (4)	Ordering cost (5)	Total cost/ year (6) =(4) + (5)
1	8000	4000	800.00	12.5	812.50
2	4000	2000	400.00	25	425.00
4	2000	1000	200.00	50	250.00
8	1000	500	100.00	100	200.00
12	666.667	333.333	66.67	150	216.67
16	500	250	50.00	200	250.00



The table and the graph indicates that an order size of 1000 units will gives the lowest total cost among the different alternatives. It also shows that minimum total cost occurs when carrying cost is equal to ordering cost.

2. Determination of EOQ by analytical method

In order to derive an economic lot size formula following assumptions are made:

(a) Demand is known and uniform.

(b) Let D denotes the total number of units purchase/produced and Q denotes the lot size in each production run.

(c) Shortages are not permitted, i.e., as soon as the level of the inventory reaches zero, the inventory is replenished.

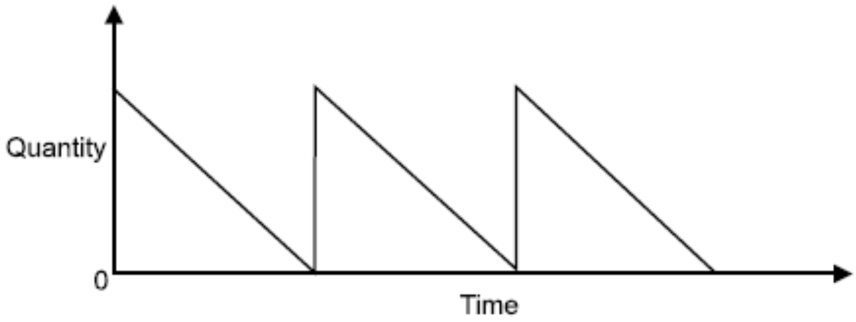
(d) Production or supply of commodity is instantaneous.

(e) Lead-time is zero.

(f) Set-up cost per production run or procurement cost is C_3.

(g) Inventory carrying cost is $C_1 = CI$, where C is the unit cost and I is called inventory carrying cost expressed as a percentage of the value of the average inventory.

This fundamental situation can be shown on an inventory-time diagram, with Q on the vertical axis and the time on the horizontal axis. The total time period (one year) is divided into n parts.



The most economic point in terms of total inventory cost exists where,

Inventory carrying cost = Annual ordering cost (set-up cost)

Average inventory = 1/2 (maximum level + minimum level)

= (Q + 0)/2 = Q/2

Total inventory carrying cost = Average inventory × Inventory carrying cost per unit

i.e., Total inventory carrying cost = $Q/2 \times C_1 = QC_1/2$

Total annual ordering costs = Number of orders per year × Ordering cost per order

i.e., Total annual ordering costs = $(D/Q) \times C_3 = (D/Q)\, C_3$

Now, summing up the total inventory cost and the total ordering cost, we get the total inventory cost C(Q).

i.e., Total cost of production run = Total inventory carrying cost + Total annual ordering costsC(Q) = $QC_1/2 + (D/Q)C_3$ (cost equation)

But, the total cost is minimum when the inventory carrying costs becomes equal to the total annual ordering costs. Therefore,

$$QC_1/2 = (D/Q)C_3$$

or $$QC_1 = (2D/Q)C_3$$

or $$Q^2 = 2C_3D/C_1$$

or $$Q = \sqrt{\frac{2C_3D}{C_1}}$$

i.e., Optimal quantity (EOQ), $Q_0 = \sqrt{\frac{2C_3D}{C_1}}$ ...(4)

$$\text{Optimum number of orders, } (N_0) = \frac{D}{Q_0} \quad ...(5)$$

$$\text{Optimum order interval, } (t_0) = \frac{365}{N_0} \text{ in days} = \frac{1}{N_0} \text{ in years or } (t_0) = \frac{Q_0}{D} \quad ...(6)$$

$$\text{Average yearly cost (TC)} = \sqrt{2C_3DC_1} \quad ...(7)$$

Illustration 2: An oil engine manufacturer purchases lubricants at the rate of Rs. 42 per piece from a vendor. The requirements of these lubricants are 1800 per year. What should be the ordering quantity per order, if the cost per placement of an order is Rs. 16 and inventory carrying charges per rupee per year is 20 paise.

Solution

Given data are:

Number of lubricants to be purchased, D = 1800 per year

Procurement cost, C_3 = Rs. 16 per order

Inventory carrying cost, CI = C_1 = Rs. 42 × Re. 0.20 = Rs. 8.40 per year

Then, optimal quantity (EOQ),

$$Q_0 = \sqrt{\frac{2C_3D}{C_1}}$$

Q_0= SQRT (2 ×16 ×1800 / 8.4)

= 82.8 or 83 lubricants (approx).

Illustration 3: A manufacturing company purchase 9000 parts of a machine for its annual requirements ordering for month usage at a time, each part costs Rs. 20. The ordering cost per order is Rs. 15 and carrying charges are 15% of the average inventory per year. You have been assigned to suggest a more economical purchase policy for the company. What advice you offer and how much would it save the company per year?

Solution

Given data are:

Number of lubricants to be purchased, D = 9000 parts per year

Cost of part, Cs = Rs. 20

Procurement cost, C_3 = Rs. 15 per order

Inventory carrying cost, CI = C_1 = 15% of average inventory per year

= Rs. 20 × 0.15 = Rs. 3 per each part per year

Then, optimal quantity (EOQ),

$$Q_0 = \sqrt{\frac{2C_3D}{C_1}}$$

Q_0= SQRT (2 ×15 ×9000 / 3)

Q_0 = 300 units

And

Optimum order interval, (t_0) = Q_0 / D in years = 300 / 9000 = 1 / 30 years

= (1 / 30) 365 days

= 122 Days

Minimum average cost = $\sqrt{2C_3DC_1}$ = SQRT (2 · 3 ·15 · 9000) = Rs. 900

If the company follows the policy of ordering every month, then the annual ordering cost is = Rs 12 × 15 = Rs. 180

Lot size of inventory each month = 9000/12 = 750

Average inventory at any time = Q/ 2 = 750/2 = 375

Therefore, storage cost at any time = 375 × C1 = 375 × 3 = Rs. 1125

Total annual cost = 1125 + 180 = Rs. 1305

Hence, the company should purchase 300 parts at time interval of 1/30 year instead of ordering 750 parts each month. The net saving of the company will be

= Rs. 1305 – Rs. 900 = Rs. 405 per year.

Discount Policy or Price-Break Model

The price-break model deals with the fact that, generally, the selling price of an item varies with the order size. This is a discrete or step change rather than a per-unit change. Based on the same assumptions as the EOQ model, the price-break model has a similar Qopt formula:

$$Q_{OPT} = \sqrt{\frac{2DS}{iC}} = \sqrt{\frac{2(\text{Annual Demand})(\text{Order or Setup Cost})}{\text{Annual Holding Cost}}}$$

i = percentage of unit cost attributed to carrying inventory

C = cost per unit

Since “C” changes for each price-break, the formula above will have to be used with each price-break cost value

Illustration 4: A company has a chance to reduce their inventory ordering costs by placing larger quantity orders using the price-break order quantity schedule below. What should their optimal order quantity be if this company purchases this single inventory item with an e-mail ordering cost of $4, a carrying cost rate of 2% of the inventory cost of the item, and an annual demand of 10,000 units?

Order Quantity(units)	Price/unit($)
0 to 2,499	$1.20
2,500 to 3,999	1.00
4,000 or more	.98

Solution:

First, plug data into formula for each price-break value of "C".

Annual Demand (D)= 10,000 units, Cost to place an order (S)= $4

Carrying cost % of total cost (i)= 2%, Cost per unit (C) = $1.20, $1.00, $0.98

Next, determine if the computed Qopt values are feasible or not

Interval from 0 to 2499, the Q_{opt} value is feasible

$$Q_{OPT} = \sqrt{\frac{2DS}{iC}} = \sqrt{\frac{2(10{,}000)(4)}{0.02(1.20)}} = 1{,}826 \text{ units}$$

Interval from 2500-3999, the Q_{opt} value is not feasible

$$Q_{OPT} = \sqrt{\frac{2DS}{iC}} = \sqrt{\frac{2(10{,}000)(4)}{0.02(1.00)}} = 2{,}000 \text{ units}$$

Interval from 4000 & more, the Q_{opt} value is not feasible

$$Q_{OPT} = \sqrt{\frac{2DS}{iC}} = \sqrt{\frac{2(10{,}000)(4)}{0.02(0.98)}} = 2{,}020 \text{ units}$$

Next, we plug the true Q_{opt} values into the total cost annual cost function to determine the total cost under each price-break.

$$TC = DC + \frac{D}{Q}S + \frac{Q}{2}iC$$

TC(0-2499)=(10000*1.20)+(10000/1826)*4+(1826/2)(0.02*1.20)

= $12,043.82

TC(2500-3999)= $10,041

TC(4000&more)= $9,949.20

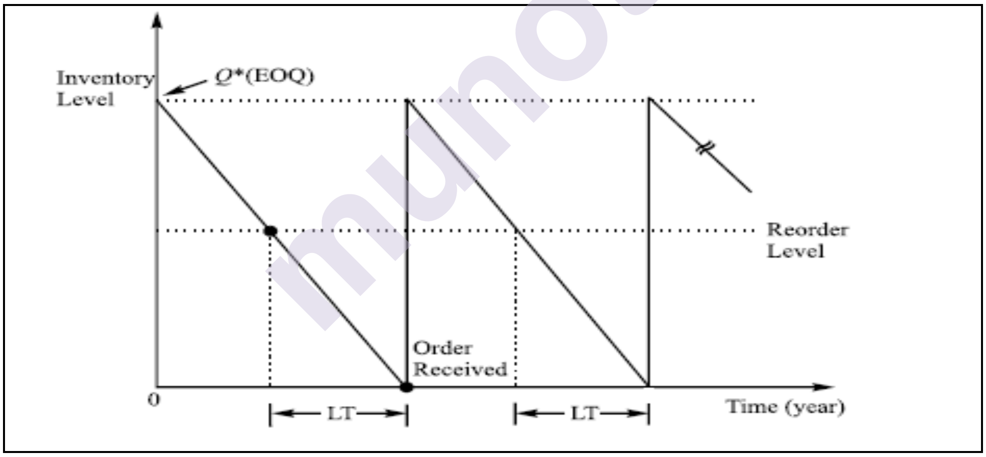
Finally, we select the least costly Q_{opt}, which is this problem occurs in the 4000 & more interval. In summary, our optimal order quantity is 4000 units.

Inventory Control Models with Uncertain Demand

The EOQ models discussed in previous sections were related to only one operating decision rule of inventory management: how much should be ordered (i.e. order quantity). In this section, another operating decision rule of inventory management: when should an order be placed for replenishment (i.e. reorder point) will be discussed.

Reorder Level with Constant Demand

When both demand and lead time are constant and known, the inventory level is monitored by a reorder level control policy. That is, when the inventory level reaches a particular level called reorder level (or point), a new order for replenishment is placed. The effective level of inventory at a particular point in time is: Stock in hand plus Stock on order minus outstanding order from the customers (if any). The outstanding order from the customers may be either customers back orders or allocations to production. In many cases no orders are outstanding when the reorder level is reached, so the reorder level is often thought of as only the number of units on hand. When both the demand and the lead time are constant and known (the stock in hand should be sufficient to meet the demand until the new order arrives. In such a case reorder level is calculated as:



Reorder level (ROL) = Demand during the replenishment lead time

$= d \times LT$

where d = demand (in units) rate per time period (e.g. daily, monthly, etc.)

LT = lead time (in time units)

Fig. above illustrates the demand and average lead time relationship at any particular time period.

Illustration 6: Demand for an item is 5,200 units per year and the EOQ is 250 units. If lead time is 2 weeks, then recorder level becomes:

ROL = 5200 / 52 units/week × 2 (weeks) = 100 × 2 = 200 units.

That is, as soon as the stock level falls to 200 units, replenishment order of, EOQ = 250 units should be placed. But this rule is possible only when lead time is less than the reorder cycle, $T = Q^*/d = 250/100 = 2.5$ weeks.

If lead time is, LT = 3 weeks, then ROL = 100 × 3 = 300 units. Since EOQ = 250 units, lead time demand of 300 units suggests that there exist an outstanding order of 50 units.

In general, the reorder policy is stated as: If lead time falls between $n \times T$ and $(n + 1)T$, then the replenishment order of size Q^* should be placed when stock on hand falls to the level $(d \times LT - n \times Q^*)$ where n is number of reorder cycle and lead time exceeds reorder cycle time, T.

Additional Stocks

When the demand rate and/or lead time are not known with certainty, additional stocks in the form of safety stock, reserve stock and buffer stock are maintained to guard against variability in both demand and lead time.

- The reserve stock is maintained to take care of variation in demand during reorder period,
- The safety stock is maintained to take care of variation in lead time.
- The buffer stock is maintained to take care of average demand during average lead time.

Both reserve stock and safety stock are added to balance inventory carrying cost resulting from the additional stock and the expected cost of shortages also to provide better customer service.

The level of additional stock to be maintained is based on the following four factors

- probability of stockout, i.e., nature and extent of variation in demand
- desired customer service level,
- probability of delay in lead time, and
- the maximum delay in lead time.

The buffer stock is calculated as:

Buffer stock (BS) = Average demand × Average lead time

Suppose, a firm had a demand of 100 units per month of an item and also the normal and the maximum replenishment lead time (LT) are 10 days and 30 days, respectively. Then buffer stock is given by:

$$\text{Buffer stock} = \frac{100}{30} \times \left(\frac{10+30}{2}\right) = 66.6 \text{ units}$$

When no stockouts are desired, the buffer stock is given by

Buffer stock = (Maximum demand during LT) – (Average demand during LT)

$$= d_{max} \times LT - \bar{d} \times LT = (d_{max} - \bar{d}) \times LT$$

The need to create buffer stock is shown in Fig. When a replenishment order is placed, variations in the demand during replenishment lead time indicate that the inventory level can drop to a point between A and C. But, if the variation in demand is equal to or less than the average demand, the inventory level reaches a point between A and B and the buffer stock is not needed. However, if the actual demand exceeds the average demand, and the inventory level reaches a point between B and C, then shortages will occur and buffer stock would be needed to avoid the shortages.

If demand varies around the average demand $(\bar{d})$ during a constant lead time (LT), then predicting the exact demand during replenishment lead time is difficult. In such a case the reorder level is defined as:

$$\text{Reorder level (ROL)} = \bar{d} \times LT$$

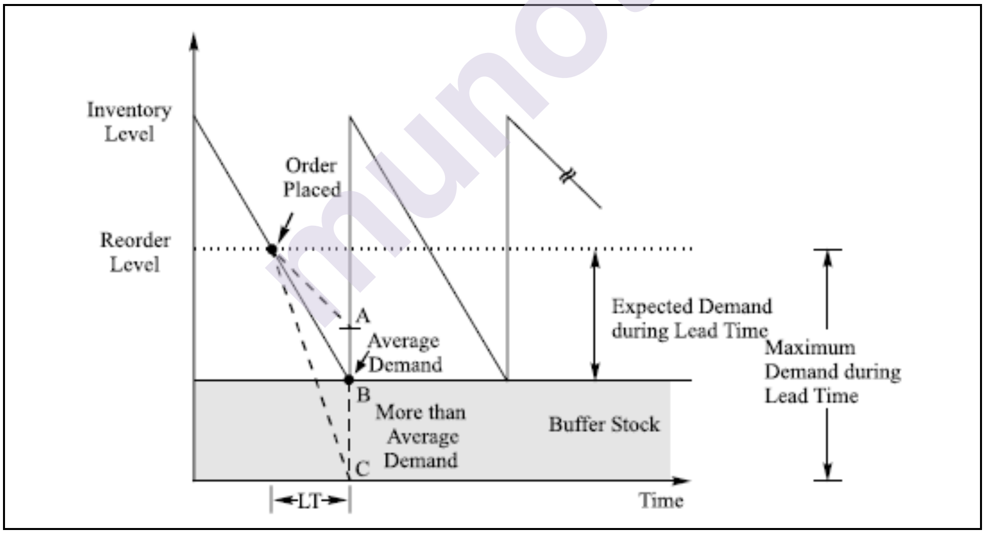


Fig. Buffer Stock to Meet Demand Variation

However, this policy of setting reorder level causes stockouts during replenishment lead time. Thus, the reorder level is readjusted taking into account an additional stock in the form of buffer stock available with the firm as follows:

$$\text{Reorder level} = \text{Buffer stock} + \bar{d} \times LT$$

Remarks

1. Quite often authors do not make distinction between the terms: buffer stock, safety stock and reserve stock.

2. These three types of additional stocks are added in order to calculate the recorder level. These are also used to maintain cushion in order to balance overstocking and understocking.

Illustration 7: The following information is provided for an item:

Annual demand: 12,000 units; Ordering cost: Rs 60 per order; Carrying cost: 10%; Unit cost of item: Rs 10, and Lead time: 10 days. There are 300 working days in a year. Determine EOQ and number of orders per year. In the past two years the demand rate has gone as high as 70 units per day. For a reordering system, based on the inventory level determine (a) buffer stock, (b) reorder level at this buffer stock, and (c) carrying costs for a year?

Solution: From the data of the problem, in usual notations, we have D = 12,000 units per year; C0 = Rs 60 per order; C = Rs 10 per unit; Ch = 10% of Rs 10 = Re 1 per unit/year and LT = 10 days

$$\text{EOQ}(Q^*) = \sqrt{\frac{2DC_0}{C_h}} = \sqrt{\frac{2 \times 12,000 \times 60}{1}} = \text{Rs } 1,200 \text{ units.}$$

$$\text{Number of orders} = \frac{D}{Q^*} = \frac{12,000}{1,200} = 10 \text{ per year.}$$

Thus, the average consumption is: 12,000/300 = 40 units per day, and the maximum consumption is: 70 units per day.

(a) Buffer stock = (Max. demand – Average demand) × LT = (70 – 40) × 10 = 30 × 10 = 300 units

(b) Reorder level = Average demand during LT + Buffer stock = 40 × 10 + 300 = 700 units

(c) Average inventory level = Buffer stock + (Q*/2) = 300 + (1,200/2) = 900 units

Inventory carrying cost = Average inventory level × Carrying cost/unit = 900 × 1 = Rs 900 per year

5.8 LET US SUM UP

The word inventory refers to any kind of resource that has economic value and is maintained to fulfill the present and future needs of an organization. During the study of this chapter we have

- understood the meaning of inventory control as well as various forms and functional role of inventory.
- calculated the economic order quantity (EOQ) for minimizing total inventory cost.

- computed the reorder level (ROL) to determine time of replenishment with known and unknown patterns of demand for inventory items.
- calculated and understand the use of buffer stock, safety stock and reserve stock with known and unknown stock out costs.
- use various selective inventory control techniques to classify inventory items into broad categories

Inventory of resources is held to provide desirable service to customers (users) and to achieve sales turnover target. Investment in large inventories adversely affects an organization’s cash flow. Working capital as investment in inventory represents substantial portion of the total capital investment in any business. It is, therefore, essential to balance the advantage of having inventory of resources and the cost of maintaining it so as to determine an optimal level of inventory of each resource. This would ensure that the total inventory cost is minimum.

5.9 EXERCISES

1. What do you mean by ‘Inventory Control’?
2. What is EOQ?
3. Explain the reasons for keeping inventories.
4. What are the objectives of inventory control?
5. What are the benefits of inventory control?

5.10 SUGGESTED READING

- Operations & Supply Chain Management by Chase, Shankar, Jocaobs
- Operations Management (6th Edition) by Nigel Slack, Stuart Chambers, Robert Johnston
- Theory & Problems in Production & Operations Management- S N Chary, Tata McGraw Hill
- Production & Operations Management -Kanishka Bedi , Oxford University Press
- Operations Management for competitive advantage-Chase & Jacob, McGraw-Hill/Irwin
- Production and Operations Management- Chunawalla & Patel, Himalaya Publishing

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6

CAPACITY AND INTRODUCTION TO AGGREGATE PLANNING, PPC

Unit Structure

6.0 OBJECTIVES

After going through this you will be able to understand the following concepts:

- Manufacturing and Service Systems
- Design and Systems Capacity
- Capacity Planning
- Process of Capacity Planning
- Aggregate Planning and the Variables used in Aggregate Planning
- Aggregate Planning Strategies
- Mixed Strategies
- Mathematical Planning Models
- Master Scheduling and Production Planning and Control

6.1 MANUFACTURING AND SERVICE SYSTEMS

Before products can flow into a market, someone must design and invest in the facilities and organisation to produce them for which the planning of the systems is needed to produce goods and services.

Capacity planning for manufacturing and service systems are different. Both must be designed with capacity limitations in mind. The approaches for long-term and short-term capacity planning will help the managers to make best use of resources.

Manufacturing and service systems are arrangements of facilities, equipment, and people to produce goods and services under controlled conditions.

Manufacturing systems produce standardized products in large volumes. This plant and machinery have a finite capacity and contribute fixed costs that must be borne by the products produced. Variable costs are added as labour is employed to combine or process the raw materials and other components. Value addition will takes place during the production process for the product. The cost of output relative to the cost of input can be measured, as the actual cost is known i.e. productivity is measurable quantity.

Service systems present more uncertainty with respect to both capacity and costs. Services are produced and consumed in the presence of the customer and there is little or no opportunity to store value, as in a finished goods inventory. As a result capacity of service systems like hospitals, restaurants and many other services must be sufficiently flexible to accommodate a highly variable demand. In addition, many services such as legal and medical involves professional or intellectual services judgments that are not easily standardized. This makes more difficult to accumulate costs and measure the productivity of the services.

6.2 DESIGN AND SYSTEMS CAPACITY

Production systems design involves planning for the inputs, transformation activities, and outputs of a production operation. Design plays a major role because they entail significant investment of funds and establish cost and productivity patterns that continue in future.

The capacity of the manufacturing unit can be expressed in number of units of output per period. In some situations measuring capacity is more complicated when they manufacture multiple products. In such situations, the capacity is expressed as man-hours or machine hours. The relationship between capacity and output is shown in the Figure

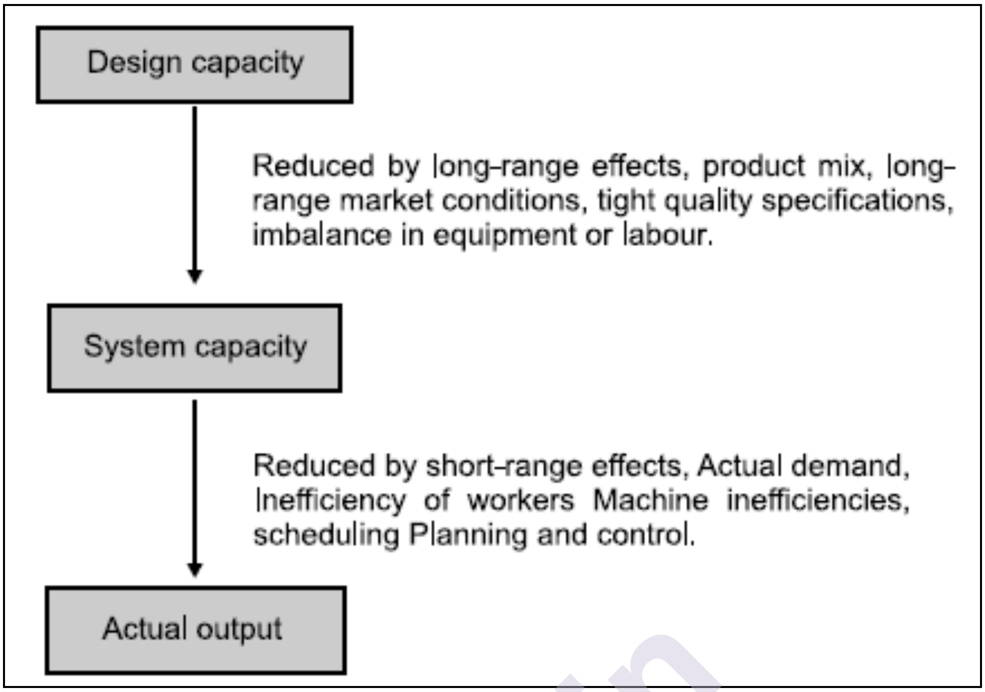


Fig. Capacity and output relationship

Design Capacity

Designed capacity of a facility is the planned or engineered rate of output of goods or services under normal or full scale operating conditions. For example, the designed capacity of the cement plant is 100 TPD (Tonnes per day). Capacity of the sugar factory is 150 tonnes of sugarcane crushing per day.

The uncertainty of future demand is one of the most perplexing problems faced by new facility planners. Organisation does not plan for enough regular capacity to satisfy all their immediate demands. Design for a minimum demand would result in high utilization of facilities but results in inferior service and dissatisfaction of customers because of inadequate capacity. The design capacity should reflect management's strategy for meeting the demand. The best approach is to plan for some in-between level of capacity.

System/effective capacity: System capacity is the maximum output of the specific product or product mix the system of workers and machines is capable of producing as an integrated whole. System capacity is less than design capacity or at the most equal it because of the limitation of product mix, quality specification, and breakdowns. The actual is even less because of many factors affecting the output such as actual demand, downtime due to machine/equipment failure, unauthorized absenteeism.

The system capacity is less than design capacity because of long-range uncontrollable factors. The actual output is still reduced because of short-term effects such as breakdown of equipment, inefficiency of labour. The system efficiency is expressed as ratio of actual measured output to the system capacity.

These different measures of capacity are useful in defining two measures of system effectiveness: efficiency and utilization.

Efficiency is the ratio of actual output to effective capacity.

Utilization is the ratio of actual output to design capacity.

$$\text{Efficiency} = \frac{\text{Actual output}}{\text{Effective capacity}}$$

$$\text{Utilization} = \frac{\text{Actual output}}{\text{Design capacity}}$$

It is common for managers to focus exclusively on efficiency, but in many instances, this emphasis can be misleading. This happens when effective capacity is low compared with design capacity. In those cases, high efficiency would seem to indicate effective use of resources when it does not.

6.3 CAPACITY PLANNING

Design of the production system involves planning for the inputs, conversion process and outputs of production operation. The effective management of capacity is the most important responsibility of production management. The objective of capacity management (i.e. planning and control of capacity) is to match the level of operations to the level of demand.

Capacity planning is to be carried out keeping in mind future growth and expansion plans, market trends, sales forecasting, etc. It is a simple task to plan the capacity in case of stable demand. But in practice the demand will be seldom stable. The fluctuation of demand creates problems regarding the procurement of resources to meet the customer demand. Capacity decisions are strategic in nature. Capacity is the rate of productive capability of a facility. Capacity is usually expressed as volume of output per period of time.

Production managers are more concerned about the capacity for the following reasons:

- Sufficient capacity is required to meet the customers demand in time.
- Capacity affects the cost efficiency of operations.
- Capacity affects the scheduling system.
- Capacity creation requires an investment.

Capacity planning is the first step when an organisation decides to produce more or new products.

6.4 PROCESS OF CAPACITY PLANNING

Capacity planning is concerned with defining the long-term and the short-term capacity needs of an organisation and determining how those needs will be satisfied. Capacity planning decisions are taken based upon the consumer demand and this is merged with the human, material and financial resources of the organisation. Capacity requirements can be evaluated from two perspectives—long-term capacity strategies and short-term capacity strategies.

1. **Long-term capacity strategies:** Long-term capacity requirements are more difficult to determine because the future demand and technology are uncertain. Forecasting for five or ten years into the future is more risky and difficult. Even sometimes company's today's products may not be existing in the future. Long-range capacity requirements are dependent on marketing plans, product development and life-cycle of the product. Long-term capacity planning is concerned with accommodating major changes that affect overall level of the output in long-term. Marketing environmental assessment and implementing the long-term capacity plans in a systematic manner are the major responsibilities of management. Following parameters will affect long-range capacity decisions.

   - **Multiple products**: Company's produce more than one product using the same facilities in order to increase the profit. The manufacturing of multiple products will reduce the risk of failure. Having more than on product helps the capacity planners to do a better job. Because products are in different stages of their life cycles, it is easy to schedule them to get maximum capacity utilization.

   - **Phasing in capacity:** In high technology industries, and in industries where technology developments are very fast, the rate of obsolescence is high. The products should be brought into the market quickly. The time to construct the facilities will be long and there is no much time, as the products should be introduced into the market quickly. Here the solution is phase in capacity on modular basis. Some commitment is made for building funds and men towards facilities over a period of 3-5 years. This is an effective way of capitalizing on technological breakthrough.

   - **Phasing out capacity:** The outdated manufacturing facilities cause excessive plant closures and down time. The impact of closures is not limited to only fixed costs of plant and machinery. Thus, the phasing out here is done with humanistic way without affecting the community. The phasing out options makes alternative arrangements for men like shifting them to other jobs or to other locations, compensating the employees, etc.

2. **Short-term capacity strategies:** Managers often use forecasts of product demand to estimate the short-term workload the facility must handle. Managers looking ahead up to 12 months, anticipate output requirements for different products, and services. Managers then compare requirements with existing capacity and then take decisions as to when the capacity adjustments are needed. For short-term periods of up to one year, fundamental capacity is fixed. Major facilities will not be changed. Many short-term adjustments for increasing or decreasing capacity are possible. The adjustments to be required depend upon the conversion process like whether it is capital intensive or labour intensive or whether product can be stored as inventory. Capital-intensive processes depend on physical facilities, plant and equipment. Short-term capacity can be modified by operating these facilities more or less intensively than normal. In labour intensive processes short-term capacity can be changed by laying off or hiring people or by giving overtime to workers. The strategies for changing capacity also depend upon how long the product can be stored as inventory.

   The short-term capacity strategies are:

   1. **Inventories:** Stock finished goods during slack periods to meet the demand during peak period.

   2. **Backlog:** During peak periods, the willing customers are requested to wait and their orders are fulfilled after a peak demand period.

   3. **Employment level (hiring or firing):** Hire additional employees during peak demand period and lay off employees as demand decreases.

   4. **Employee training:** Develop multi skilled employees through training so that they can be rotated among different jobs. The multi skilling helps as an alternative to hiring employees.

   5. **Subcontracting:** During peak periods, hire the capacity of other firms temporarily to make the component parts or products.

   6. **Process design:** Change job contents by redesigning the job.

6.5 IMPORTANCE OF CAPACITY DECISIONS

1. Capacity decisions have a real impact on the ability of the organisation to meet future demands for products and services; capacity essentially limits the rate of output possible. Having capacity to satisfy demand can allow a company to take advantage of tremendous opportunities.

2. Capacity decisions affect operating costs. Ideally, capacity and demand requirements will be matched, which will tend to minimize

operating costs. In practice, this is not always achieved because actual demand either differs from expected demand or tends to vary (e.g., cyclically). In such cases, a decision might be made to attempt to balance the costs of over and under capacity.

3. Capacity is usually a major determinant of initial cost. Typically, the greater the capacity of a productive unit, the greater is its cost. This does not necessarily imply a one for-one relationship; larger units tend to cost proportionately less than smaller units.

4. Capacity decisions often involve long-term commitment of resources and the fact that, once they are implemented, it may be difficult or impossible to modify those decisions without incurring major costs.

5. Capacity decisions can affect competitiveness. If a firm has excess capacity, or can quickly add capacity, that fact may serve as a barrier to entry by other firms. Then too, capacity can affect delivery speed, which can be a competitive advantage.

6. Capacity affects the ease of management; having appropriate capacity makes management easier than when capacity is mismatched.

Illustration 1: Given the information below, compute the efficiency and the utilization of the vehicle repair

Department: Design capacity = 50 trucks per day

Effective capacity = 40 trucks per day

Actual output = 36 trucks per day

Solution

$$\text{Efficiency} = \frac{\text{Actual output}}{\text{Effective capacity}} = \frac{36 \text{ trucks per day}}{40 \text{ trucks per day}} = 90\%$$

$$\text{Utilisation} = \frac{\text{Actual output}}{\text{Design capacity}} = \frac{36 \text{ trucks per day}}{50 \text{ trucks per day}} = 72\%$$

Illustration 2: The design capacity for engine repair in our company is 80 trucks per day. The effective capacity is 40 engines per day and the actual output is 36 engines per day. Calculate the utilization and efficiency of the operation. If the efficiency for next month is expected to be 82%, what is the expected output?

Solution

$$\text{Utilization} = \frac{\text{Actual output}}{\text{Design capacity}} = \frac{36}{40} = 45\%$$

$$\text{Efficiency} = \frac{\text{Actual output}}{\text{Effective capacity}} = \frac{36}{40} = 90\%$$

$$\begin{aligned}\text{Expected output} &= (\text{Effective capacity})(\text{Efficiency}) \\ &= (40)(0.82) = 32.8 \text{ engines per day}\end{aligned}$$

Illustration 3: Given: F = Fixed Cost = Rs. 1000, V = Variable cost = Rs. 2 per unit and P = Selling price = Rs. 4 per unit, Find the break-even point in Rs. and in units. Develop the break-even chart.

$$\text{Break-even point}(\$) = \text{BEP}(\$) = \frac{F}{1-\frac{V}{P}} = \frac{1000}{1-\frac{2}{4}} = \frac{1000}{0.5} = \$2,000$$

$$\text{Break-even point}(x) = \text{BEP}(x) = \frac{F}{P-V} = \frac{1000}{4-2} = 500$$

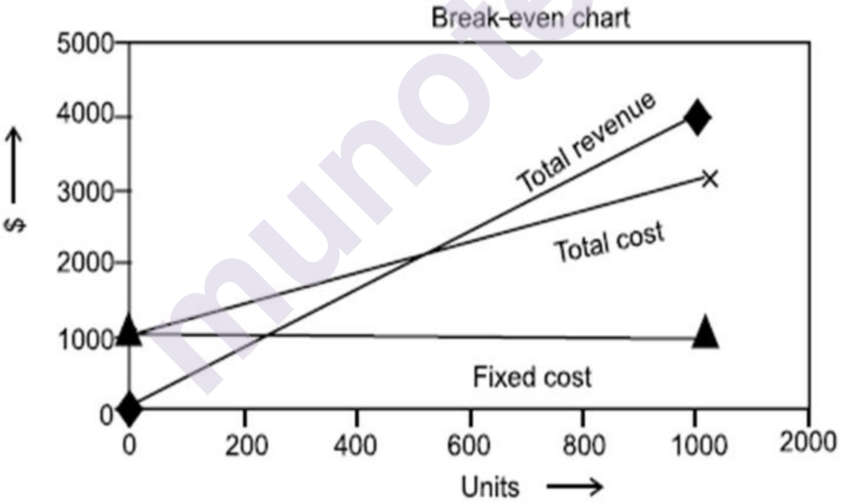


Illustration 4: Jack's Grocery is manufacturing a "store brand" item that has a

variable cost of Rs. 0.75 per unit and a selling price of Rs. 1.25 per unit. Fixed costs are Rs. 12,000. Current volume is 50,000 units. The Grocery can substantially improve the product quality by adding a new piece of equipment at an additional fixed cost of Rs. 5,000. Variable cost would increase to Rs. 1.00, but their volume should increase to 70,000 units due to the higher quality product. Should the company buy the new equipment? What are the break-even points (Rs. and units) for the two processes? Develop a break-even chart.

Solution

Profit = TR – TC

Option A: Current Equipment

BEP Sales in value (Rs.)

BEP Sales in Quantity (Units)

Option B: Adding New Equipment

BEP Sales in value (Rs.)

BEP Sales in Quantity (Units)

Option A:

Profit = 50000 * (1.25 – 0.75) –12000 = Rs.13000.

Option B: Add equipment:

Profit = 70000 * (1.25 – 1.00) – 17000 = Rs.500.

Therefore, the company should continue as is with the present equipment as this returns a higher profit.

Using current equipment:

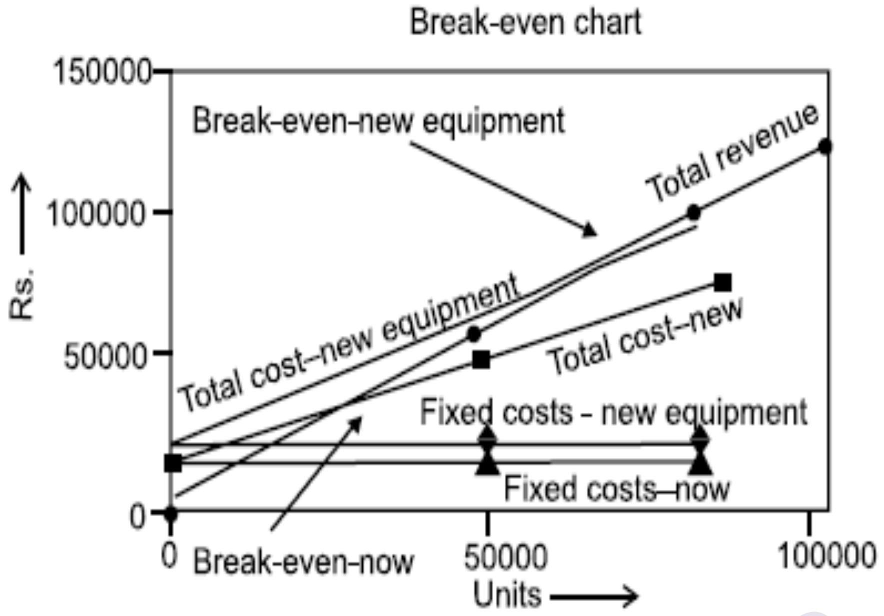
$$\text{BEP(sales is value)} = \frac{F}{1-\frac{V}{P}} = \frac{12,000}{1-\frac{0.75}{1.25}} = \frac{12,000}{1-0.60} = \frac{12,000}{0.40} = \text{Rs. } 30,000$$

$$\text{BEP(is quality)} = \frac{F}{P-V} = \frac{12,000}{1.25-0.75} = 24,000 \text{ units}$$

Adding a new equipment:

$$\text{BEP (sales is value)} = \frac{F}{1-\frac{V}{P}} = \frac{17,000}{1-\frac{1.00}{1.25}} = \frac{17,000}{1-0.80} = \frac{17,000}{0.2} = \text{Rs. } 85,000.$$

$$\text{BEP(is quality)} = \frac{F}{P-V} = \frac{17,000}{1.25-1.00} = \frac{17,000}{0.25} = 68,000 \text{ units}$$



6.6 WHAT IS AGGREGATE PLANNING? WHAT ARE THE VARIABLES USED IN AGGREGATE PLANNING?

What is aggregate Planning?

Aggregate planning is the process of planning the quantity and timing of output over the intermediate range (often 3 to 18 months) by adjusting the production rate, employment, inventory, and other controllable variables. Aggregate planning links long-range and short-range planning activities. It is "aggregate" in the sense that the planning activities at this early stage are concerned with homogeneous categories (families) such as gross volumes of products or number of customers served.

Master scheduling follows aggregate planning and expresses the overall plan in terms of the amounts of specific end items to produce and dates to produce them. It uses information from both forecasts and orders on hand, and it is the major control (driver) of all production activities. Table below illustrates a simplified aggregate plan and master schedule.

Aggregate plan and master schedule for electric motors

Aggregate Plan

Month	J	F	M	A	M	J	J	A	S
No. of Motors	40	25	55	30	30	50	30	60	40

Master Schedule

Month	J	F	M	A	M	J	J	A	S
AC motors	-	-	-	-	-	-	-	-	-
5hp	15	-	30	-	-	30	-	-	10
25hp	20	25	25	15	15	15	20	30	20
DC Motors	-	-	-	-	-	-	-	-	-
20hp	-	-	-	-	-	-	10	10	-
ER Motors	-	-	-	-	-	-	-	-	-
10hp	5	-	-	15	15	5	-	20	10

What are the Variables used in Aggregate Planning?

Aggregate planning is a complex problem largely because of the need to coordinate interacting variables in order for the firm to respond to the (uncertain) demand in an effective way. Table below identifies some of the key variables available to planners and the costs associated with them.

	Decision variable		Associated cost
1	Varying size of work force	1	Hiring, training, and layoff costs
2	Using overtime or accepting idle time	2	Wage premiums and non-productive time costs
3	Varying inventory levels	3	Carrying and storage costs
4	Accepting back orders	4	Stockout costs of lost orders
5	Subcontracting work to others	5	Higher labour and material costs
6	Changing the use of existing capacity	6	Delayed response and higher fixed costs

To best understand the effect of changes in these variables, it is useful to first focus upon the impact of a change in only one variable at a time, with other variables held constant. The examples that follow show the effect on production costs of (isolated) changes in the decision variables. They are presented in a simplified format in order to best convey the underlying concept; more realistic examples follow in later sections.

Illustration 1: Paris Candy Company has estimated its quarterly demand (cases) as shown in Table and Figure. It expects the next demand cycle to be similar to this one and wishes to restore ending inventory, employment, etc., to beginning levels accordingly.

Each quarterly change of 200 units output has an incremental labour cost of Rs. 2,000 and ending levels must be restored to initial levels. What is the cost associated with changing the work force size?

Demand	
Quarter	Units
1st	500
2nd	900
3rd	700
4th	300

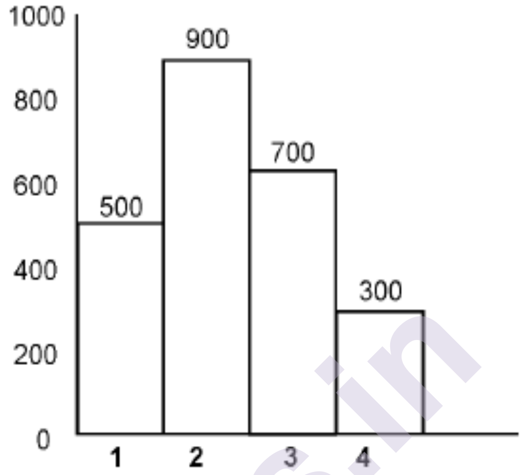


Fig. Histogram of demand

Solution

Six changes of work force have to be made. Employment change cost = 6 (Rs.2,000)

= Rs.12,000.

Period	Demand	Work force required	Change of work	Cost
1	500	3	1	2000
2	900	5	2	4000
3	700	4	1	2000
4	300	2	2	4000

Illustration 2: (Overtime and idle time) Maintain a stable work force capable of producing 600 units per quarter, and use OT (at Rs. 5 per unit) and IT (at Rs. 20 per unit).

Solution

As shown in Table, 400 units will be produced on overtime, and workers will be idle when 400 units could have been produced. Total cost is Rs.10000.

Period	Demand	OT production (units)	Idle Time (IT) capacity (units)	Cost in Rs.
1	500	-	100	2000
2	900	300	-	1500
3	700	100	-	500
4	300	-	300	6000
		Total cost		10000

ILLUSTRATION 3: Vary inventories: Vary inventory levels, but maintain a stable work force producing at an average requirement rate (of 2,400 units + 4 quarters = 600 units per quarter) with no OT or IT. The carrying cost (based on average inventory) is Rs. 32 per unit per year, and the firm can arrange to have whatever inventory level is required before period I at no additional cost. Annual storage cost (based on maximum inventory) is Rs. 5 per unit.

Solution

Quarter	Forecast	Rate of production	Change in inventory	Cls. balance	End balance
1	500	600	100	100	400
2	900	600	–300	–200	100
3	700	600	–100	–300	0
4	300	600	300	0	300
Total	2400				800

As shown in Table, inventory is accumulated during quarters 1 and 4, and depleted in quarters 2 and 3. The preliminary inventory balance column shows a negative inventory of 300 in quarter 3, so 300 must be on hand at the beginning of quarter 1 to prevent any shortage. The average inventory on hand is the ending balance total of 800 units divided by 4 quarters = 200 units.

Carrying cost, Cc (on avg. inventory) = (Rs. 32 per unit-yr) (200 units) = Rs. 6,400

Storage cost,Cs (on max. inventory) = (Rs. 5 per unit) (400 units) = Rs. 2,000

Total inventory cost (Cc + Cs) = Rs. 8,400

Illustration 4: Back orders: Produce at a steady rate of 500 units per period, and accept a limited number of back orders when demand exceeds 500. The Stockout cost of lost sales is Rs. 20 per unit.

Solution: A back order is an arrangement to fill a current order during a later period. Stockout costs occur when some sales (or customers) are lost because products are not immediately available. In this example, 200 units of the excess demand in period 2 are placed on back order for delivery in period 4. The other 200 units demanded in period 2 are lost, along with the 200 in period 3.

Stockout cost = (200 + 200) (Rs.20 per unit) = Rs. 8,000

Illustration 5: Subcontract: Produce at a steady rate of 300 units per period, and subcontract for excess requirements at a marginal cost of Rs. 8 per unit.

Solution: The firm must subcontract 200 units in period 1, 600 in period 2, and 400 in period 3, as shown in table.

Subcontract cost = (1200)(Rs. 8 per unit) = Rs.9,600

Of the five decision variables considered above, accepting back orders results in the least cost (Rs. 8,000).

Qt.	Demand unit	Rs.	Subcontract
1	500	300	200
2	900	300	600
3	700	300	400
4	300	300	400
		Total	1200

6.7 AGGREGATE PLANNING STRATEGIES

Several different strategies have been employed to assist in aggregate planning. Three “pure” strategies are recognized. The pure strategies stem from early models that depicted production results when only one of the decision variables was permitted to vary all others being held constant.

Three focused strategies are:

1. **Vary production to match demand by changes in employment (Chase demand strategy):** This strategy permits hiring and layoff of workers, use of overtime, and subcontracting as required in each period. However, inventory build-up is not used.

2. **Produce at a constant rate and use inventories. (Level production strategy):** This strategy retains a stable work force producing at a constant output rate. Inventory can be accumulated to satisfy peak demands. In addition, subcontracting is allowed and back orders can be accepted. Promotional programmes may also be used to shift demand.

3. **Produce with stable workforce but vary the utilization rate (Stable work-force strategy):** This strategy retains a stable work force but permits overtime, part-time, and idle time. Some versions of this strategy permit back orders, subcontracting, and use of inventories. Although this strategy uses overtime, it avoids the detrimental effects of layoff.

We can use the following data in Figs to illustrate the three focused strategies described above. These figures display a histogram of a 9-month forecast for motors. The total requirement for the 9 months is 360 motors. This works out to an average (mean) of 40 motors per month, which is shown as a dotted line in Figure.

Table

Month	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Total
Forecast	40	25	55	30	30	50	30	60	40	360
Cumulative Demand	40	65	120	150	180	230	260	320	360	

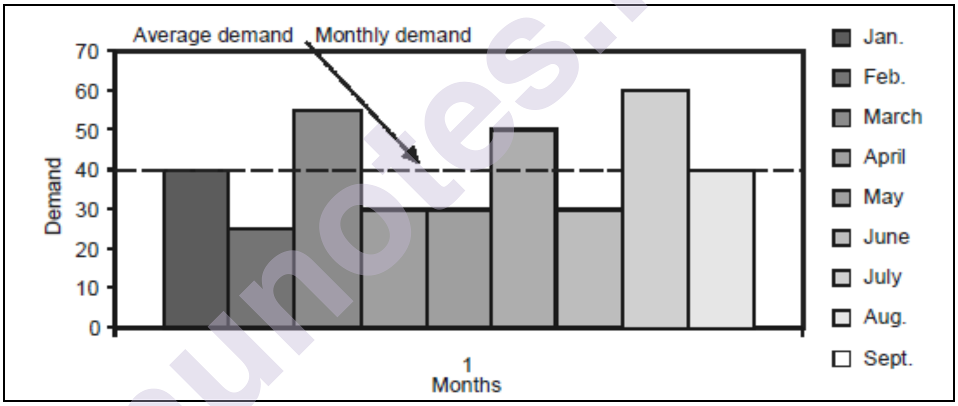


Fig.

1. **Chase Strategy:** If the production planner designed a plan to exactly match the forecast of demand shown in Figure, by adding or laying off employees to change the level of production, the planner would be using a chase strategy. Some overtime or subcontracting might also be used, but no inventories would be accumulated.

2. **Level Production Strategy:** The graph in Figure shows (visually) that the demand exceeds the average requirement in some months and is below average in others. A production plan could be developed to produce at the constant rate of 40 motors per month, accumulating inventory in months 2, 4, 5, and 7, and using that inventory to meet the above average demands in months 3, 6, and 8. Table shows that the cumulative demand (forecast) never exceeds the cumulative averages (production), so no initial inventory is needed to prevent shortages. However, if there were shortages, some back orders could be allowed under a level production, or inventory strategy.

3. **Stable Work-Force Strategy**: Referring to Figure, suppose the firm has a stable work force capable of producing 36 motors per month on regular time. Production might go as high as 60 motors per month by using overtime, but if demand falls to less than 36 motors per month, some workers would be idle. Using overtime and idle time to meet demand would be employing a stable work-force strategy. As part of this strategy, however, it seems likely that planners would build up some inventory during what might otherwise be idle time periods.

Illustration 6: An aggregate plan is to be developed for the forecast of demand covering nine periods shown in Table. Other relevant production and cost information is also provided. Find the cost associated with an aggregate plan that involves varying the size of the work force in order to have a production rate that matches demand.

Note: Since this plan does not allow for any inventory buildup, a decision has been made to carry 10 units of safety stock, but no overtime or subcontract labour is used.

Table: Demand, production, and cost information

Month	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Total
Forecast	40	25	55	30	30	50	30	60	40	360

Production information		Cost information	
Current number workers	10	Hiring cost	Rs.600/employee
Worker time/month	160 hr	Layoff cost	Rs.500/employee
Time to produce one unit	40 hr	Regular-time cost	Rs. 30/hr
Individual worker output:		Overtime cost	Rs. 45/hr
(160 hr/mo/40 hr/unit)	4 units	Subcontract labor cost	Rs. 50/hr
Safety stock of inventory required	10 units	Inventory carrying cost	Rs. 35/period

Solution: The cost associated with changing the employment level is calculated in Table below. The number of workers required is first determined by dividing the forecast amount by the worker output of 4 units per month. Fractional values have been rounded up. Beginning with the current level of 10 workers, the number that must be hired, or laid off, is then determined. Costs are then computed for (1) regular-time hours, (2) hiring and layoff, and (3) carrying safety stock. These are added to get the total plan cost of Rs. 470,450.

Table: Cost calculations for varying work force to match demand

PERIOD	1	2	3	4	5	6	7	8	9
Production forecast (units/mo)	40	25	55	30	30	50	30	60	40
WORK-FORCE SIZE DATA									
No. Workers required (fost./o/p of 4 units/wk-mo)	10	7	14	8	8	13	8	15	10
(a) No. hired @ beg. of mo	0	0	7	0	0	5	0	7	0
(b)No. laid off @ beg. of mo	0	3	0	6	0	0	5	0	5
COSTS									
Regular time cost, Rs. (No. Wkr)(Rs.30/wkr-hr) (l60 hr/wkr-mo)	48, 000	33,600	67,200	38,400		38,400	62,400	38,400	72,000
Hiring or layoff cost, Rs.: @(a) (Rs.600) or (b) (Rs.500)	0	1,500	4,200	3,00	0	3,000	2,500	4,200	2,500
Inventory carrying cost (10 units) (Rs.35/unit-period)	350	350	350	350	350	350	350	350	350
Total cost for plan = SRegular-time employment + SHiring and layoff + SInventory carrying cost = Rs. 446,400 + Rs. 20,900 + Rs. 3,150 = Rs. 470,450									

Illustration 7: Produce at a constant rate: Using the demand shown in previous Table (plus 10 more units in periods 8 and 9), develop an aggregate plan based upon the use of the 10 regular-time production workers at a constant rate, with inventories used to satisfy peak demand. The inventory carrying cost is Rs. 35 per unit per period. Some subcontracting can be used at a labour cost of Rs. 50 per hour if necessary. Assume a constant output rate of 40 units per period. No safety stock is required, but total demand of 380 units must be met.

The costs associated with producing at a constant rate and using— inventories to help meet non-uniform demands are shown in below Table. Note that the constant production rate of 40 units per period yields 360 units, which is 20 units short of total demand. Insofar as the additional demand is in periods 8 and 9—when demand already consumes all production-the additional demand will be subcontracted out in these two periods. The labour cost for each subcontracted unit is (40 hours per unit) (Rs. 50 per hour) = Rs. 2,000 per unit, so for the 10 units in periods 8 and 9, the subcontracting costs is Rs. 20,000 in each period.

Table: Costs calculation for using inventories to meet demand

Period	1	2	3	4	5	6	7	8	9
Production forecast	40	25	55	30	30	50	30	70	50
PRODUCTION DATA									
Output: Regular time	40	40	40	40	40	40	40	40	40
Subcontract	–	–	–	–	–	–	–	10	10
Output-forecast	0	15	–15	10	10	–10	10	–20	0
Inventory:									
Beginning-of-period	0	0	15	0	10	20	10	20	0
End-of-period	0	15	0	10	20	10	20	0	0
Average inventory	0	7.5	7.5	5	15	15	15	10	0
COSTS									
Regular-time cost, Rs. (L0)(Rs.30/hr)(L60 hr)	48,000	48,000	48,000	48,000	48,000	48,000	48,000	48,000	48,000
Subcontract (@ Rs. 2,000/per unit)	–	–	–	–	–	–	–	20,000	20,000
Inventory carrying cost (avg. inv.) (Rs.35/period)	0	263	263	175	525	525	525	350	0

Total cost for plan = SRegular-time employment + SSubcontract cost + SInventory carrying cost

= Rs. 432,000 + Rs. 40,000 + Rs. 2,826

= Rs. 474,826

Inventory costs under this format are computed by first determining how many units go into (or out of) inventory. This amount (i.e., the output minus production forecast) is shown in the table. For period 1, where forecast and output are both 40 units, it is zero. For period 2, when 40 units are produced and only 25 are needed, 15 go into inventory. The beginning- and end-of-period inventory rows in the table show how the inventory balance fluctuates. Average inventory is the sum of beginning- plus end-of-period inventory divided by two. The inventory carrying cost is the average amount multiplied by the Rs. 35 per period carrying charge.

6.8 MIXED STRATEGIES

The number of mixed strategy alternative production plans is almost limitless. However, the realities of the situation will most likely limit the number of practical solutions. These can be evaluated on a trial-and-error basis to find which plan best satisfies the requirements, taking cost, employment policies, etc., into account.

Illustration 8: Custom Furniture Co. currently has 100 employees and has forecast quarterly demand as shown in Table below. The historical average production rate is 40 units per employee per quarter, and the firm has a beginning (safety stock) inventory of 1,000 units. The hiring and training cost is Rs. 400 per employee, and the layoff cost is Rs. 600 per employee. Inventory is carried at a cost of Rs. 8 per unit per quarter. Use the data to develop an aggregate plan that uses variable employment and inventory to meet demand.

Table: Quarterly demand forecast for furniture manufacture

Quarter	1	2	3	4	Total
Demand	3,500	5,000	4,000	3,450	15,950

Solution: One alternative plan is shown in below Table. (Many others, including better ones, are possible.) The planner has chosen to build some extra inventory in quarter 1 with the workers already on the payroll. Producing at a rate of 40 units per employee, the first quarter production of 4,000 units is 500 more than demand (3,500), so the ending inventory equals the beginning 1,000 plus 500, or 1,500 units. This results in a carrying cost of Rs.8 (1,500) = Rs.12,000. Twenty employees are hired at the beginning of quarter 2 to help meet the larger demand during the quarter. This results in a hiring cost of Rs.400 (20) = Rs.8,000. Employment is cut back again at the beginning of quarter 3, as the firm dips into safety stock, and employment is restored to its original level at the beginning of quarter 4. (Note: This firm bases inventory cost on ending inventory balance.)

Table: Aggregate plan for varying work force and inventory levels

(1) Qtr.	(2) Fcst. or demand	(3) No. of empl.	(4) Change in empl.	(5) Total prodn.	(6) Cum. prodn.	(7) Cum. demand	(8) Ending inv.	(9) Inv. cost @Rs.8	(10) Empl. chg cost @Rs.400 or Rs. 600
1	3,500	100	–	4,000	4,000	3,500	1,500	12,000	–
2	5,000	120	+ 20	4,800	8,800	8,500	– 1,300	10,400.	8,000
3	4,000	80	– 40	3,200	12,000	12,500	500	. 4,000	24,000
4	3,450	100	+20	4,000	16,000	15,950	1,050	8,400	8,000
							Totals	34,800	40,000

The total (comparative) cost for this is Rs. 34,800 + Rs. 40,000 = Rs. 74,800. Note that inventory and employment costs are not well balanced, and employment is the lowest during quarter 3 when demand is relatively high. With some additional trials, the planner could undoubtedly develop a plan that would result in a lower total cost. Large fluctuations in production often result in more problems (and higher costs) than more steady-state operations.

6.9 MATHEMATICAL PLANNING MODELS

Mathematical models attempt to refine or improve upon the trial-and-error approaches. Table below identifies four mathematical approaches. The value from some of these models is more theoretical than practical. The LDR is not easily understood, nor are the outputs always realistic. The management coefficients model is non-optimal and not easily transferable, whereas the computer search models do not necessarily yield a "global" minimum cost.

Table: Summary of some mathematical aggregate planning models

Approach	Linear programming	Linear decision rule (LDR)	Management coefficients	Computer search models
Application	Minimizesx cost of employment, over-time, and inventories subject to meeting demand.	Uses quadratic cost functions to derive rules for workforce size and number of units.	Develops regression model that incorporate managers' past decisions to predict capacity needs.	Computer routine searches numerous combinations of capacity and selects the one of least cost.

A useful version of the linear-programming model (the transportation algorithm) views the aggregate planning problem as one of allocating capacity (supply) to meet forecast requirements (demand) where supply consists of the inventory on hand and units that can be produced using regular time (RT), overtime (OT), and subcontracting (SC), etc. Demand consists of individual-period requirements plus any desired ending inventory. Costs associated with producing units in the given period or producing them and carrying them in inventory until a later period are entered in the small boxes inside the cells in the matrix, as is done in the standard transportation linear-programming format.

Illustration 9: Given the accompanying supply, demand, cost, and inventory data

(Below two Tables) for a firm that has a constant work force and wishes to meet all demand (that is, with no back orders), allocate production capacity to satisfy demand at minimum cost.

Table: Supply capacity (units)

Period	Regular time (Rs. 100/unit)	Overtime (Rs. 125/unit)	Subcontract (Rs. 130/unit)
1	60	18	1,000
2	50	15	1,000
3	60	18	1,000
4	65	20	1,000

*50 per cent of cost is labour

Table: Demand and inventory

Demand:				
Period	1	2	3	4
Units	100	50	70	80
Initial = 20, Final = 25			Carrying cost = Rs. 2 per unit-period	

The initial linear-programming matrix in units of capacity is shown in the next table, with entries determined as explained below. Because total capacity exceeds demand, a slack demand of unused capacity is added to achieve the required balance in supply versus demand.

Initial inventory: There are 20 units available at no additional cost if used in period 1. Carrying cost is Rs. 2 per unit per period if units are retained until period 2, Rs. 4 per unit until period 3, and so on. If the units are unused during any of the four periods, the result is Rs.6 per-unit cost, plus Rs. 2 per unit to carry it forward to the next planning horizon, for Rs. 8 total if unused.

Regular time: Cost per unit-month is Rs.100 if units are used in the month produced; otherwise, a carrying cost of Rs. 2 per unit-month is added on for each month the units are retained. Unused regular time costs the firm 50 per cent of Rs. 100 = Rs. 50.

Overtime: Cost per unit is Rs. 125 if the units are used in the month produced; otherwise, a carrying cost of Rs. 2 per unit-month is incurred, as in the regular-time situation. Unused overtime has zero cost.

Table: Linear programming format for scheduling

Supply units from		Demand, Units for				Capacity	
		Period 1	Period 2	Period 3	Period 4	Unused	Total available
	Initial inventory	0	2	4	6	8	20
Period 1	Regular	100	102	104	106	50	16
	Overtime	125	127	129	131	0	18
	Subcontract	130				0	1000
Period 2	Regular		100	102	104	50	50
	Overtime		125	127	129	0	15
	Subcontract		130			0	1000
Period 3	Regular			100	102	50	60
	Overtime			125	127	0	18
	Subcontract			130		0	1000
Period 4	Regular				100	50	65
	Overtime				125	0	20
	Subcontract				130	0	1000
Demand		100	5	70	105	4001	4326

Subcontracting: Cost per unit is Rs.130 plus any costs for units carried forward. This latter situation is unlikely, however, because any reasonable demand can be obtained when needed, as indicated by the arbitrarily high number (1,000) assigned to subcontracting capacity. There is no cost for unused capacity here.

Note: If the initial allocations are made so as to use regular time as fully as possible, the solution procedure is often simplified. Overtime and subcontracting amounts can also be allocated on a minimum-cost basis.

Final inventory: The final-inventory requirement (25 units) must be available at the end of period 4 and has been added to the period 4, demand of 80 units to obtain a total of 105 units. Since no back orders are permitted, production in subsequent months to fill demand in a current month is not allowed. These unavailable cells, along with the cells associated with carrying forward any subcontracted units, may therefore be blanked out, since they are infeasible. The final solution, following normal methods of distribution linear programming, is shown in table below. This result flows from a least-cost allocation.

Table: Master Schedule for Furniture Company

Supply units from		Demand, Units for				Capacity	
		Period 1	Period 2	Period 3	Period 4	Unused	Total available
	Initial inventory	0 20	2	4	6	8	20
Period 1	Regular	100 60	102	104	106	50	16
	Overtime	125 18	127	129	131	0	18
	Subcontract	130 2				0	1000
Period 2	Regular		100 50	102	104	50	50
	Overtime		125	127	129 12	0 3	15
	Subcontract		130			0 100	1000
Period 3	Regular			100 60	102	50	60
	Overtime			125 10	127 8	0	18
	Subcontract			130		0 1000	1000
Period 4	Regular				100 65	50	65
	Overtime				125 20	0	20
	Subcontract				130 0	0 100	1000
Demand		100	5	70	105	4001	4326

The optimal solution values can be taken directly from the cells. Thus in period 2, the planners will schedule the full 50 units to be produced on regular time plus 12 units on overtime to be carried forward to period 4. This leaves 3 units of unused overtime capacity and no subcontracting during that period. Because of the similar carrying cost for units produced on regular time or overtime, it does not matter which physical units are carried forward, once overtime production is required. Thus, different optimal solutions (but with identical costs) may be obtained.

6.10 MASTER SCHEDULING AND PRODUCTION PLANNING AND CONTROL

- **Master Scheduling**

  The Master Production Schedule (MPS) formalizes the production plan and translates it into specific end-item requirements over a short to intermediate planning horizon. The end items are then exploded into specific material and capacity requirements by the Material Requirements Planning (MRP) and Capacity Requirements Planning (CRP) systems. Thus, the MPS essentially drives the entire production and inventory system.

  The major inputs to the master production schedule are:

  1. Forecasts of demand, e.g., of end items and service parts.
  2. Customer orders, i.e., including any warehouse and interplant needs.
  3. Inventory on-hand from the previous period.

  Forecasts of demand are the major input for make-to-stock items. However, to be competitive, many make-to-order firms must anticipate orders by using forecasts for long lead-time items and by matching the forecasts with customer orders as the orders become available.

- **Master Scheduling Planning Horizon**

  The time horizon of master scheduling depends upon the type of product, volume of production, and component lead times. It can be weeks, months, or some combination, but the schedule must normally extend far enough into the future so that the lead times for all purchased and assembled components are adequately encompassed.

  Master schedules frequently have both firm and flexible (or tentative) portions. Table below illustrates an MPS for a furniture company that has one such schedule-where the firm and flexible portions have been marked. The firm portion encompasses the minimum lead-time necessary and is not open to change.

Table: Master schedule for Furniture Company

									Week									
Item	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
R28 table	50		50	50		40			40	40		40	40			40		
R30 table		80		20	60		80	80			60				80			
L7 lamp	20		20		10	20			20	20	10	20	20	20				
	(Firm)					(Flexible)								(Open)				
	(Emergency changes only)					(Capacity firm and material ordered)								(Additions and changes OK)				

Two-time fence can be identified in MPS: A demand and a planning time fence.

(a) **A demand time fence is** the firm or 'frozen' portion of the master schedule (beginning with the current period) during which no changes can be made to the schedule without management approval.

(b) **A planning time fence** is the portion of the master schedule (also beginning with the current period) during which changes will not automatically be made (i.e., via computer) to accommodate demand. This gives the master scheduler a manageable base to work from and still allows some discretion in overriding the constraint.

Question: How does master scheduling differ under manufacturing strategies of (a) make-tostock, (b) assemble-to-order, and (c) make-to-order?

See Figure below where the shorter line segments represent fewer items.

In (a) make-to-stock operations, the (fewer) end items are stocked; to support customer service, and the master production schedule (MPS) is structured around those end items.

In (b) assemble-to-order plants, such as in automobile manufacturing, the master scheduling is done for the major sub-assembly-level items.

In (c) make-to-order products, such as customized furniture, there are fewer raw materials than end items; the end items may even be one of a kind. Here, the master schedule is typically structured around the raw material usage.

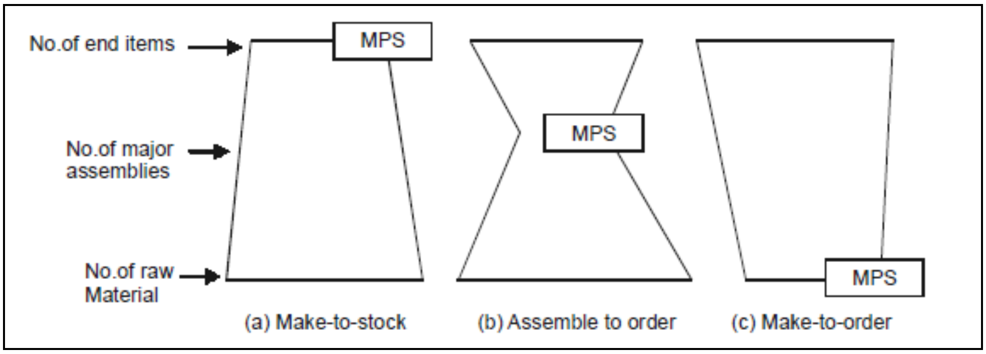


Fig. Location of master scheduling activities

- **Master Scheduling Format**

  Planning production that integrates a forecast of demand, incoming customer orders, and current inventory levels is difficult–especially when it must be done over a multi week period. These difficulties are amplified as hundreds or thousands of items become involved. Numerous computer programmes have been designed to assist in the scheduling and to provide detailed reports and graphs for analyzing and testing proposed master schedules. Although the extras differ from one programme to another, much of the logic is similar. It consists of (l) incorporating the forecast and customer orders, (2) determining whether the inventory balance is sufficient to satisfy the larger of either the forecast or the orders on hand for the period, and (3) scheduling the production of a predetermined lot size in periods whenever the inventory balance is inadequate.

Illustration 10: Use the master schedule shown in Table below to answer the following:

(a) Does this product appear to be made primarily for stock, or is it made-to-order?

(b) How long is the planning period, and how many production runs will be scheduled in response to demand?

(c) Why is no production run scheduled for week 1, and how is the projected available balance determined?

(d) How many end items will be "exploded" into component parts in the MRP system as a result of the MPS requirements during week 3?

(e) Does the capacity appear to be fully utilized during the 6-week planning period?

Table: Master schedule for TR28 blood analyzer unit

Lead time 0	Lot size 25			Demand time fence 0					
On-hand 30	Safety stock 0			Planning time fence 6					
Period	1	2	3	4	5	6	7	8	9
Forecast		20	20	20	20	20	20		
Customer orders (booked)									
Projected available balance	10	15	20	0	5	10			
Master production schedule		25	25		25	25			

Solution:

(a) Product appears to be made for stock in response to a forecast; no customer orders are shown.

(b) The planning time fence is 6 weeks, and the schedule calls for four production runs (i.e., of 25 units each in weeks 2, 3, 5, and 6).

(c) No production is needed in week 1 because the beginning inventory of 30 is more than enough to meet the forecast demand of 20 needed in week 1.

Projected Available Balance = Previous available balance + MPS – Current period requirements

(@ end of period) = 30 + 0 – 20 = 10 units.

(Note: No changes are normally accepted up to the Demand Time Fence (DTF). Prior to the DTF the Projected Available Balance is based upon customer orders only, and disregards the forecast.)

(d) The MPS amount in week 3 (25 units). All MPS items become projected requirements in the MRP system.

(e) We cannot tell the extent to which capacity is utilized without additional information from the capacity planning system. One of the uses of the MPS is to provide the information to drive rough-cut capacity planning. However, no production of blood analyzer units is scheduled for weeks 1 and 4, so the production facilities might be idle at that time-unless they are being used for another product.

- **Available-to-Promise Quantities**

In make-to-order operations, as actual customer orders are received, they essentially take the place of an equivalent amount in the forecast, or consume the forecast. For this reason, the scheduled production of a lot is initiated by the larger demand of either the forecast amount or the actual (booked) customer orders.

As new orders are evaluated (and received), it is important to provide marketing with realistic promises of when shipments can be made. In well-designed master scheduling systems, this information is provided by a simple calculation that yields an available-at-promise inventory.

Available-to-Promise (ATP) inventory is that portion of the on-hand inventory plus scheduled production that is not already committed to customer orders. For the first (current) period, the ATP includes the beginning inventory plus any MPS amount in that period, minus the total of booked orders up to the time when the next MPS amount is available. In subsequent periods, the ATP inventory consists of the MPS amount in that period, minus the actual customer orders already received for that period and all other periods until the next MPS amount is available.

Illustration 11: Find the ATP inventory values for the master schedule shown in Table.

Table: Master schedule for tractor levellers

On-hand 23	Lot size 25			Planning time fence 6					
Period	1	2	3	4	5	6	7	8	9
Forecast	10	10	10	10	20	20			
Customer orders (booked)	13	5	3	1					
Projected available balance	10	0	15	5	10	15			
Master production schedule			25		25	25			
Available-to-promise									

Available-to-Promise values are computed for the current period (1) and for other periods when the MPS shows that a lot will be produced.

For period

1. ATP1 = (On-hand Inv.) – (orders in periods 1 and 2) = 23 – (13 + 5) = 5

2. ATP3 = (MPS amount in 3) – (orders in periods 3 and 4) = 25 – (3 + 1) = 21

3. ATP5 = (MPS amount in 5) – (orders in period 5) = 25 – 0 = 25

4. ATP6 = (MPS amount in 6) – (orders in period 6) = 25 – 0 = 25

The last row should have values of 5, 21, 25 and 25 in the columns for periods 1, 3, 5 and 6 respectively.

Illustration 12: From the following forecast determine the monthly inventory balances required to follow a plan of letting the inventory absorb all fluctuations in demand. In this case, we have a constant work force, no idle time or overtime, no back orders, no use of subcontractors, and no capacity adjustment. Assume that the firm does not use safety stock or cushion inventory to meet the demand.

Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Forecast demand	220	90	210	396	616	700	378	220	200	115	95	260
Production days	22	18	21	22	22	20	21	22	20	23	19	20

Solution:

$$\text{Average requirements} = \left[\frac{\text{total demand}}{\text{total production days}}\right] = \frac{3500}{250} = 14 \text{ units per day.}$$

The firm can satisfy demand by producing at an average requirement (14 units per day) and by accumulating inventory during periods of slack demand and depleting it during periods of strong demand. Disregarding any safety stock, the inventory balance is:

$$\text{Inventory balance} = \Sigma \text{ (production} - \text{demand)}.$$

See Table for the solution. The pattern of demand is such that column 4 reveals a maximum negative balance of 566 units at the end of July, so 566 additional units must be carried in stock initially if demand is to be met. Column 5 shows the resulting inventory balances required.

Month	(1) Production at 14 units/day	(2) Forecast demand	(3) Inventory change	(4) Ending inventory balance	(5) Ending balance with 566 as on Jan. 1st
January	308	220	+88	88	654
February	252	90	+162	250	816
March	294	210	+84	334	900
April	308	396	-88	246	812
May	308	616	-308	-62	504
June	280	700	-420	-482	84
July	294	378	-84	-566	0
August	308	220	+88	-478	88
September	280	200	+80	-398	168
October	322	115	+207	-191	375
November	266	95	+171	-20	546
December	280		+20	0	566
		3,500			

Illustration 13: Given the data of Illustration 12, suppose the firm has determined that to follow a plan of meeting demand by varying the size of the work force would result in hiring and layoff costs estimated at Rs.12,000. If the units cost Rs.100 each to produce, the carrying costs per year are 20 per cent of the average inventory value, and the storage costs (based on maximum inventory) are Rs. 90 per unit, which plan results in the lower cost: varying inventory, or varying employment?

Solution: From Illustration 12

Maximum inventory requiring storage = 900 units (from Table, column 5)

$$\text{Average inventory balance} = \cong \frac{654+816+900+\ldots\ldots+566}{12} \cong 460 \text{ units}$$

Plan 1 (varying inventory): Inventory cost = carrying cost + storage cost

= (0.20)(460)(Rs.100) + (Rs.0.90)(900) = Rs.10,010

Plan 2 (varying employment): Rs.12,000

Therefore, varying inventory is the strategy with the lower cost.

Illustration 14: Michigan manufacturing produces a product that has a 6-month demand cycle, as shown in Table 8.23. Each unit requires 10 worker-hours to produce, at a labour cost of Rs. 6 per hour regular rate (or Rs. 9 per hour overtime). The total cost per unit is estimated at Rs. 200, but units can be subcontracted at a cost of Rs. 208 per unit. There are currently 20 workers employed in the subject department, and hiring and training costs for additional workers are Rs. 300 per person, whereas layoff costs are Rs. 400 per person.

Company policy is to retain a safety stock equal to 20 per cent of the monthly forecast, and each month's safety stock becomes the beginning inventory for the next month. There are currently 50 units in stock carried at a cost of Rs. 2 per unit-month. Unit shortage, or stockouts, has been assigned a cost of Rs. 20 per unit month.

	January	February	March	April	May	June
Forecast demand	300	500	400	100	200	300
Workdays	22	19	21	21	22	20
Work hr at 8 per day	176	152	168	168	176	160

Three aggregate plans are proposed.

Plan 1: Vary work force size to accommodate demand.

Plan 2: Maintain constant work force of 20, and use overtime and idle time to meet demand.

Plan 3: Maintain constant work force of 20, and build inventory or incur Stockout cost. The firm must begin January with the 50-unit inventory on hand.

Compare the costs of the three plans in table form.

Solution: We must first determine what the production requirements are, as adjusted to include a safety stock of 20 per cent of next month's forecast. Beginning with a January inventory of 50, each subsequent month's inventory reflects the difference between the forecast demand and the production requirement of the previous month. See Table. The costs of the three plans are shown in the following Tables.

	Forecast demand	Cumulative demand	Safety stock @20 per cent forecast	Beginning inventory	Production requirement (fest. + SS – beg. inv.)
January	300	300	60	50	300 + 60 – 50 = 310
February	500	800	100	60	500 + 100 – 60 = 540
March	400	1,200	80	100	400 + 80 – 100 = 380
April	100	1,300	20	80	100 + 20 – 80 = 40
May	200	1,500	40	20	200 + 40 – 20 = 220
June	300	1,800	60	40	300 + 60 – 40 = 320

Plan 1(Vary Work-force Size)

January	February	March	April	May	June	Total
1. Production required	310	540	380	40	220	320
2. Production hours Required (1 × 10)	3,100	5,400	3,800	400	2,200	3,200
3. Hours available per Worker at 8/day	176	152	168	168	176	160
4. Number of workers Required (2/3)	18	36	23	3	13	20
5. Number of workers Hired		18			10	7
6. Hiring cost (S × Rs. 300)		Rs. 5,400		Rs. 3,000	Rs. 2,100	Rs. 10,500
7. Number of workers Laid off	2		13	20		
8. Layoff cost (7 × Rs. 400)	Rs. 800		Rs. 5,200	Rs. 8,000		Rs. 14,000

Table: Plan 2 (Use Overtime and Idle Time)

	January	February	March	April	May	June	Total
1. Production required	310	540	380	40	220	320	
2. Production hours Required (1 × 10)	3,100	5,400	3,800	400	2,200	3,200	
3. Hours available. per Worker at 8/ day	176	152	168	168	176	160	
4. Total hours available (3 × 20)	3,520	3,040	3,360	3,360	3,520	3,200	
5. Number of OT hours Required (2 – 4)	2,360	440			0		
6. OT prem.* (5 × Rs. 3)	Rs. 7,080	Rs. 1,320			0	Rs. 8,400	
7. Number IT hours (4–2)	420			2,960	1,320		
8. IT cost (7 × Rs.6)	Rs. –2,520	Rs. 17,760	Rs. 7,920		Rs.28,200		

*Incremental cost of OT = overtime cost – regular time cost = Rs. 9 – Rs. 6 = Rs. 3.

Table: Plan 3 (Use Inventory and Stockout Based on Constant 20-Worker Force)

	January	February	March	April	May	June	Total
1. Production required	310	540	380	40	220	320	
2. Cumulative production Required	310	850	1,230	1,270	1,490	1,810	
3. Total hours available at 20 workers	3,520	3,040	3,360	3,360	3,520	3,200	
4. Units produced (3/10)	352	304	336	336	352	320	
5. Cumulative production	352	656	992	1,328	1,680	2,000	
6. Units short (2 – 5)		194	238				
7. Shortage cost (6 × Rs. 20)		Rs. 3,880	Rs. 4,760				Rs. 8,640
8. Excess units (5 – 2)	42			58	190	190	
9. Inventory cost (8 × Rs. 2)	Rs. 84			Rs. 116	Rs. 380	Rs. 380	Rs. 960

Note that plan 3 assumes that a Stockout cost is incurred if safety stock is not maintained at prescribed levels of 20 per cent of forecast. The firm is in effect managing the safety-stock level to yield a specific degree of protection by absorbing the cost of carrying the safety stock as a policy decision.

Summary

Plan 1: Rs. 10,500 hiring + Rs. 14,000 layoff = Rs. 24,500

Plan 2: Rs. 8,400 overtime + Rs. 28, 200 idle time = Rs. 36,600

Plan 3: Rs. 8,640 Stockout + Rs. 960 inventory = Rs. 9,600 **(least-cost plan)**

Illustration 15: Use the data from Illustration 14 except modify as follows: Monthly demand and number of workdays per month are as shown below, employees work 8 hours per day, and time to produce one unit is 40 hours. Regular-time cost is (Rs.30 per hour) (40hours per unit) = Rs.1,200 per unit, and subcontract time cost is (Rs.50 per hour) (40 hours per unit) = Rs.2,000 per unit. Produce with a (minimal) constant work force of six workers on regular time and subcontract to meet additional requirements.

Solution:

(1) Month	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Total
(2) Forecast	40	25	55	30	30	50	30	60	40	360
(3) Workdays/mo	22	18	21	22	22	20	21	22	20	
(4) Prod. hr avail. =[3](6 wkrs) (8 hr)	1056	864	1008	1056	1056	960	1008	1056	960	

(5) Reg.-time prod. [4] 740 hr/unit	26.4	21.6	25.2	26.4	26.4	24.0	25.2	26.4	24.0	
(6) Units subcon't (2)-(3)	13.6	3.4	29.8	3.6	3.6	26.0	4.8	33.6	16.0	
(7) Subcon't cost (6) (Rs.2,000)	27,200	6,800	59,600	7,200	7,200	52,000	9,600	67,200	32.000	268,800
(8) Reg.-time cost(5) (Rs.1,200)	31,680	25,920	30,240	31,680	31,680	28,800	30,240	31,680	28,800	270,720

The total cost of this plan is Rs. 268,800 + Rs. 270,720 = Rs. 539,520.

Illustration 16: Idaho Instrument Co. produces calculators in its Lewiston plant and has forecast demand over the next 12 periods, as shown in Table 8.29. Each period is 20 working days (approximately 1 month). The company maintains a constant work force of 40 employees, and there are no subcontractors available who can meet its quality standards. The company can, however, go on overtime if necessary and encourage customers to back-order calculators. Production and cost data follow.

Period	Units	Period	Units	Period	Units
1	800	5	400	9	1,000
2	500	6	300	10	700
3	700	7	400	11	900
4	900	8	600	12	1,200

Production capacity:

Initial inventory: 100 units (final included in period 12 demand)

RT hours: (40 employees)(20 days/period)(8 hr/day) = 6,400 hr/period OT hours:

(40 employees) (20 days/period) (4 hr/day) = 3,200 hr/period Standard labor hours per unit: 10 hr Costs:

Labor: RT = Rs. 6/hr OT = Rs. 9/hr

Material and overhead: Rs. 100/unit produced

Back-order costs: apportioned at Rs. 5/unit-period (and increasing in reverse) Inventory carrying cost: Rs. 2/unit-period

Assume that five periods constitute a full demand cycle, and use the transportation linear programming approach to develop an aggregate plan based on the first five periods only.

(Note: A planning length of five periods is useful for purposes of methodology, but in reality the planning horizon should cover a complete cycle, or else the plan should make inventory, personnel, and other such allowances for the whole cycle.)

Solution

RT capacity, avail. /period = 6,400 hr/10 hr/unit = 640 units

OT capacity, avail./period = 3,200 hr/10 hr /unit = 320 units

RT cost = (10 hr/unit)(Rs. 6/hr) + Rs. 100 mat's. And OH = Rs. 160/unit

OT cost =(10 hr/unit)(Rs. 9/hr)+Rs. 100 mat' I. And OH=Rs. 190/unit

Supply	units from	Demand, Units for						Capacity
		Period 1	Period 2	Period 3	Period 4	Period 5	Unused	Total available
	Initial inventory	0 100	2	4	6	8	10	100
Period 1	Regular	160 640	162	164	166	168	60	640
	Overtime	190	192	194	196	198	0 320	320
Period 2	Regular	165 60	160 500	162 60	164 20	166	60	640
	Overtime	195	190	192	194	196	0 320	320
Period 3	Regular	170	165	160 640	162	164	80	640
	Overtime	200	195	190	192	194	0 320	320
Period 4	Regular	175	170	165	160 640	162	60	640
	Overtime	205	200	195	190	192	0 320	320
Period 5	Regular	180	175	170	165	160 400	60	640
	Regular	210	205	200	195	190	0 320	320
	Demand	800	500	700	900	400	1600	4900

Illustration 17: Taiwan Shoe Company schedules running shoe production in lot sizes of 40 units (each of which consists of a carton of pairs). They have a beginning inventory of 45 units and have developed a forecast of demand as shown in Table 8.31. The company has received orders for 22 units in week 1, 9 units in week 2, 4 units in week 3, 15 units in week 4, and 5 units in week 5. Set up a master production schedule, and find the ATP inventory values for weeks 1 through 8.

Table: Master Schedule for Running Shoe Production

On-hand 45	Lot size 40			Planning time fence 8				
Period	1	2	3	4	5	6	7	8
Forecast	20	20	30	20	20	13	15	20
Customer orders (booked)	22	9	4	15	5			
Projected available balance	23	3	13	33	13	0	25	5
Master production schedule			40	40			40	
Available-to-promise								

Solution:

Period	1	2	3	4	5	6	7	8
Available-to-promise	14		36	20			40	

See the above Table. The period 1 balance is 45–22 (i.e., 22, because orders are larger than forecast) = 23, and period 2 balance is 23 – 20 = 3. Period 3 balance would be a negative (3 – 30), so a lot size of 40 goes into the MPS in week 3, resulting in a balance of (3 + 40) – 30 = 13.

For period 1, ATP = (On-hand Inv.) – (Orders in periods 1 and 2) = 45 – (22 + 9) = 14; and ATP3 = (MPS amount in 3) – (Orders for period 3) = 40 – (4) = 36. For week 4, ATP4 = (MPS amount in 4) – (Orders for periods 4, 5 and 6) = 40 – (15 + 5) = 20.

- **Production Planning and Control**

  For efficient, effective and economical operation in a manufacturing unit of an organization, it is essential to integrate the production planning and control system. Production planning and subsequent production control follow adaption of product design and finalization of a production process.

  Production planning and control address a fundamental problem of low productivity, inventory management and resource utilization.

  Production planning is required for scheduling, dispatch, inspection, quality management, inventory management, supply management and equipment management. Production control ensures that production team can achieve required production target, optimum utilization of resources, quality management and cost savings.

Planning and control is an essential ingredient for success of an operation unit. The benefits of production planning and control are as follows:

- It ensures that optimum utilization of production capacity is achieved, by proper scheduling of the machine items which reduces the idle time as well as over use.
- It ensures that inventory level are maintained at optimum levels at all time, i.e. there is no over-stocking or under-stocking.
- It also ensures that production time is kept at optimum level and thereby increasing the turnover time.
- Since it overlooks all aspects of production, quality of final product is always maintained.

Production Planning

Production planning is one part of production planning and control dealing with basic concepts of what to produce, when to produce, how much to produce, etc. It involves taking a long-term view at overall production planning. Therefore, objectives of production planning are as follows:

- To ensure right quantity and quality of raw material, equipment, etc. are available during times of production.
- To ensure capacity utilization is in tune with forecast demand at all the time.
- A well thought production planning ensures that overall production process is streamlined providing following benefits:
- Organization can deliver a product in a timely and regular manner.
- Supplier are informed will in advance for the requirement of raw materials.
- It reduces investment in inventory.
- It reduces overall production cost by driving in efficiency.

Production planning takes care of two basic strategies' product planning and process planning. Production planning is done at three different time dependent levels i.e. long-range planning dealing with facility planning, capital investment, location planning, etc.; medium-range planning deals with demand forecast and capacity planning and lastly short term planning dealing with day to day operations.

Production Control

Production control looks to utilize different type of control techniques to achieve optimum performance out of the production system as to achieve overall production planning targets. Therefore, objectives of production control are as follows:

- Regulate inventory management
- Organize the production schedules
- Optimum utilization of resources and production process
- The advantages of robust production control are as follows:
- Ensure a smooth flow of all production processes
- Ensure production cost savings thereby improving the bottom line
- Control wastage of resources
- It maintains standard of quality through the production life cycle.
- Production control cannot be same across all the organization. Production control is dependent upon the following factors:
- Nature of production (job oriented, service oriented, etc.)
- Nature of operation
- Size of operation

Production planning and control are essential for customer delight and overall success of an organization.

6.11 LET US SUM UP

In this unit Capacity planning and concepts and strategies of the aggregate planning and production planning and control have been explained.

6.12 EXERCISES

1. What is meant by 'phasing in' capacity?

2. Distinguish between design capacity and system capacity.

3. How the following organizations adjust to the daily fluctuations in demand?

(a) Airlines, (b) Restaurants, (c) Dentists.

4. A manufacturer of TV watches uses three TRS7 electronic chips in each TV watches produced. Demand estimates for the number of TV watches that could be sold next year are shown

Demand X	20000	40000	50000
P (X)	0.30	0.50	0.20

(a) Assuming the firm decides to produce on an expected value basis, how many TRS7 chips should they plan to produce for next year's sales?

(b) What capacity is required to meet 150 percent of expected demand?

5. An automatic drive-in teller at American National Bank has the capacity of handling 2,000 entries per regular banking day (according to the firm that sold it to the bank). However, because of limitations imposed by automobile access, the teller is available only 60 per cent of the time. It is actually being used for about 800 entries per day. What is the system efficiency?

6. What is aggregate planning?

7. What is scheduling, and does it differ from aggregate planning?

8. What focused strategies are employed by production planners to meet non-uniform demands?

9. What are the major inputs to master production schedule?

10. What determines the planning horizon length (time span) of a master schedule?

11. How do firms accommodate changes in their master schedule?

12. What is meant by the terms (a) demand time fence and (b) planning time fence?

13. How does master scheduling differ under manufacturing strategies of (a) make-to-stock, (b) assemble-to-order, and (c) make-to-order?

14. What is available-to-promise inventory, and it is determined?

6.13 SUGGESTED READING

- Operations & Supply Chain Management by Chase, Shankar, Jocaobs
- Operations Management (6th Edition) by Nigel Slack, Stuart Chambers, Robert Johnston
- Theory & Problems in Production & Operations Management- S N Chary, Tata McGraw Hill
- Production & Operations Management -Kanishka Bedi , Oxford University Press
- Operations Management for competitive advantage-Chase & Jacob, McGraw-Hill/Irwin
- Production and Operations Management- Chunawalla & Patel, Himalaya Publishing

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7

BASICS OF MRP

Unit Structure

7.0 OBJECTIVES

After going through this you will be able to understand the following concepts:

- MRP and CRP Objective
- MRP Inputs and Outputs
- MRP Logic
- System Refinements
- Safety Stock, Lot Sizing and System Updating
- CRP Inputs and Outputs
- Loading

7.1 MRP AND CRP OBJECTIVE

The demand for a finished good tends to be independent and relatively stable. However, firms typically make more than one product on the same facilities, so production is generally done in lots, e.g., of different end items or models. The quantities and delivery times for the materials needed to make those end items are determined by the production schedule.

Material Requirements Planning (MRP) is a computer-based technique for determining the quantity and timing for the acquisition of dependent demand items needed to satisfy the master schedule requirements.

By identifying precisely what, how many, and when components are needed, MRP systems are able to reduce inventory costs improve scheduling effectiveness, and respond quickly to market changes.

Capacity Requirements Planning (CRP) is the process of determining what personnel and equipment capacities (times) are needed to meet the production objectives embodied in the master schedule and the material requirements plan.

MRP focuses upon the priorities of materials, whereas CRP focuses primarily upon time. Although both MRP and CRP can be done manually and in isolation, they are typically integrated within a computerized system, and CRP (as well as production activity control) functions are often assumed to be included within the concept of “an MRP system.” Computerized MRP systems can effectively manage the flow of thousands of components throughout a manufacturing facility.

Following are some of the terminology used to describe the functioning of MRP systems:

- **MRP:** A technique for determining the quantity and timing dependent demand items.
- **Dependent demand:** Demand for a component that is derived from the demand for other items.
- **Parent and component items:** A parent is an assembly made up of basic parts, or components. The parent of one subgroup may be a component of a higher-level parent.
- **Bill of materials:** A listing of all components (subassemblies and materials) that go into an assembled item. It frequently includes the part numbers and quantity required per assembly.
- **Level code:** The level on which an item occurs in the structure, or bill-of-materials format.
- **Requirements explosion:** The breaking down (exploding) of parent items into component parts that can be individually planned and scheduled.
- **Time phasing:** Scheduling to produce or receive an appropriate amount (lot) of material so that it will be available in the time periods when needed-not before or after.
- **Time bucket:** The time period used for planning purposes in MRP-usually a week.
- **Lot size**. The quantity of items required for an order. The order may be either purchased from a vendor or produced in-house. Lot sizing is the process of specifying the order size.

- **Lead-time offset:** The supply time, or number of time buckets between releasing an order and receiving the materials.

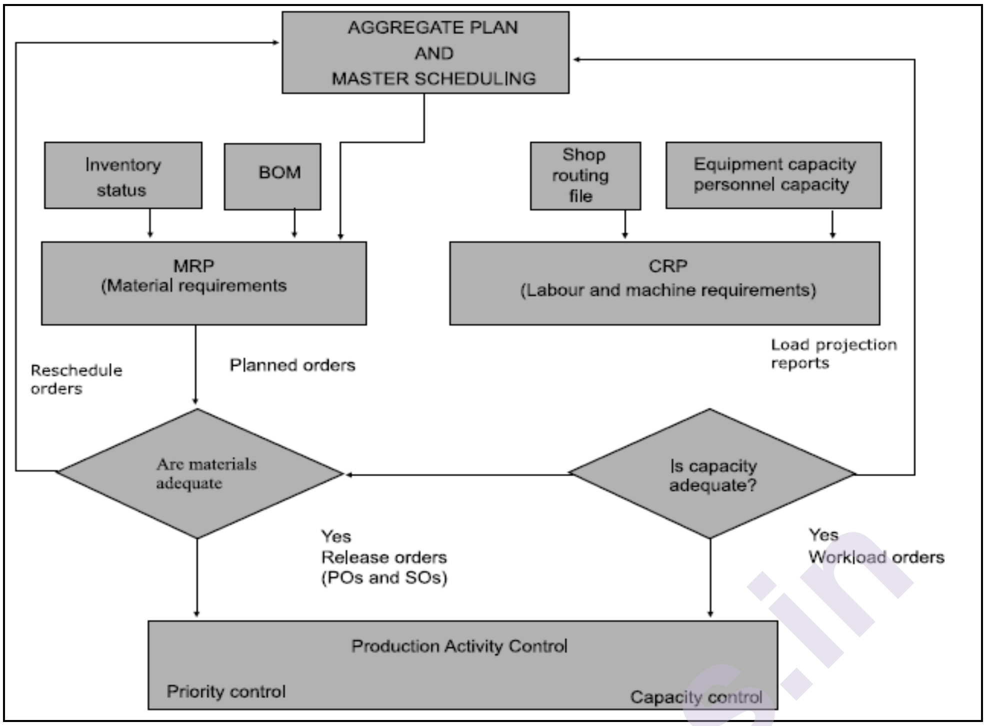


Fig. Material and capacity planning flowchart

Figure describes MRP and CRP activities in schematic form. Forecasts and orders are combined in the production plan, which is formalized in the master production schedule (MPS). The MPS, along with a bill-of-material (BOM) file and inventory status information, is used to formulate the material-requirements plan. The MRP determines what components are needed and when they should be ordered from an outside vendor or produced in-house. The CRP function translates the MRP decisions into hours of capacity (time) needed. If materials, equipment, and personnel are adequate, orders are released and the workload is assigned to the various work centers.

End items, such as TV sets, have an **independent demand** that is closely linked to the ongoing needs of consumers. It is random but relatively constant. Dependent demand is linked more closely to the production process itself. Many firms use the same facilities to produce different end items because it is economical to produce large lots once the set-up cost is incurred. The components that go into a TV set, such as 24-inch picture tubes, have a dependent demand that is governed by the lot size. **Dependent demand** is predictable.

MRP systems compute material requirements and specify when orders should be released so that materials arrive exactly when needed. The process of scheduling the receipt of inventory as needed over time is time phasing.

7.2 MRP INPUTS AND OUTPUTS

The essential inputs and outputs in an MRP system are listed below:

Inputs	Outputs
• MPS of end items required. • Inventory status file of on-hand and on-order items, lot sizes, lead times, etc. • Product structure (BOM) file of what components and subassemblies go into each end product.	• Order release data to CRP for load profiles • Orders to purchasing and in-house production shops. • Rescheduling data to MPS. • Management reports and inventory updates.

Bill of Materials

A bill of materials (BOM) is a listing of all the materials, components, and subassemblies needed to assemble one unit of an end item. Major function of the bill of materials is to provide the product structure hierarchy that guides the explosion process.

Different methods of describing a BOM are in use. Figure below shows (a) a product structure tree, and (b) an indented BOM. Both are common ways of depicting the parent-component relationships on a hierarchical basis. Knowledge of this dependency structure reveals clearly and immediately what components are needed for each higher-level assembly. A third method (c) is to use single-level bills of material.

Low-level Coding

Figure below also includes level coding information. Level 0 is the highest (e.g., the end-item code) and level 3 the lowest for this particular BOM. Note that the four clamps (C 20) constitute a subassembly that is combined with base (A 10) and two springs (B 11) to complete the end-item bracket (Z 100). However, the same clamp (C 20) is also a component of the base (A 10). To facilitate the calculation of net requirements, the product tree has been restructured from where the clamp components might have been (shown dashed) to the lower level consistent with the other (identical) clamp. This low-level coding enables the computer to scan the product structure level-by-level, starting at the top, and obtain an accurate and complete count of all components needed at one level before moving on to the next.

Bill of materials for Z 100 bracket is shown below:

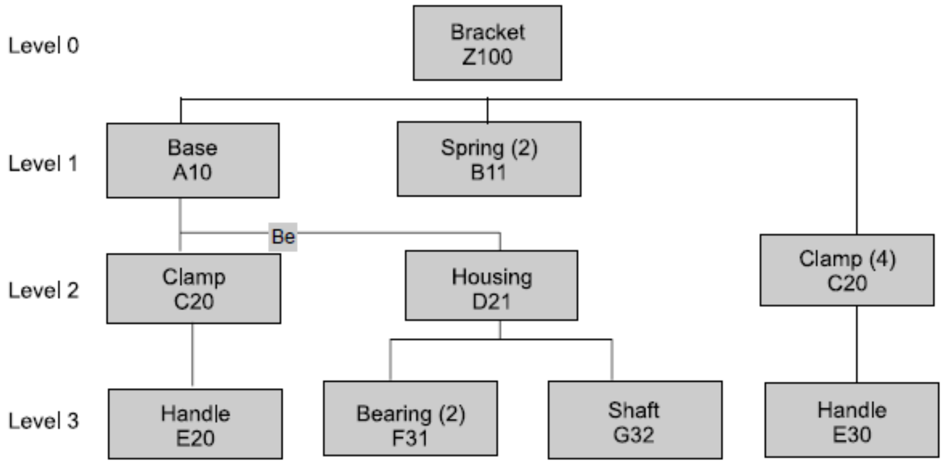


Fig: Product structure tree

Table: Indented bill of materials

Bill of Materials					
Item: Z 100 Bracket					**Level 0**
Part No.			**Description**	**NO.**	**Level**
	C20		Clamp	4	2
		E30	Handle	1	3
A10			Base	1	1
	C20		Clamp	1	2
		E30	Handle	1	3
	D21		Housing	2	2
		F31	Bearing	2	3
		G32	Shaft	1	3
B11			Spring	2	1

Single-Level BOM

Previous Table depicts a single-level bill of materials for Z 100 bracket. It is a less intuitive but more efficient means of storing the information on computer. In the single-level bill each entry (on the left) contains only an item or part number followed by a list of the part numbers and quantities of components needed to make up the parent item only. This type of listing avoids the searches for duplicate items down through several levels of a tree. On the other hand, it necessitates that the computer search through many single-level bills to find all the components that are included in a product that has several levels of code. Single-level bills frequently contain "pointers" to link the records of components with their parents and accommodate the retrieval of a complete bill of materials for an item.

Table: Single-level BOM

	Number	Description
ZI00		Bracket
	A10 (1)	Base
	B 11 (2)	Spring
	C20 (4)	Clamp
AI0		Base
	C20(1)	Clamp
	D21 (2)	Housing
C20		Clamp
	E30 (1)	Handle
D21		Housing
	F31 (2)	Bearing
	G32(1)	Shaft

Illustration 1: Determine the quantities of A10, B11, C20, D2l, E30, F3l, and G32 needed to complete 50 of the Z100 brackets depicted in Fig.

Solution:

Table: Determining BOM requirements

Component	Dependency Effect	Requirements
A (base)	1A per Z	1
B (spring)	2B's per Z	2
C (clamp)	(IC per A)' (IA per Z) + (4C's per Z)	5
D (housing)	(2D's per A)' (IA per Z)	2
E (handle)	(IE per C) (IC per A)' (IA per Z) + (IE per C)' (4C's per Z)	5
F (bearing)	(2F's per D) . (2D's per A) . (IA per Z)	4
G (shaft)	(IG per D) . (2D's per A) . (IA per Z)	2

First determine the requirements for one bracket as shown in Table above, and then multiply by 50.

Note that parts C and E are used in two different subassemblies, so their separate amounts must be summed. For 50 brackets, each of the requirements column amounts must be multiplied by 50 to obtain the gross requirements.

Illustration 2: Given the product structure tree shown in Figure 9.3 for wheelbarrow W099, develop an indented bill of materials.

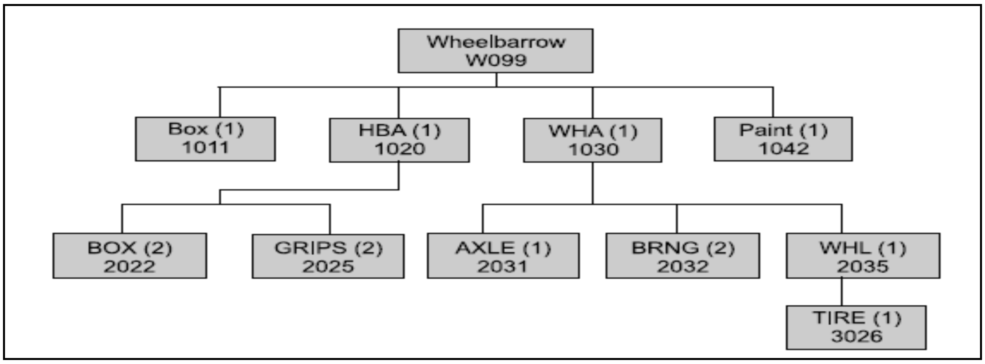


Table: Bill of Materials

Part No. W099: Wheelbarrow					Level: 0
Part No.		**Description**	**Quantity/Assembly**	**Units**	**Level**
1011		Box: deep size, aluminum	1	Each	1
1020		Handlebar assembly	1	Each	1
	2022	Aluminum bars	2	Each	2
	2025	Grips: neoprene	2	Each	2
1030		Wheel assembly	1	Each	1
	2031	Axle	1	Each	2
	2032	Bearing: normal-duty	2	Each	2
	2035	Wheel	1	Each	2
	3026	Tire: size A	1	Each	3
1042		Paint: blue	1	Pint	1

Illustration 3: Design an indented bill of materials for the flashlight in Illustration 3.

(Note: Assign appropriate four-digit part numbers to the components.)

Bill of Materials						
Item:0010 flashlight						**Level: 0**
		Part No.		**Description**	**No.**	**Level**
1001				Head assembly	1	1
	2001			Plastic head	1	2
		4001		Plastic powder	1	4
	2002			Lens	1	2
	2003			Bulb assembly	1	2
		3001		Bulb	1	3
		3002		Bulb holder	1	3
	2004			Reflector	1	2
1002				Batteries	2	1
						I
1003				Body assembly	1	1'
	2005			Shell assembly	1	2'
		3903		On-off switch	1	3
			4002	Knob	1	4
			4003	Metal slides	2	4
		3004		Connector bars	2	3
		3005		Plastic shell	1	3
			4001	Plastic powder	3	4
	2006			Spring	1	2

Gross requirements are the total quantities needed to produce the 200 flashlights, whereas net requirements are the quantities needed in addition to existing inventory levels (or scheduled receipts).

The net requirements must therefore take into account the components already assembled (or hidden) in completed assemblies.

We shall first determine the gross requirements by taking account of all dependencies.

For example the gross requirements of connector bars (No. 3004) are (2 connector bars per shell assembly) times (1 shell assembly per body assembly) times (1 body assembly per flashlight) times (200 flashlights), or 2 × 1 × 1 × 200 = 400. See next Table.

Then we complete the on-hand inventory by totaling both the individual stock items on hand plus any units of the same item that are already in subassemblies or assemblies.

For example, the on hand inventory of lenses consists of 12 lenses in stock plus 10 lenses already installed in the head assemblies.

Requirements will be computed on a level-by-level basis so that components used in more than one subassembly (such as the plastic powder, no. 4001) can be combined.

PartNo.	Description	Gross requirements	On hand	Net requirements
0010	Flashlight	200	0	200
1001	Head assembly	1 × 200 = 200	10	190
1002	Batteries	2×200 = 400	0	400
1003	Body assembly	1 × 200 = 200	0	200
2001	Plastic head	(1 × 1 × 200) = 200	10	190
2002	Lens	1 × 1 × 200 = 200	22	178
2003	Bulb assembly	1 × 1 × 200 = 200	10	190
2004	Reflector	1 × 1 × 200 = 200	10	190
2005	Shell assembly	1 × 1 × 200 = 200	0	200
2006	Spring	1 × 1 × 200 = 200	50	150
3001	Bulb	1 × 1 × 1 × 200 = 200	10	190
3002	Bulb holder	1 × 1 × 1 × 200 = 200	10	190
3003	On-off switch	1 × 1 × 1 × 200 = 200	15	185
3004	Connector bars	2 × 1 × l × 200 = 400	0	400
3005	Plastic shell	1 × 1 × 1 × 200 = 200	0	200
4001	Plastic powder	(1 × 1 × 1 × 200) +	10	790
		(3 " × 1 × 1 × 1 × 200) = 800		
4002	Knob	1 × 1 × 1 × 1 × 200 = 200	15	185
4003	Metal slides	2 × I × I × I × 200 = 400	30	370

7.3 MRP LOGIC

Following are some of the terms frequently used on (computerized) MRP planning forms. Note, however, that not all programs use the same terms or provide the same detail of information.

1. **Gross requirements:** Projected needs for raw materials, components, subassemblies, or finished goods by the end of the period shown. Gross requirements come from the master schedule (for end items) or from the combined needs of other items.

2. **Scheduled receipts:** Materials already on order from a vendor or in-house shop due to be received at the beginning of the period. MRP form shows quantity and projected time of receipt. (**Note:** Some MRP forms include planned receipts here too.)

3. **On hand/available:** The quantity of an item expected to be available at the end of the time period in which it is shown. This includes amount available from previous period plus planned-order receipts and scheduled receipts less gross requirements.

4. **Net requirements**: Net amount needed in the period. This equals the gross requirements less any projected inventory available from the previous period along with any scheduled receipts.

5. **Planned-order receipt**: Materials that will be ordered from a vendor or in-house shop to be received at the beginning of the period, otherwise similar to a scheduled receipt.

6. **Planned-order release:** The planned amount to be ordered in the time period adjusted by the lead-time offset so that materials will be received on schedule. Once the orders are actually released, the planned-order releases are deleted from the form and the planned-order receipts they generated are changed to scheduled receipts. The master production schedule dictates gross or projected requirements for end items to the MRP system. Gross requirements do not take account of any inventory on hand or on order. The MRP computer program then "explodes" the end-item demands into requirements for components and materials by processing all relevant bills of materials on a level-by-level (or single-level) basis. Net requirements are then calculated by adjusting for existing inventory and items already on order as recorded in the inventory status file.

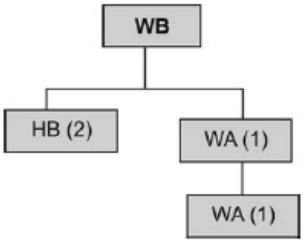
Net requirements = gross requirements – (on hand/available + scheduled receipts)

Order releases are planned for components in a time-phased manner (using lead-time data from the inventory file) so that materials will arrive precisely when needed. At this stage the material is referred to as a planned-order receipt. When the orders are actually issued to vendors or to in-house shops, the planned receipts become scheduled receipts. The inventory on hand at the end of a period is the sum of the previous period on-hand amount plus any receipts (planned or scheduled) less the gross requirements.

On hand/available = on hand at end of previous period + receipts – gross requirements

Illustration 4: A firm producing wheelbarrows is expected to deliver 40 wheelbarrows in week 1, 60 in week 4, 60 in week 6, and 50 in week 8. Among the requirements for each wheelbarrow are two handlebars, a wheel assembly, and one tire for the wheel assembly. Orders quantities, lead times, and inventories on hand at the beginning of period 1 are shown in Table below:

Table: BOM and inventory data for wheelbarrow components



Part	Order quantity	Lead time	Inventory on hand
Handlebars	300	2 week	100
Wheel assemblies*	200	3 week	220
Tires	400	1 week	50

*90 wheel assemblies are also needed in period 5 for a garden tractor shipment.

A shipment of 300 handlebars is already scheduled to be received at the beginning of week 2 (i.e., a scheduled receipt). Complete the MRP for the handlebars, wheel assemblies, and tires; and show what quantities or orders must be released and when they must be released to satisfy the master schedule.

Solution: Table next depicts the master schedule and component part schedules. We shall assume that the customer completes the final assembly, so no time allowance is required there. Note that because each wheelbarrow requires two handlebars, the gross requirements for handlebars are double the number of end products. Thus the gross requirements in period 1 are $40 \times 2 = 80$ units.

Table: Master schedule and MRP component plans for wheelbarrows

Master schedule (wheelbarrow)	Week number	1	2	3	4	5	6	7	8
	Quantity	40			60		60		50
Item ID: HB	Gross requirements	80			120		120		100
Level code: 1	Scheduled receipts		300						
On hand: 100	On hand/Available	20	320	320	200	200	80	80	280
Lot size: 300	Net requirements								20
LT (wk): 2	Planned-order receipts								300
Safety stock: 0	Planned-order release						300		
Item ID: WA	Gross requirements	40			60	90*	60		50
Level code: 1	Scheduled receipts								
On hand: 220	On hand/Available	180	180	180	120	30	170	170	120
Lot size: 200	Net requirements						30		
LT (wk): 3	Planned-order receipts						200		
Safety stock: 0	Planned-order releases			200					
Item ID: Tire	Gross requirements			200					
Level code: 2	Scheduled receipts								
On hand: 50	On hand/Available	50	50	250	250	250	250	250	250
Lot size: 400	Net requirements			150					
LT (wk): 1	Planned-order receipts			400					
Safety stock: 0	Planned-order releases		400						

*** Requirements from another product (garden tractor) that uses the same wheel assembly.**

The 100 handlebars on hand at the beginning of period 1 are adequate to supply the gross requirement of 80 handlebars, leaving 20 on hand at the end of period 1. With the (scheduled) receipt of 300 handlebars in period 2, the on-hand inventory remains adequate until the end of week 8, when 80 units are on hand. However, the gross requirement for 100 units in period 9 exceeds the on-hand inventory. This results in net requirements (using Eq. 9.1) of 100 – 80 = 20 units.

To satisfy this, a planned-order receipt for the standard order quantity (300) is scheduled for the beginning of period 8. In so far as the handlebars have a 2 week lead-time, the planned order for the handlebars must be released 2 weeks earlier (week 6). The planned order receipt will result in a projected end-of-period on-hand inventory (using Eq. 9.2) of 80 + 300 – 100 = 280 units.

7.4 SYSTEM REFINEMENTS

Key features of MRP systems are (1) the generation of lower-level requirements, (2) time phasing of those requirements, and (3) the planned-order releases that flow from them. Note particularly that planned-order releases of parent items generate gross requirements at the component level (e.g., tires).

Additional features of many MRP systems are their capability to handle (a) simulations, (b) firm-planned orders, (c) pegging, and (d) the availability of planning bills of material.

Simulation: The simulation capability allows planners to "trial fit" a master schedule onto the MRP system before the schedule is actually accepted and released. With this feature, a planner can "try" a potential customer order on the system to see if materials and delivery dates can be met even before the order is accepted. If lead times, materials, and capacities are sufficient, the order can be accepted; otherwise, changes in quantities or delivery times may have to be negotiated, or the order may even have to be turned down.

Firm-Planned Orders: Sometimes the "normal" manufacturing times are not enough to meet an emergency, secure a special order, or service a valued customer. Firm-planned order capability enables planners to instruct the computer to accept certain requirements, even though normal MRP logic would automatically delay or reschedule such orders. By designating certain orders as "firm planned orders", planners can ensure that the computer will not automatically change the release date, the planned-order receipt date, or the order quantity. In addition, the system can establish a "time fence" around the planned-order release date to preclude the scheduling of other orders near that time so as to ensure that resources are available to do the special job.

Pegging: Pegging refers to the ability to work backward from component requirements to identify the parent item; or items that generated those requirements. For example, suppose an automobile manufacturer learned that some of the brake materials (already used in production) were defective. The "where used" pegging file would allow production analysts to trace requirements upward in the product structure tree to determine what end-item models contained the defective components.

Modular and Planning Bills: Modular bills of materials describe the product structure for basic subassemblies of parts that are common to different end items. For example, several models of a manufacturer's automobiles may contain the same transmission, drive train, air-conditioning, and braking systems. By scheduling these items as (common) modules, production can sometimes be more effectively "smoothed" and inventory investment minimized.

7.5 SAFETY STOCK, LOT SIZING AND SYSTEM UPDATING

Safety stock: Note that the MRP component plan shown in Table on Master schedule and MRP component plans for wheelbarrows includes space for an entry of safety stock. Although one of the reasons for using MRP to manage dependent demand inventory items is to avoid the need for safety stock, in reality firms may elect to carry safety stock on some items for a variety of reasons: Safety stock amounts are sometimes deducted before showing the On hand/Available quantities.

Following are some of the reasons for carrying safety stock of components on an MRP format:

1. Not all demand is dependent. Some items (e.g., repair parts) may have a service requirement that has an independent demand component.
2. Variable lead times from suppliers are a common source of uncertainty to many firms.
3. Firms may experience machine breakdowns, scrap losses, and last-minute customer changes.

Lot sizing: Order quantities are not always specified in advance. Different lot-sizing methods are in use, they are (1) fixed-order quantity amounts, e.g., 300 handlebars; (2) EOQ or ERL amounts; (3) lot for lot, which is ordering the exact amount of the net requirements for each period; (4) fixed period requirements, e.g., a 2-month supply; and (5) various least-cost approaches, e.g., least-unit cost, least-total cost.

The part-period algorithm is a method that uses a ratio of ordering costs to carrying costs per period, which yields a part-period number. Then requirements for current and future periods are cumulated until the cumulative holding cost (in part-period terms) is as close as possible to this number.

System updating: MRP system designs typically use one of two methods to process data, update files, and ensure that the system information is valid and conforms with actual: (1) regenerative processing or (2) net change processing.

Regenerative MRP systems: use batch processing to replan the whole system (full explosion of all items) on a regular basis (e.g., weekly).

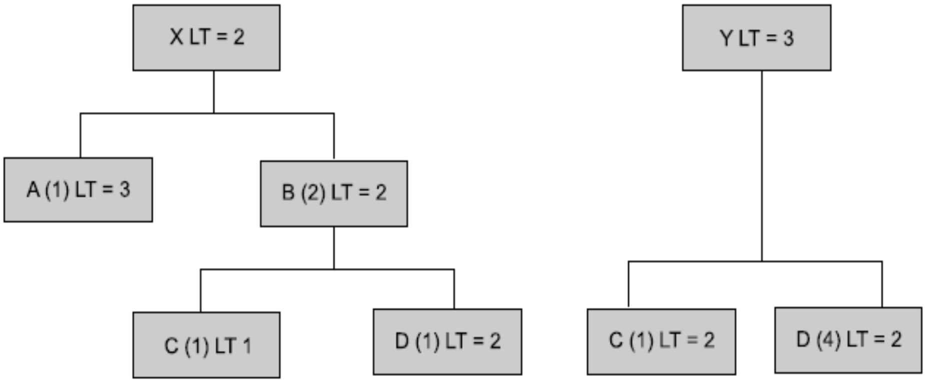
Net change MRP systems: are online and react continuously to changes from the master schedule, inventory file, and other transactions.

Early MRP installations were largely of the regenerative type, but then as net change systems became perfected, more firms began installing them. However, being "activity driven," net change systems are sometimes "nervous" and tend to overreact to changes. The major disadvantage of regenerative systems is the time lag that exists until updated information is incorporated into the system.

System application: Although MRP systems are widely used, they are most beneficial in manufacturing environments where products are manufactured to order, or assembled to order or to stock. MRP does not provide as much advantage in low-volume, highly complex applications or in continuous flow processes, such as refineries. It does, however, enjoy wide application in metals, paper, food, chemical, and other processing applications.

Illustration 4: Clemson Industries produces products X and Y, which have demand, safety stock, and product structure levels as shown in Fig. 9.4. The on hand inventories are as follows: X = 100, Y = 30, A = 70, B = 0, C = 200 and D = 800. The lot size for A is 250, and the lot size for D is 1,000 (or multiples of these amounts); all the other items are specified on a lot-for-lot (LFL) basis (that is, the quantities are the same as the net requirements). The only scheduled receipts are 250 units of X due in period 2. Determine the order quantities and order release dates for all requirements using an MRP format. (Note: Assume safety stock amounts are to be included in the on hand/Available).

Products		Demand in period							
		1	2	3	4	5	6	7	8
X	50			300			200		250
Y	30							400	



First, establish the codes (lowest level) applicable to each product as shown in Table below Items C and D appear both at level 1 in product Y and at level 2 in product X, so they are assigned to level 2. Thus their requirements are not netted out until all level 0 and 1 requirements have been netted out.

Item	Low-Level Code
	0
Y	0
A	1
B	1
2	
D	2

Fig. Product structure with BOM

Next, set up an MRP format for all items (see next Table), and enter the end-item gross requirements for X and Y. They both have low-level codes of 0 and so can be netted out using order quantities that match their requirements (preserving safety stocks, of course). This results in planned order releases of 200 and 250 units for X (periods 4 and 6) and 400 units of Y (period 4).

Next, explode the planned-order releases for X and Y (that is, multiply them by the quantities required of the level l items, A and B). (Note that C and D are not level l items.) Projected requirements for A (200 and 250 units) are direct results of the planned-order releases for X. Two units of B are required for each X, so item B’s projected requirements in periods 4 and 6 are 400 and 500, respectively. Items A and B are then netted, and the order release dates and amounts are set.

Next, explode the level 2, planned-order releases to the level 3 items. The arrows in next Table show that requirements for C and D come from planned-order releases for both B and Y. End item Y requires 4 units of D, so the projected requirements in period 4 are 2,100 units, with 1,600 from Y (that is, 4 × 400) and 500 from B. Together, they generate a planned-order release for 2,000 units of Din period 2.

Item ID: D	Gross requirements		400		2100				
Level code: 2	Scheduled receipts								
On hand: 800	On hand/Available	800	400	400	300	300	300	300	300
Lot size: 1000	Net requirements				1700				
LT (wk): 2	Planned-order receipts				2000				
Safety stock:	Planned-order releases		2000						

	Week number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Item ID: X	Gross requirements	300					300		200
Level code: 0	Scheduled receipts								
On hand: 100	On hand/Available	50	50	50	50	50	50	50	50
Lot size: LFL	Net requirements						150		200
LT (wk): 2	Planned-order receipts						200		250
Safety stock: 50	Planned-order releases				300		250		
Item ID: Y	Gross requirements							400	
Level code: 0	Scheduled receipts								
On hand: 30	On hand/Available	30	30	30	30	30	30	30	30
Lot size: LFL	Net requirements							400	
LT (wk): 3	Planned-order receipts							400	
Safety stock: 30	Planned-order releases				400				
Item ID: A	Gross requirements				200		250		
Level code: 1	Scheduled receipts								
On hand: 30	On hand/Available	70	70	70	120	120	120	120	120
Lot size: 250	Net requirements				130		130		
LT (wk): 3	Planned-order receipts				250		250		
Safety stock:	Planned-order releases	250		250					
Item ID: B	Gross requirements				400		500		
Level code: 1	Scheduled receipts								
On hand: 0	On hand/Available	0	0	0	0	0	0	0	0
Lot size: LFL	Net requirements				400		500		
LT (wk): 2	Planned-order receipts				400		500		
Safety stock:	Planned-order releases		400		500				
Item ID: C	Gross requirements		400		900				
Level code: 2	Scheduled receipts								
On hand: 200	On hand/Available	200	0	0	0	0	0	0	0
Lot size: LFL	Net requirements		200		900				
LT (wk): 1	Planned-order receipts		200		900				
Safety stock:	Planned-order releases	200		900					

7.6 CRP INPUTS AND OUTPUTS

Capacity is a measure of the productive capability of a facility per unit of time. In terms of the relevant time horizon, capacity management decisions are concerned with the following:

1. Long range-resource planning of capital facilities, equipment, and human resources.
2. Medium range-requirements planning of labor and equipment to meet MPS needs.
3. Short range-control of the flow (input-output) and sequencing of operations.

Capacity-requirements planning (CRP) applies primarily to medium-range activities. The CRP system receives planned and released orders from the material-requirements planning system and attempts to develop loads for the firm's work centers that are in good balance with the work-center capacities. Like MRP, CRP is an iterative process that involves planning, revision of capacity (or revision of the master schedule), and replanning until a reasonably good load profile is developed. Planned-order releases (in the MRP system) are converted to standard hours of load on key work centers in the CRP system.

Following are the essential inputs and outputs in a CRP system:

Inputs	Outputs
• Planned and released orders from the MRP system	• Verification reports to the MRP system
• Loading capacities from the work-center status file	• Load reports of planned and released orders on key work centers
• Routing data from the routing file	• Rescheduling data to the MPS
• Changes that modify capacity, give alternative routings, or alter planned orders	• Capacity modification data

7.7 LOADING

There are two basic techniques for planning the control of a production system. One of these is loading; the other is scheduling. Of the two loading is the easier to do. But scheduling can give more control and is more detailed, although it is usually done for a shorter time period. A load is the amount of work assigned to a facility work centre or operator, and loading is the assignment of work. Loading does not specify the sequence in which the work is done or when it is to be done. Loading is the aggregate assignment of jobs to specific entities. Inputs necessary for loading include:

- Routing
- Standard hours per operation or work centre
- Gross machine/man-hour available
- Efficiency factors
- Due date.

Loading is closely tied to capacity planning in the sense that loading is the first indication that capacity levels need adjusting.

Steps in the Loading

Typically, the loading process considered as a six step procedure. Step 1 through 4 is managerial decision steps that usually do not change week to week or month to month. The last two steps are required on a periodic basis as an input to scheduling.

1.	Choose load centers;	4.	Choose loading method
	• Department		• To infinite capacity
	• Group		• To finite capacity
	• Machine/Work-center		• Combination
2.	Develop efficiency factors by load centers	5.	Load schedule orders into load centers
3.	Determine capacity by centers	6.	Unload completed hours

Step 1: The first step in machine loading is to choose the load centers. Some companies load by department only if all the machines are interchangeable. When different machine centers within the department have different capacities, the typical approach is to break the machines down into similar machine groups. For example, all 24 inch boring machines might be included in the same group, if jobs are interchangeable among the machines. The trend is to group as many machines together as possible since doing so will reduce the complexity of the loading problem and tend to stabilize the load.

Step 2: The second step is to develop efficiency factors by load centers/work stations. A load center with two people is theoretically capable of 80 hours of production per week, but actual output might be considerably less than 80 hours of production per week, indirect activities, or other non-value adding activities. If they are working on incentives, they could be turning out more than 80 standard hours of production.

Step 3: The third step is to determine the gross capacity by load centers. This capacity is either human or machine dependent. A center is machine dependent if all machines have at least one operator assigned. A center is human dependent if there are more workers than machines and machine stand idle while all workers are busy. With the number of people or machine as an input, the gross capacity is the gross number of hours that the resources are available per planning period. The center's capacity is then the gross capacity times of the efficiency factor.

Step 4: The fourth step is to choose the loading method, which may be either to finite or to infinite capacity. Infinite capacity loading means showing the work for a work center in the time period required, regardless of the work center's capacity. Finite capacity loading means putting no more work into a work center than it can be expected to execute.

Step 5: The fifth step is to load the scheduled orders into the load centers while at the same time considering the capacity and other restrictions.

Step 6: The sixth step is to select the unloading technique. Unloading is the process of removing the planned work from the work center load as jobs are partially or totally completed. Manual systems may require shortcuts, such as considering a job to be completed when the first lot of pieces is reported. This saves posting many partial lots and recalculating load balances, but the load is always understated by the number of hours remaining on jobs unloaded. Another short-cut relieves the load only when the last lot is completed, giving a load constantly overstated by the hours completed but not removed. The number of hours to be unloaded must be equal to the number of hours loaded for each job.

A work center load, based on the actual work order released, is a good short-term technique for highlighting the under load or overloads on work centers and showing the need for overtime, temporary transfer, subcontracting or other short-range adjustments.

Loading Concepts

Why use loading? The major reason is that it can predict some future events. A chart tells of an overload, and it tells this in advance. 'This same chart can warn of excess capacity before the machine and workers are idle. Therefore, loading is most useful to dispatchers, supervisors, and production schedulers planning shop work. Loading can be used to smooth the workload from month to month or between the work centers. It is an aid in identifying the critical departments or machines and in judging the effect of break-downs, rush orders, and new products. It is also useful for documenting the requirements for more or less capacity.

Infinite Loading

Infinite capacity loading means showing the work for a work center in the time period required, regardless of the work center's capacity. When using infinite loading to create the schedule, it is necessary to check the load to determine whether there is sufficient capacity available in the time period in which the work is required.

Finite Loading

Finite capacity loading means putting no more work into a work center than it can be expected to execute. Loading to finite capacity by operation is more complex than infinite capacity. A facility activity that does not go according to schedule may require that the load be recalculated, and therefore, loads will fall in different time periods. Finite loading also requires that the company establish priority for loading the jobs. In practice, finite loading is unsatisfactory since it assumes that the present capacity is all that is available and does not show the time period in which overloads will occur if an attempt is made to meet desirable schedules.

Combination Loading

A good machine loading system involves a combination of both techniques. Orders are first scheduled and loaded to infinite capacity to see where overload will occur, then rescheduled to level the load based on available capacity after corrective actions have been taken wherever possible.

Companies have successfully used computer machine loads over longer planning periods to assist capacity planning. Forecasts of individual finished products to be manufactured during this period can be exploded into detailed requirements of production hours for each of major work centers. The machine hours based on these aggregate hours will give dependable data on the average capacity required to meet the forecasted demand on manufacturing facilities.

The work may be assigned by the nature of the job. If the work can be done by more than one center, it must be assigned to just one. If it can be done by only one work center, then there is no alternative, but to one work center. The work may be assigned on an individual job basis, but if the jobs are repetitive, they may be assigned on a standard basis by the use of routings. Standard routings shows all operations that must be done to make the part or assembly. If the standard routings are not available, someone must assign the individual jobs to the facilities and must estimate the work content of the assignments. The work contents must be in terms that are comparable between jobs. Measures that can be used are hours, pieces, batches, gallons and so on per hour, per shift, per day and so on.

Work assignments must be accumulated by the facility in order to calculate the load on each facility. One method is to use a ledger in which the job members and job loads are entered by each facility. When the job is completed, it is marked off. The jobs are then added periodically to obtain the load on the facility.

Another method is to accumulate the assignments in 'buckets' one bucket for each facility. The bucket may be box, a file, a peg and so on. A ticket is prepared for each job assigned to the facility and is placed in the bucket. A perpetual total of the facility load may be kept for each bucket. Job tickets, as added to the bucket are added to this total. When completed and removed from the bucket, they are deducted from the total. If a computer is available, bucket may be computer file. If standard routings are available, these can be kept as computer files.

7.8 LET US SUM UP

MRP systems are able to reduce inventory costs improve scheduling effectiveness, and respond quickly to market changes.

CRP is the process of determining what personnel and equipment capacities (times) are needed to meet the production objectives embodied in the master schedule and the material requirements plan.

A bill of materials (BOM) is a listing of all the materials, components, and subassemblies needed to assemble one unit of an end item. Major function of the bill of materials is to provide the product structure hierarchy that guides the explosion process.

Key features of MRP systems are (1) the generation of lower-level requirements, (2) time phasing of those requirements, and (3) the planned-order releases that flow from them. Note particularly that planned-order releases of parent items generate gross requirements at the component level (e.g., tires).

Additional features of many MRP systems are their capability to handle (a) simulations, (b) firm-planned orders, (c) pegging, and (d) the availability of planning bills of material.

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Loading is the aggregate assignment of jobs to specific entities. Companies have successfully used computer machine loads over longer planning periods to assist capacity planning. Forecasts of individual finished products to be manufactured during this period can be exploded into detailed requirements of production hours for each of major work centers. The machine hours based on these aggregate hours will give dependable data on the average capacity required to meet the forecasted demand on manufacturing facilities.

7.9 EXERCISES

1. (a) What is meant by “time phasing” (b) What is a “time bucket”?

2. (a) Why is the BOM file sometimes called a product structure tree? (b) Suppose a 5-level BOM has one subassembly (AX205) on level 2 and another (BY407) on level 4. Which subassembly has a level code nearest the end item?

3. Why do MRP programs use single-level BOMs?

4. What is the advantage of low-level coding?

5. What are the three essential sources of data for an MRP program?

6. What must take place to change a planned-order release to a scheduled receipt?

7. By using a time-phased plan for component inventories, a firm can reduce average inventory levels from 105 units to 42.5 units. If the average component value is Rs.12 and the reduction applies to 4,000 components, how much of a saving would result? Use inventory-carrying costs of 30 per cent per year.

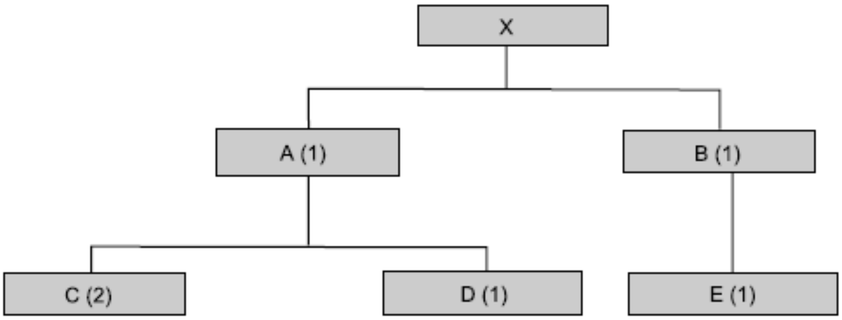
8. Determine the net requirements for the three items shown in table.

	Switches	Microprocessor	Keyboards
Gross requirements	55	14	28
On-hand Inventory	18	2	7
Inventory on order (scheduled receipt)	12	12	10

Ans: 25 Switches, 0 Microprocessors and 11 Keyboards

9. Given the product structure tree shown in table compute the net requirements for A, B, C, D, and E, to produce 50 units of X.

Components	A	B	C	D	E
Inventory on hand and on order	20	10	15	30	100



7.10 SUGGESTED READING

- Operations & Supply Chain Management by Chase, Shankar, Jocaobs
- Operations Management (6th Edition) by Nigel Slack, Stuart Chambers, Robert Johnston
- Theory & Problems in Production & Operations Management- S N Chary, Tata McGraw Hill
- Production & Operations Management -Kanishka Bedi , Oxford University Press
- Operations Management for competitive advantage-Chase & Jacob, McGraw-Hill/Irwin
- Production and Operations Management- Chunawalla & Patel, Himalaya Publishing

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8

SEQUENCING TECHNIQUES AND SCHEDULING AND CONTROLLING OF PRODUCTION

Unit Structure

8.0 OBJECTIVES

After going through this unit you will be able to understand the following concepts:

- Concept of Single Machine Scheduling
- Measures of Performance
- Shortest Processing Time (SPT) Rule
- WSPT Rule
- Earliest Due Date (EDD) Rule
- Minimizing the Number of Tardy Jobs
- Flow Shop Scheduling
- Johnson's Problem
- CDS Heuristic
- Job Shop Problem
- Types of Schedules
- Two Jobs and M Machines Scheduling.

8.1 INTRODUCTION

Scheduling is the allocation of starts and finish time to each particular order. Therefore scheduling can bring productivity in shop floor by providing a calendar for processing a set of jobs.

The **single machine-scheduling problem** consists of n jobs with the same single operation on each of the jobs, while the **flow shop-scheduling problem** consists of n jobs with m operations on each of the jobs. In this problem, all the jobs will have the same process sequences. The **job shop scheduling problem** contains n jobs with m operations on each of the jobs; but, in this case, the process sequences of the jobs will be different from each other.

8.2 CONCEPT OF SINGLE MACHINE SCHEDULING

The basic single machine scheduling problem is characterized by the following conditions:

1. A set of independent, single-operation jobs is available for processing at time zero.
2. Set-up time of each job is independent of its position in jobs sequence. So, the set-up time of each job can be included in its processing time.
3. Job descriptors are known in advance.
4. One machine is continuously available and is never kept idle when work is waiting.
5. Each job is processed till its completion without break.

Under these conditions, one can see one-to-one correspondence between a sequence of the n jobs and a permutation of the job indices 1, 2, ... n. The total number of sequences in the basic single machine problem is n! which is the number of different permutation of n elements.

The following three basic data are necessary to describe jobs in a deterministic single machine-scheduling problem.

Processing time (tj): It is the time required to process job j. The processing time, tj will normally include both actual processing time and set-up time.

Ready time (rj): It is the time at which job j is available for processing. The ready time of a job is the difference between the arrival time of that job and the time at which that job is taken for processing. In the basic model, as per condition I, rj = 0 for all jobs.

Due date (dj): It is the time at which the job j is to be completed.

Completion time (Cj): It is the time at which the job j is completed in a sequence. Performance measures for evaluating schedules are usually function of job completion time. Some, sample performance measures are Flow time, Lateness, Tardiness, etc.

Flow time (Fj): It is the amount of time job j spends in the system. Flow time is a measure, which indicates the waiting time of jobs in a system. This in turn gives some idea about in-process inventory due to a schedule. It is the difference between the completion time and the ready time of the job j. i.e. Fj = Cj – rj.

Lateness (Lj): It is the amount of time by which the completion time of job j differs from the due date (Lj = Cj – d). Lateness is a measure which gives an idea about conformity of the jobs in a schedule to a given set of due dates of the jobs. Lateness can be either positive lateness or negative lateness. Positive lateness of a job means that the job is completed after its due date. Negative lateness of a job means that the job is completed before its due date. The positive lateness is a measure of poor service. The negative lateness is a measure of better service. In many situations, distinct penalties and other costs are associated with positive lateness, but generally, no benefits are associated with negative lateness. Therefore, it is often desirable to optimize only positive lateness.

Tardiness (Tj): Tardiness is the lateness of job j if it fails to meet its due date, or zero, otherwise

Tj = max {O, Cj – dj}

= Max {O, Lj }.

8.3 MEASURES OF PERFORMANCE

The different measures of performance which are used in the single machine scheduling are listed below with their formulas.

$$\text{Mean flow time: } \overline{F} = \frac{1}{n}\sum_{j=1}^{n} F_j$$

$$\text{Mean tardiness: } \overline{T} = \frac{1}{n}\sum_{j=1}^{n} T_j$$

$$\text{Maximum flow time: } F_{\max} = \underset{1\le j\le n}{Max}\{F_j\}$$

$$\text{Maximum tardiness: } T_{\max} = \underset{1\le j\le n}{Max}\{T_j\}$$

$$\text{Number of tardy jobs: } N_T = \sum_{j=1}^{n} f(T_j)$$

where

$$f(T_j) = I, \text{ if } T_j > 0, \text{ and } f(T_j) = 0, \text{ otherwise.}$$

8.4 SHORTEST PROCESSING TIME (SPT) RULE

In single machine scheduling problem, sequencing the jobs in increasing order of processing time is known as the shortest processing time (SPT) sequencing.

Sometimes we may be interested in minimizing the time spent by jobs in the system. This, in turn, will minimize the in-process inventory. Also, we may be interested in rapid turnaround/throughput times of the jobs.

The time spent by a job in the system is nothing but its flow time, and the 'rapid turnaround time' is its mean flow time (F). Shortest processing time (SPT) rule minimizes the mean flow time.

Illustration 1: Consider the following single machine-scheduling problem.

Job (j)	1	2	3	4	5
Processing time (t) (hrs)	15	4	5	14	8

Find the optimal sequence, which will minimize the mean flow time and also obtain the minimum mean flow time.

Solution:

No. of jobs = 5

Arrange the jobs as per the SPT ordering

Job (j)	2	3	5	4	1
Processing time (t) (hrs)	4	5	8	14	15

Therefore, the job sequence, which will minimize the mean flow time, is **2-3-5-4-1**.

Computation of **Fmin**:

Job (j)	2	3	5	4	1
Processing time (t) (hrs)	4	5	8	14	15
Completion time (Cj) (Fj)	4	9	17	31	46

Since, the ready time rj = 0 for all j, the flow time (Fj) is equal to Cj for all j.

$$\bar{F} = \frac{1}{n}\sum_{j=1}^{n} F_j = \frac{1}{5}(4+9+17+31+46) = \frac{1}{5}(107) = 21.4 \text{ hours}$$

Therefore, the optimal mean flow time = 21.4 hours.

8.5 WSPT RULE

Sometimes, the jobs in a single machine-scheduling problem will not have equal importance. Under such situation, each job is assigned a weight, wj . The mean flow time, which is computed after considering wj is called, weighted mean flow time, which is shown below:

$$\bar{F}w = \frac{\sum_{j=1}^{n} w_j \cdot F_j}{\sum_{j=1}^{n} w_j}$$

In single machine scheduling problem, sequencing the jobs in increasing order of weighted processing time is known as Weighted Shortest Processing Time (WSPT) sequencing. The weighted processing time of a job is obtained by dividing its processing time by its weight.

Illustration 2: Consider the following single machine-scheduling problem with weights:

Job (j)	1	2	3	4	5
Processing time (tj) (hrs)	15	4	5	14	8
Weight (w)	1	2	1	2	3

Determine the sequence, which will minimize the weighted mean flow time of the above problem. Also find the weighted mean flow time.

Solution:

Job (j)	1	2	3	4	5
Processing time (tj) (hrs)	15	4	5	14	8
Weight (w)	1	2	1	2	3
T/wj	15	2	5	7	2.67

Arrange the jobs in the increasing order of tj / wj (i.e. WSPT ordering). From the above table, we get the following relation.

$$t_2/w_2 \leq t_5/w_5 \leq t_3/w_3 \leq t_4/w_4 \leq t_1/w_1$$

Therefore optimal sequence, which will minimize the weighted mean flow time, is, 2 – 5 – 3 – 4 – 1.

Job (j)	2	3	5	4	1
Tj 4	5	8	14	5	
Cj(Fj) 4	9	17	31	46	
Fj*Wj 4	9	17	31	46	

$$\bar{F}w = \frac{\sum_{j=1}^{n} w_j F_j}{\sum_{j=1}^{n} w_j} = \frac{(8+36+17+62+46)}{(2+3+1+2+1)} = \frac{169}{9} = 18.78 \text{ hours.}$$

8.6 EARLIEST DUE DATE (EDD) RULE

The lateness (Lj) of a job is defined as the difference between the completion time and the due date of that job. Lj can be either positive or negative values.

Lj = Cj – dj

The maximum job lateness (Lmax) and the maximum job tardiness (Tmax) are minimized by Earliest Due Date sequencing. In a single machining scheduling problem, sequencing of jobs in increasing order of due date is known as 'Earliest Due Date Rule'.

Illustration 3: Consider the following single machining scheduling problem:

Job (j)	1	2	3	4	5	6
Processing time (tj)	10	8	8	7	12	15
Due date (dj)	15	10	12	11	18	25

Determine the sequence which will minimize the maximum lateness (Lmax). Also, determine Lmax with respect to the optimal sequence.

Solution:

Arrange the jobs as per EDD rule (i.e. in the order of their due dates). The EDD sequence is 2-4-3-1-5-6.This sequence gives a minimum value for Lmax.

Job (j) (EDD Sequence)	2	4	3	1	5	6
Processing time (tj)	8	7	8	10	12	15
Completion time (Cj)	8	15	23	33	45	60
Due date (dj)	10	11	12	15	18	25
Lateness (Lj)	-2	4	11	18	27	35

From the table, the maximum is 35. This is the optimal value for Lmax. The Lmax of any other non-EDD sequence will not be less than 35.

8.7 MINIMIZING THE NUMBER OF TARDY JOBS

If a job is completed beyond its due date, then it is called tardy job; otherwise it is called non-tardy job. In many organizations, the objective may be to minimize the total number of tardy jobs.

If the EDD sequence yields zero tardy or it yields exactly one tardy job, then it is an optimal sequence for minimizing the total number of tardy jobs (NT), If it yields more than one tardy job, the EDD sequence may not yield the optimal solution. An exact algorithm for the general case is given below. The final sequence consists of two streams of jobs as given below:

(a) First, a set (E) of early jobs, in EDD order.

(b) Then, a set (L) of late jobs, in any order.

This algorithm gives optimal sequence, which will result in minimum number of tardy jobs (NT).

Hodgson's Algorithm to Minimize NT

Step 1: Arrange the jobs in EDD order and assume this, as set E. Let set L be empty.

Step 2: If no jobs in E are late, then stop. Find the union of E and L (Note: The remaining jobs in E should be in EDD order. But the jobs in L can be in any order); otherwise, identify the first late job in E. Let it be job K.

Step 3: Identify the longest job, among the first K jobs in the sequence. Remove this job from E and place it in L. Revise the completion times of the jobs remaining in E and return, to Step 2.

This algorithm is demonstrated using the following problem.

Illustration 4 A computer systems consulting company is under contract to carry out seven projects, all with deadliness assured in days from now. The consultants are a small group and they work together on each project, so that the project will be started and completed sequentially. Under the terms of contract, the consultants will receive Rs. 24,000 for each project completed on time, but they will incur Rs. 40,000 in penalties for each project completed late. Each project has an, associated duration, which is the anticipated number of days required to carry out the project as shown below.

How should the projects be sequenced in order to maximize net revenues?

Project Id	1	2	3	4	5	6	7
Duration (Dj)	2	4	6	8	10	12	14
Deadlines (d)	6	12	30	19	12	18	24

Solution: From the statement of the problem, one can identify that the objective is to maximize net revenues. This can be achieved by simply obtaining a sequence, which will minimize the number of tardy jobs (NT), hence, we apply Hodgson's algorithm to minimize NT.

Step 1: The earliest due date order is shown below:

a(ij)	2	12	12	18	19	24	30
Project (j)	1	2	5	6	4	7	3

Place the above sequence of projects which is in EDD order in set E. Therefore,

Set E = (1, 2, 5, 6, 4, 7,3)

Set L = (Empty).

Step 2: The lateness of the projects are checked as shown below:

Project (j)	1	2	5	6	4	7	3
Duration (tj)	2	4	10	12	8	14	6
Completion time (Cj)	2	6	16	28	38	50	56
Due date (d)	6	12	12	18	19	24	30
Tardy/Non-tardy (1/0)	0	0	1	1	1	1	1

In the above table, in the last row, 0 means that the project is non-tardy and 1 means that the project is tardy.

As per the sequence in the set E, there are five tardy projects. The first tardy project is 5, which is in the third position [3].

Step 3: The project with the largest duration among the first-three projects in the sequence is 5.

Remove this project and append it to L. Therefore

L = {5}

E = {1, 2, 6, 4, 7, 3}.

The completion times of the projects in the set E are revised as shown below:

Project (j)	1	2	6	4	7	3
Duration (tj)	2	4	12	8	14	6
Completion time (Cj)	2	6	18	26	40	46
Due date (d)	6	12	18	19	24	30
Tardy/Non-tardy (1/0)	0	0	0	1	1	1

Step 2: From Step 3, it is clear that there are three tardy projects. The first tardy project is 4, which is in the fourth position of the sequence in the set E.

Step 3: The project with the longest duration among the first-four projects is 6. Remove the project-6 from the set E and append it to the set L. Therefore

E = {1, 2, 4, 7, 3}

L = {5, 6}.

The completion times of the projects in the set E are revised as shown:

Project (j)	1	2	4	7	3
Duration (tj)	2	4	8	14	6
Completion time (Cj)	2	6	14	28	34
Due date (d)	6	12	19	24	30
Tardy/Non-tardy (1/0)	0	0	0	1	1

Step 2: From the table shown in Step 3 it is known that there are two tardy projects. The first tardy project is 7, which is at the fourth position in the set E.

Step 3: The project with the longest duration. Among the first-four projects in the set E are 7.

Remove this job from the set E and append it to the set L.

E = {1, 2, 4, 3}

L = {5, 6, 7}.

The completion times of the projects are revised as shown below:

Project (j)	1	2	4	3
Duration (tj)	2	4	8	6
Completion time (Cj)	2	6	14	20
Due date (d)	6	12	19	30
Tardy/Non-tardy (1/0)	0	0	0	0

Step 2: From the table in the previous step, it is clear that all the projects are non-tardy jobs.

Hence, we reached the optimal sequence in E.

Now merge E and L to get the complete sequence.

Final sequence = E U L={1,2,4,3,5,6,7}

In the above optimal sequence, total number of tardy projects is 3, which is the minimum value.

8.8 FLOW SHOP SCHEDULING

In flow shop scheduling problem, there are n jobs; each require processing on m different machines.

The order in which the machines are required to process a job is called process sequence of that job.

The process sequences of all the jobs are the same. But the processing times for various jobs on a machine may differ. If an operation is absent in a job, then the processing time of the operation of that job is assumed as zero.

The flow-shop scheduling problem can be characterized as given below:

1. A set of multiple-operation jobs is available for processing at time zero (Each job requires m operations and each operation requires a different machine).
2. Set-up times for the operations are sequence independent, and are included in processing times.
3. Job descriptors are known in advance.
4. m different machines are continuously available.
5. Each individual operation of jobs is processed till its completion without break.

The main difference of the flow shop scheduling from the basic single machine scheduling is that the inserted idle time may be advantageous in flow shop scheduling. Though the current machine is free, if the job from the previous machine is not released to the current machine, we cannot start processing on that job. So, the current machine has to be idle for some time. Hence, inserted idle time on some machines would lead to optimality.

For example, consider the following flow-shop problem:

Job	Machine 1	Machine 2
1	5	4
2	3	1
3	6	2
4	7	8

If the sequence of the job is 2-1-4-3, then the corresponding make span is computed as shown in Fig. Here the make span is 25. Also, note the inserted idle times on machine 2 are from 0 to 3, 4 to 8 and 12 to 15.

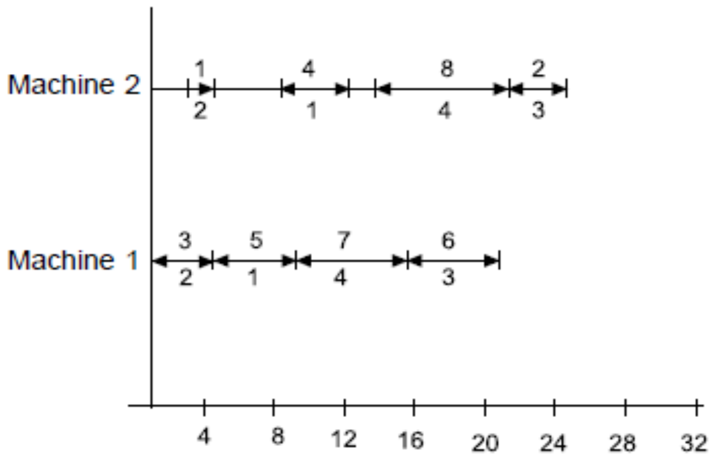

Fig. Gantt chart for sequence 2-1-4-3

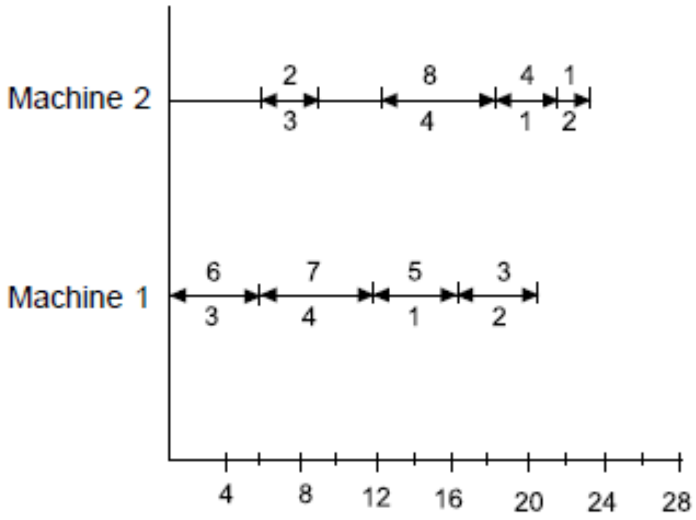

Fig. Gantt chart for sequence 3-4-1-2

Consider another sequence say 3-4-1-2. The Gantt chart for this sequence is shown in above second Fig.

The make span for the schedule in Fig. is 26. The machine 2 has idle time from 0 to 6 and from 8 to 13.

This problem has 4 jobs. Hence, 4! sequences are possible. Unlike in single machine scheduling, in flow shop scheduling, inserted idle time would minimize the make span.

In the above two sequences, 2-1-4-3 and 3-4-1-2, the first sequence has lesser make span. Like this, one can enumerate all 4! sequences, then select the sequence with the minimum make span as the optimal sequence. Since, n! grows exponentially with n, one needs some efficient procedure to solve the problem. For large size of n, it would be difficult to solve the problem. Under such situation we can use some efficient heuristic.

8.9 JOHNSON'S PROBLEM

As mentioned in the earlier section, the time complexity function for a general flow shop problem is exponential in nature. This means, the function grows exponentially with an increase in the problem size. But, for a problem with 2 machines and n jobs, Johnson had developed a polynomial algorithm to get optimal solution, i.e., in a definite time, one can get the optimal solution.

Consider the following flow shop problem:

Job	Machine 1	Machine 2
1	t_{11}	t_{12}
2	t_{21}	t_{22}
3	t_{31}	t_{32}
n	t_{n1}	t_{n2}

In the above table, t_{ij} represents the processing time of the job i on the machine j.

Johnson's Algorithm

The technique requires several preconditions:

- The time for each job must be constant.
- Job times must be mutually exclusive of the job sequence.
- All jobs must be processed in the first work center before going through the second work center.
- All jobs are equally prioritized.

Johnson's rule is as follows:

1. List the jobs and their times at each work center.
2. Select the job with the shortest activity time (ti1 and ti2). If that activity time is for the first work center, then schedule the job first. If that activity time is for the second work center then schedule the job last. Break ties arbitrarily.
3. Eliminate the shortest job from further consideration.
4. Repeat steps 2 and 3, working towards the center of the job schedule until all jobs have been scheduled.

Given significant idle time at the second work center (from waiting for the job to be finished at the first work center), job splitting may be used.

Illustration 5: Each of five jobs needs to go through work center A and B. Find the optimum sequence of jobs using Johnson's rule.

Job	Machine 1	Machine 2
A	3.2	4.2
B	4.7	1.5
C	2.2	5.0
D	5.8	4.0
E	3.1	2.8

Solution: The workings of the algorithm are summarized in the form of a table, which is shown below:

1. The smallest time is located in Job B (1.5 hours). Since the time is in Work Center B, schedule this job last.

   Eliminate Job B from further consideration.

?	?	?	?	B

2. The next smallest time is located in Job C (2.2 hours). Since the time is in Work Center A, schedule this job first.

   Eliminate Job C from further consideration.

C	?	?	?	B

3. The next smallest time after that is located in Job E (2.8 hours). Since the time is in Work Center B, schedule this job last.

   Eliminate Job E from further consideration.

C	?	?	E	B

4. The next smallest time after is located in Job A (3.2 hours). Since the time is in Work Center A, schedule this job first.

   Eliminate Job A from further consideration.

C	A	?	E	B

5. The only job left to consider is Job D.

C	A	D	E	B

So, the jobs must be processed in the order C → A → D → E → B, and must be processed in the same order on both work centers.

Extension of Johnson's Rule

Processing n Jobs through Three Machines: Sequencing Problem

This case is similar to the previous case except that instead of two machines, there are three machines. Problems falling under this category can be solved by the method developed by Johnson. Following are the two conditions of this approach:

- The smallest processing time on machine A is greater than or equal to the greatest processing time on machine B, i.e.,

$$\text{Min. } (A_i) \geq \text{Max. } (B_i)$$

- The smallest processing time on machine C is greater than or equal to the greatest processing time on machine B, i.e.,

$$\text{Max. } (B_i) \leq \text{Min. } (C_i)$$

If **either or both** of the above conditions are satisfied, then we replace the three machines by two fictitious machines G & H with corresponding processing times given by

$G_i = A_i + B_i$
$H_i = B_i + C_i$

Where G_i & H_i are the processing times for i^{th} job on machine G and H respectively.

After calculating the new processing times, we determine the optimal sequence of jobs for the machines G & H in the usual manner.

Illustration 6: The MDH Masala company has to process five items on three machines:- A, B & C. Processing times are given in the following table:

Item	**A_i**	**B_i**	**C_i**
1	4	4	6
2	9	5	9
3	8	3	11
4	6	2	8
5	3	6	7

Find the sequence that minimizes the total elapsed time.

Solution:

Here, Min. (A_i) = 3, Max. (B_i) = 6 and Min. (C_i) = 6. Since the condition of Max (B_i) ≤ Min. (C_i) is satisfied, the problem can be solved by the above procedure. The processing times for the new problem are given below.

Item	**$G_i = A_i + B_i$**	**$H_i = B_i + C_i$**
1	8	10
2	14	14
3	11	14
4	8	10
5	9	13

The optimal sequence is: 1 4 5 3 2

Item	Machine A		Machine B		Machine C	
	Time In	Time Out	Time In	Time Out	Time In	Time Out
1	0	4	4	8	8	14
4	4	10	10	12	14	22
5	10	13	13	19	22	29
3	13	21	21	24	29	40
2	21	30	30	35	40	49

Total elapsed time = 49

Idle time for machine A = 49 – 30 = 19 hours

Idle time for machine B = 4 + (10 - 8) + (13 - 12) + (21 - 19)+ (30 - 24) + (49 - 35) = 29 hours

Idle time for machine C = 8 + (14 - 14) + (22 - 22) + (29 - 29)+ (40 - 40) = 8 hours

8.10 CDS HEURISTIC

For large size problems, it would be difficult to get optimum solution in finite time, since the flow shop scheduling is a combinatorial problem. This means the time complexity function of flow shop problem is exponential in nature. Hence, we have to use efficient heuristics for large size problems.

CDS (Campbell, Dudek and Smith) heuristic is one such heuristic used for flow shop scheduling.

The CDS heuristic corresponds to multistage use of Johnson's rule applied to a new problem formed from the original processing time.

At stage 1

$t^1_{j1} = t_{ji}$ and $t^1_{j2} = t_{jm}$

In other words, Johnson's rule is applied to the first and mth operations and intermediate operations are ignored.

At stage 2

$T^2_{j1} = t_{ji} + t_{j2}$ and $t^2_{j2} = t_{jm} + t_{j\ m-1}$

That is, Johnson's rule is applied to the sum of the first two and the last two operation processing times.

In general at stage i,

$t^{i}_{ji} = \Sigma_{ji}$ and $t^{i}_{j2} = \Sigma t_{j,m-k+1}$

For each stage i (i = 1, 2, ... m – 1), the job order obtained is used to calculate a make span for the original problem. After m – 1, stages, the best make span among the m – 1 schedule is identified (Some of the m – 1 sequences may be identical).

Illustration 7: Find the make span using the CDS heuristic for the following flow shop problem:

Job j	t_{j1}	t_{j2}	t_{j3}	t_{j4}
1	4	3	7	8
2	3	7	2	5
3	1	2	4	7
4	3	4	3	2

Solution:

Job (j)	M/c–1 t_{j1}	M/c–1 t_{j2}
1	4	8
2	3	5
3	1	7
4	3	2

The optimal sequence for the above problem is as shown below:

3-2-1-4

The make span calculation for the above schedule is shown below:

Processing time (in hour)								
Job	M/c–1		M/c–2		M/c–3		M/c–4	
	In	Out	In	Out	In	Out	In	Out
3	0	1	1	3	3	7	7	14
2	1	4	4	11	11	13	14	19
1	4	8	11	14	14	21	21	29
1	8	11	14	18	21	24	29	31

Make span of this problem = 31.

Stage 2

Job (j)	M/c–1 T_{j1}	M/c–2 t_{j2}
1	7	15
2	10	7
3	3	11
4	7	5

After applying Johnson's algorithm to the above problem, we get the sequence, 3-1-2-4. The make span calculation is summarized in the following table:

Processing time (in hour)									
Job	M/c–1		M/c–2		M/c–3		M/c–4	
	In	Out	In	Out	In	Out	In	Out
3	0	1	1	3	3	7	7	14
1	1	5	5	8	8	15	15	23
2	5	8	8	15	15	17	23	28
4	8	11	15	19	19	22	28	30

The makes pan for the sequence 3-1-2-4 is 30.

Stage 3

Job	M/c–1	M/c–2
	T_{j1}	T_{j2}
1	14	18
2	12	14
3	7	13
4	10	9

The application of Johnson’s algorithm to the above data yields the sequence 3-2-1-4. The determination of the corresponding make span is shown below:

Job	M/c–1		M/c–2		M/c–3	
	In	Out	In	Out	In	Out
3	0	1	3	7	7	14
2	1	4	11	13	14	19
1	4	8	14	21	21	29
4	8	11	21	24	29	31

stage	sequence	Makespan
1	3-2-14	31
2	3-1-2-4	30
3	3-2-1-4	31

The best sequence is 3-1-2-4, which has the make span of 30.

8.11 JOB SHOP PROBLEM

In job-shop problem, we assume that each job has m different operations. If some of the jobs are having less than m operations, required number of dummy operations with zero process times is assumed. By this assumption, the condition of equal number of operations for all the jobs is ensured.

In job-shop scheduling problem, the process sequences of the jobs are not the same. Hence, the flow of each job in job-shop scheduling is not unidirectional.

The time complexity function of the job shop problem is combinatorial in nature. Hence, heuristic approaches are popular in this area.

Unlike the flow shop model, there is no initial machine that performs only the first operation of a job nor there a terminal machine that performs only the last operation of a job.

In the flow shop, an operation number in the operation sequence of a job may be same as the position number of the required machine. Hence, there is no need to distinguish between them. But, in the job shop case, different jobs will have different operation sequences. So, we cannot assume a straight flow for the job shop problem. Each operation j in the operation sequence of the job i in the job shop problem will be described with triplet (i, j, k) where k is the required machine for processing the j^{th} operation of the i^{th} job.

Consider the following data of a job shop scheduling involving four jobs, three operations and hence three machines.

The first table consists of operation processing times and the second table consists of operation (process) sequences of the jobs. The set of machines required for a given job constitute a routing.

For example, job 4 has a routing of 1-3-2.

Processing times (hrs)			
	Operations		
	1	2	3
Job 1	2	3	4
Job 2	4	4	1
Job 3	2	2	3
Job 4	3	3	1

Routing			
	Operations		
	1	2	3
Job 1	1	2	3
Job 2	3	2	1
Job 3	2	3	1
Job 4	1	3	2

8.12 TYPES OF SCHEDULES

In general, infinite number of feasible schedules is possible for any job shop problem, because one can insert any arbitrary amount of idle time at any machine between adjacent pairs of operations.

These idle times are not useful in any sense. In fact, these will lead to non-optimal solution while minimizing make span measure. Adjusting the start time of some operations towards left without affecting the operations sequences will minimize the unwanted idle time. This type of adjustment is called **local-left -shift**, or a **limited-left-shift**. Given an operation sequence for each machine, there is only one schedule in which no local-left-shift can be made. The set of all schedules in which no local-left-shift can be made is called **the set of semi-active schedules** and is equivalent to the set of all schedules that contain none of the unwanted idle time described above. This set dominates the set of all schedules, which means that it is sufficient to consider only semi-active schedules to optimize any regular measure of performance.

The number of semi-active schedules is finite and is less than the total number of possible schedules. In a semi-active schedule, the start time of a particular operation is constrained either by (a) processing a different job on the same machine or (b) by processing the directly preceding operation on n different machines. In the former case, where the completion of an earlier operation on the same machine is constrained, it may still be possible to find obvious means of improvement.

Even when no local-shifts are possible, a better schedule can obviously be devised by shifting operations to the left and beyond other operations already scheduled on some machine. This type of adjustment in which some operation is begun earlier without delaying any other operation is called a **global left-shift** or **simply a left-shift**. The set of all schedules in which no global left-shift can be made is called the set of active schedules. It is clearly a subset of the set of semi-active schedules.

The set of active schedules dominates the set of semi-active schedules in terms of optimizing any regular measure of performance. So it is sufficient to consider only active schedules.

If no machine is kept idle at a time when it could begin processing some operation then it is called a **non-delay schedule**. We can identify a subset of schedules from the set of active schedules satisfying this property, which is known as a **set of non-delay schedules**.

All non-delay schedules are active schedules, since no left-shift is possible. There is no guarantee that the non-delay subset will contain an optimum.

The Venn diagram showing the relative sizes between different types of schedules is shown in the following Fig. There will be at least one optimal schedule in the set of active schedules.

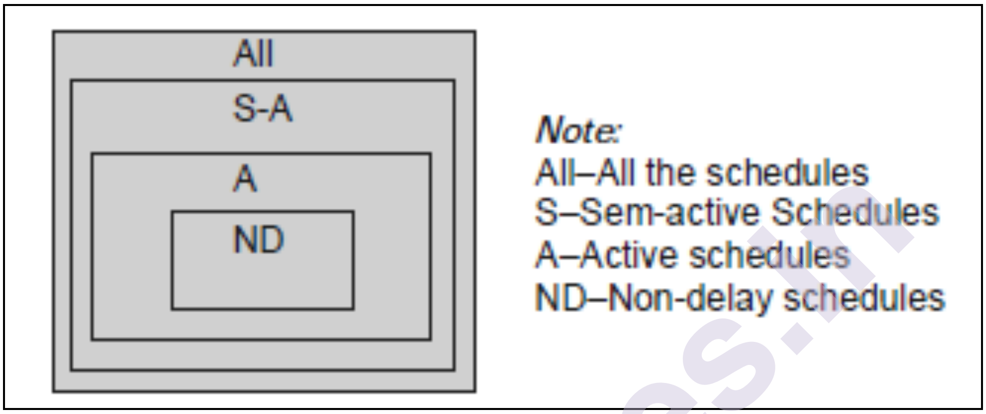

Fig. Venn diagram showing different schedules

8.13 HEURISTIC PROCEDURES

Since, the job shop problem comes under combinatorial category; the time taken to obtain optimum solution will be exponential in nature. In this type of problem, the number of feasible schedules will grow exponentially, even for small increment in problem size. As a result, it will be impossible to solve large size problems optimally. Hence, we should resort to heuristic approach to get near optimal solution.

8.14 LET US SUM UP

In this unit we have discussed the concept of single machine scheduling. Measures of Performance like flow time, tardiness and tardy jobs are introduced.

Different scheduling algorithms like Shortest Processing Time (SPT) Rule, WSPT Rule, Earliest Due Date (EDD) Rule and Johnson's Rule are discussed with examples.

Flow Shop Scheduling, CDS Heuristic, Job Shop Problem and Types of Schedules with Heuristic Procedures are also explained.

These concepts can be used extensively in the practical production environment.

8.15 EXERCISES

1. Briefly discuss different measures of performance in single machine scheduling with independent jobs.
2. Consider the following problem in single machine scheduling with independent jobs.

job	1	2	3	4	5	6	7	8
Processing time (t_j)	5	12	8	10	3	15	8	6
Due date (d_j)	10	16	11	16	6	25	12	14
Weight (w_j)	2	1	1	2	3	4	2	3

Obtain the optimal schedule for each of the following performance measures:

(a) To minimize mean flow time.

(b) To minimize the maximum lateness.

(c) To minimize weighted mean flow time.

3. Consider the following two machines and 6 jobs flow shop problem.

Job	Machine 1	Machine 2
1	5	7
2	10	8
3	8	13
4	9	7
5	6	11
6	12	10

Obtain the optimal schedule and the corresponding make span for the above problem.

8.16 SUGGESTED READING

- Operations & Supply Chain Management by Chase, Shankar, Jocaobs
- Operations Management (6th Edition) by Nigel Slack, Stuart Chambers, Robert Johnston
- Theory & Problems in Production & Operations Management- S N Chary, Tata McGraw Hill
- Production & Operations Management - Kanishka Bedi, Oxford University Press
- Operations Management for competitive advantage-Chase & Jacob, McGraw-Hill/Irwin
- Production and Operations Management- Chunawalla & Patel, Himalaya Publishing

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9

INTRODUCTION TO SERVICE OPERATIONS MANAGEMENT

Unit Structure

9.0 OBJECTIVES

After studying this unit, you will be able to understand the concepts of :

- service operation management
- service encounter
- service marketing

9.1 SERVICE OPERATION MANAGEMENT

As India moves increasingly toward a services economy, marketers need to know more about marketing service products. On a simplistic note, one can say that services are activities or benefits that one party can offer to another that are essentially intangible and do not result in the ownership of anything. Thus we see how services are different from goods.

During the past decade services have increasingly assumed an important role in the Indian economy. Ever since this trend was set in the nineties, services have gained dominance. The competition, simultaneously, in service organisation, is becoming intense and severe. As a result these organizations have to have a more professional approach to managing their businesses. Perhaps it is in this context that the role of operations and marketing is gaining importance in service organisation. In this unit, you will be introduced to the concept of services.

Marketable products can be broadly classified as tangible goods and intangible service. All of us use or consume tangible goods like food products, vegetables, oils, television, fan, refrigerator, etc. day in and day out. Similarly, we consume services like transportation, health care, education, telecommunication, entertainment, etc. Services in fact became a vital part in the lifestyles of people around the globe and many say that services are changing the lifestyle and quality of life. Services are integral part of every economy in the world. It stands along with agriculture and industry as one of the major components of an economy.

Service sector has registered substantial growth in all the countries during the last three decades. This sector overpowered agriculture and industry and occupied significantly dominant position in the economies of all the developed countries and many developing countries. The share of services sector in the Gross Domestic Profit (GDP) of a country is treated as a benchmark to designate an economy as service economy. An economy is called service economy when the contribution of the service sector to the GDP of the nation is more than 50 per cent. United States of America (USA) was the first economy declared as service economy way back in 1948. Most of the economies in the world now became service economies. India became service economy in the year 2000-01.

To understand the concept of services better let us analyze the following definitions:

The American Marketing Association (1960): Services are “activities, benefits or satisfactions which are offered for sale or provided in connection with the sale of goods”.

This definition provides limited view of services. However, this was the first major attempt to identify services differently in valuing the output of a society. The definition does to provide or valuing services involved in producing the tangible goods.

William L. Stanton (1974): Services are “separately identifiable, intangible activities which provide want satisfaction when marketed to consumers and/or industrial users and which are not necessarily tied to the sale of a product or another service”. This definition focuses upon several issues for recognition. They are:

1. Services are those activities that are identifiable separately.
2. Services are intangibles that provide want satisfaction to consumers.
3. Services are marked directly to consumers and also to the industrial users.
4. Services may or may not be tied with the sale of goods.
5. A service may be or may not be tied with the sale of another service.

Philip Kotler and Bloom (1984): Service is “any activity or benefit that one party can offer to another that is essentially intangible and does not result in the ownership of anything. Its production may or may not be tied to a physical product.” This definition more or less follows the earlier ones. The focus was given to the absence of ownership as a special feature of services which has significantly business implications.

Christian Gronroos (1990): Service is “an activity or series of activity or series of activities of more or less intangible nature that normally, not necessarily take place in interacting between the customer and service employee and/or physical resources or goods and/or systems of the service provider, which are provided as solutions to customer problems." This is the definition in which an attempt was made to include all important issues relating to services management and marketing.

Zeithmal VA and Mary Jo Bitner (1996): "Services are deeds, processes and performances". Although it seems that the definition is more precise, it provides marketing orientation to the services concept. It gives an understanding that the consumer is interested in deeds, processes and performances in perceiving the value of the service.

Christopher Lovelock: He described services through two different approaches. A service is an act or performance offered by one party to another. Although the process may be tied to a physical product, the performance essentially intangible and does not normally result in ownership of any of the factors of production. Services are economic activities that create value and provide benefits from customers at specific times and places as a result of bridging about a desired change in – or on behalf of – the recipient of the service. The definition given by marketing experts clearly establishes the scope of services. The scope of services marketing includes marketed and marketable services. The shortest definition to services marketing is "meeting service needs of the consumers at a profit".

The service movement was driven, in part, by a realization that classes were filled with students who would be, or were, involved in non-manufacturing tasks. There was some disillusion felt with the existing operations management material, by both the students and by academics. Economic batch quantities, line balancing and stock control are just a few of the topics widely taught then which bore little relation to the key issues faced by managers running service operations. That is not to say that these tools and techniques were of no value, but customer service, service quality and service design were central issues facing many service operations managers, yet there were no tools or techniques to help them in these matters.

The need for service-based material was also timely. It matched the emerging realization of the importance of the customer and a more customer-oriented view of operations. This was a significant shift away from the more internally-focused efficiency view of operations management. It also fitted with a growing "strategic" trend in operations. This questioned the traditional reactive role of operations and attempted to make the subject more market-oriented by understanding how operations could not only support but also help develop a strategic advantage.

Service operations have great appeal, and they are all around us. There is a plethora of examples and experiences and, indeed, research data that can be gleaned from everyday life: service operations are all-pervasive. They are therefore a normal part of our students' lives. They can easily relate to the problems of scheduling hospital beds, the layout of a multiplex cinema or the quality of a retail encounter. Although undoubtedly important, car factories, paper mills and plastic coating lines can seem remote from many people's lives. Furthermore, each one of us is almost constantly playing out some role or other within a service operation. As students sit in a lecture they are playing a part in a service experience, just as we are delivering, or rather orchestrating, that service. As they go to the library, or to eat, or to socialize, they are having interactive service experiences.

Operations academics, just like operations practitioners, tend to be enthusiasts. On plant tours, students experience their teacher's fascination and insights into the processes and the systems and procedures that support them. Student feedback lays testimony to their enthusiasm, understanding and fascination with all things operational. Service operations are even more compelling.

This growing and compelling interest in service was happening in many parts of the world and in different functional areas. In marketing, accounting and HRM for example, academics were waking up to their service based students. There was growing concern about the product-based nature of their material. Marketing seemed preoccupied with the marketing of white goods. Accountancy academics used examples which were based around an imaginary product. Thus the service management movement was born in many different disciplines by people united by a shared enthusiasm and interest for all things intangible.

From these early beginnings, a large-scale, worldwide movement gained pace and membership. Over the last ten to 20 years this has had a profound effect on research and teaching. The service operations movement, like the service marketing movement, has been characterized by a number of stages; an initial realization of the difference between goods and service, the development of conceptual frameworks and the empirical testing of these frameworks. We are now entering a fourth stage concerned with the application of the tools and frameworks to improve service management. As the service movement has grown, with increasing overlap between the subjects of operations, marketing and HRM for example, this fourth stage is also characterized by a "return to roots", a realization that we might have lost, or inadvertently ignored, the strength of our core disciplines and the need to bring a sense of academic rigor and depth to the developing subject of service management.

The next sections briefly chart the development of operations through the first three stages and lay out the challenges as we enter this fourth stage in the development of service operations management. Several areas for future research are discussed.

Note Service management is integrated into supply chain management as the intersection between actual sales and the customers.

Stage one — Service Awakening

Before 1980, business academics were primarily concerned with the production, marketing and management of physical goods. By 1955 the service sector accounted for just over 50 per cent of the UK's gross domestic product, overtaking the product-based sectors. Yet it took another 20 years before the operations management academics of the day started to apply their knowledge and skills to service operations. Operations management in 1970 was known as production management. It had developed out of an even more focused view of operations and factory management. Factory management was the name given to the search for efficiency in the post-industrial revolution era based upon Frederick Taylor's philosophy of scientific management developed in 1911. Production management was concerned with applying method study techniques, production planning and control, capacity management and materials management, for example in production settings, with examples coming from a wider base than "pure" manufacturing and including examples such as distribution, transportation, hospitals, libraries and publishers.

In the 1970s there was an emerging recognition of service operations and the first two texts to place some emphasis on the service sector were Johnson and Buffa. Both books were entitled Operations Management "to reflect the growing emphasis on the breadth of application of production management concepts and techniques – non-manufacturing and service industries as well as manufacturing".

Service operations were a little slower off the mark, as service operations management was "essentially Operations Research (OR) applied to service settings". A major breakthrough came in 1976 with the publication of Earl Sasser's article "Match supply and demand in service industries" in the Harvard Business Review, followed two years later by the pioneering textbook Management of Service Operations by Sasser in 1978 containing what are now regarded as classic cases and issues. Dick Chase also wrote a service article for the HBR "Where does the customer fit in a service operation?" in 1978. He challenged the operations management community to consider two types of operations; the traditional back office factory and the customer-facing, customer-contact front office. Chase and Sasser provided academic credibility and authority to the study of customer-based operations.

In essence, stage one, using the analogy of the development of the human species was the "crawling out" stage and was characterized by recognition of the existence of service. The nature of academic work was primarily descriptive and focused on the difference between goods and services. Service operations were still very wedded to its factory roots. Furthermore, whilst there was awareness of some of the efforts in other functions, the concept of a cross-functional subject of service management was some way off.

Stage two — Breaking Free from Product-based Roots

The period between 1980 and 1985 was a time of "high interest and enthusiasm" in services. It was accepted that services were different from goods (though that debate rumbled. During this "scurrying about" period, many substantive issues were debated. The work was principally conceptual in nature and was characterized by the development of frameworks to help understand the characteristics of service and service management. Service operations academics continued their work on “customer operations”. This focus on the customer and the service encounter was growing apace in the other functions. Publications on this topic included “The critical incident as a technique for analyzing the service encounter”, “Boundary spanning role employees and the service encounter: some guidelines for management research” and “Perceived control and the service encounter”.

Operations academics were also breaking ground with new perspectives on traditional themes. We also witnessed the first “challenge” papers on service operations research; “The service sector: challenges and imperatives for research in operations management” and “Service operations management: research and application”.

The main characteristic of stage two was that the study of service appeared to have broken free from its product-based roots. There was also recognition of, and reference to, the research undertaken in the other disciplines undertaking service research. Service quality was a topic which was seen as important by all of the different functional areas and where they could all make a contribution. Interest in internally-focused service operations did not cease, however.

For operations this was a period when the nature of service and service operations was classified as a prelude to the development of tools and concepts. The dimensions included customer contact time, degree of customization, the amount of judgment exercised by front office staff, whether the value was added in the front or back office, the operation’s product or process focus These discussions resulted in the now widely-accepted categorization of service operations; mass, professional and service shop.

Stage Three — The Service Management Era

The third stage in the development of the service movement has been characterized by the cross-disciplinary nature of service research; a coming together of disciplines. Marketing, operations and HRM, in particular, brought together their various strengths and perspectives to issues of common concern. This period, from around 1985 to 1995, was the era of service management (as distinct from service marketing or service operations); a subject whose strength lies in its cross-disciplinary nature and approaches.

The research undertaken in this stage was predominantly concerned with the empirical testing of ideas and frameworks resulting in underpinned and tested models. Conceptual frameworks and ideas continued to emerge to form the basis for fresh empirical work. This period was certainly an important milestone in the development of the subject. Industry-focused studies, survey research and case studies seem to have dominated this stage of development.

Stage Four — Return to Roots?

We have now entered a fourth stage: one that could be considered the final step in the creation of a "mature" subject which has been in evidence since 1995: the intention and ability to be prescriptive. A stage when much (but not necessarily all) of the material can be taken and applied, and where the outcome of its application can be predicted.

However, a new significant wind of change is that the previous trend towards cross-functional work seems in reverse. We are witnessing some tensions between the functions. Indeed it is suggested that rather than seeing a continuance of the overlapping of the areas of marketing, operations and HRM for example, we are witnessing their moving apart from each other. This change is driven by a basic desire to re-establish the service material within the core disciplines. It appears that we have forgotten, or mislaid, our established. We seem to have been swept along on the tide of interest in service focused predominantly from a customer perspective. Whilst there is nothing unhealthy, or indeed inappropriate, in this, we seem to have ignored the strength that our core discipline has to offer. In service quality, for example, we have focused on customer-based notions of service quality but appear to have ignored quality of conformance and the delivery of customer-based quality, surely key issues for operations managers and academics.

In service design, we seem to have followed the blueprinting movement but we appear to have ignored the process of design in favour of this descriptive activity and the relationship between important and often ignored, back-office activities in favour of customer-facing processes.

9.2 A SERVICE OPERATIONS MANAGEMENT AGENDA

This growing awareness of the need to re-operationalize service management material has led to an attempt to develop an agenda. This section identifies some possible research issues and questions emphasizing the core operational issues.

Linking operational performance to business drivers

Today, there is growing awareness of the importance of linking business drivers such as leadership, customer orientation and more operational issues such as benchmarking, quality control and service design, with their impact on business performance. There is much more work to do. Indeed there is significant practitioner interest in this area, witnessed by the growing interest in the use of the Baldrige criteria and the UK/European Foundation for Quality Awards on this side of the Atlantic. Service operations is the appropriate discipline to begin to move business from its current emphasis on reengineering to the next step — revenue enhancement". Two key research questions are:

(1) What are the most efficient operational profit levers and under what circumstances?

(2) Can we map the relationships between the controllable and the outcome variables?

Performance Measurement and Operations Improvement

Despite some major work in the performance measurement area, many organizations seem reluctant to critically review and develop their performance measurement systems. The balanced scorecard, although a major step forward for many organizations, has led to a degree of complacency once an organisation, and its SBUs, have found measures of performance.

- How can we develop frameworks to help organizations review the nature and effect of the performance measures used?
- In what situations are historical measures and targets appropriate and in what situations are externally based targets more appropriate?
- Do radical step change improvement programmes yield better or faster results than TQM type continuous change programmes?
- Does benchmarking yield the desired results or does it get caught up in interminable and unfruitful discussions about "apples and pears" or degenerate into "industrial tourism"?

Guarantees, Complaints and Service Recovery — Tools for Performance Improvement

Much organizational practice in the area of complaints and recovery has regressed into mere marketing ploys. Complaints procedures in some organizations have become mechanisms to pass on tokens or small pay-outs to disgruntled customers. Guarantees often seem little more than your statutory rights, or an "opportunity" to purchase insurance so that, if the product or service fails, the vendor is not troubled with the problem (and so is unaware of the in-built problems of their products or services). Service recovery appears to have become reactive, with staff carefully listening to, sympathizing with, and then paying off the customer but never sorting out the root problem:

- How can we link complaints and failures to organizational improvement?
- How can organizational learning develop from mistakes?
- How can organizations be proactive in finding and dealing with mistakes before their customers tell them (or more often don't tell them)?
- What are good service guarantees and how can they be operationalized?
- What evidence is there that complaints, guarantees or service recovery drive improvements within an organisation?
- How is learning best captured and applied?

People Management

Despite some excellent additions to the literature in the FIRM area, operations academics need to retrace their roots and focus on the design of jobs. The problem is not knowing that customers expect empathy, reliability, assurance etc., but delivering it time after time, month after month, week after week, day after day, hour after hour. We need to understand how all employees can deliver constant and consistent high levels of service and how we can design jobs and motivate employees to do this:

- What are the key service operational competencies?
- How do we develop those competencies?
- How do operations managers go about maintaining the energy and commitment of frontline workers?
- How does one ensure that a constant level of service is provided?

Service Design

The service design models used in the literature are strongly based upon product design processes, yet there is some evidence that product design processes are not used, or indeed applicable, in service situations. Do we understand how services are designed from conception to consumption and how existing product-based models can be applied?

- What is a service design?
- How is a service concept developed into a service?
- What is a service concept?
- What are the most effective methods of developing a service?
- What are good design tools and techniques?
- Seamless service is a great idea for a customer but how does one achieve this in most “silobased” organisations?
- How can the World Wide Web be utilized to create new services, even virtual services and the use of virtual reality simulations in service?
- How do we capture the technological dimensions of the next century?

Service Technology

There are a few documented examples of technological disasters, yet there are many more but less well-known, or documented, examples of technological successes. One reason for failure is that technology is often superimposed on inefficient, outdated operational systems, in the expectation that it will overcome inherent problems. Unfortunately there is only limited material in the service literature about the difficulties of implementing new technology, or indeed any categorization of the various types of technologies in use. It would also appear that managers seem to have a difficulty in assessing the "true" impact of new technology. Furthermore, investment in service technology does not appear to have significantly reduced costs for the provision of services.

- What are the categories of service technologies and their relative impact?
- What are the inherent difficulties in implementing new technology?
- What are the success factors?
- What is the relationship between investment in technology and cost reduction?

The Design of Internal Networks

Internal service encounters are defined as the didactic interrelation between an internal customer and an internal service provider. The supply chain literature, however, has moved away from such simplistic relationships to the idea of networks of relationships. This network approach needs to underpin future research in the internal customer chain. Can notions of external quality and customer satisfaction be used with internal supply chains? Internal customers cannot be treated in exactly the same way as external customers. External customers usually, though not always, operate in a free market. The internal customer is often a captive customer and so many of the current concepts of service quality and performance measurement from an external customer perspective (e.g. customer satisfaction) have found little credence in internal customer-supplier relationships. This seems to be changing as organizations are looking increasingly at contracting-out internal services:

- Can supply chain networks be implemented within organisations?
- How well does service quality translate to internal supply networks?
- What is the relationship between internal service quality and staff satisfaction and external quality and customer satisfaction?
- How can organisations cost and value internal services?

The Service Encounter

The service encounter is the crux of service delivery, yet how much do we know about which are the right scripts, attitudes, behaviours to achieve the desired effect? How do we ensure that each encounter in a service process has the right cumulative effect on customers' overall perceived service quality:

- What are the "right" scripts for different types of service?
- Do we know how to design and control the series of encounters that comprise the service process?

Managing Service Capacity

Some work exists in the management of service capacity in terms of staff scheduling. Strategies for managing demand and supply in service operations have also been documented. This is an area which is fundamental to the planning and control of service. Another issue, the subject of a preliminary investigation, is the relationship between capacity levels and the level of service quality delivered.

- What are appropriate capacity strategies? How does customer contact relate to types of strategies?
- What is the relationship of capacity levels and capacity strategies to the level of service quality delivered, for example?
- How can organisations best manage their quality-capacity relationships?

Manufacturing, service and agriculture are the major economic activities in any country. In India, manufacturing and services together constitute nearly 75% of the GDP. Moreover, in recent years the growth in GDP is primarily due to the growth in these sectors of the economy.

During the last ten years, the share of services in the GDP has grown steadily from about 40% to about 51%. The Union Government began taxing three services in 1994-95. This has grown steadily and as of 2004-05 the number of services taxed has gone up to 71.

All these indicate the growing importance of services in the Indian economy and the need to apply management practices to plan and control operations in the service sector. Service organisations respond to the requirements of customers to satisfy some needs and leave certain experiences in the minds of the customer through a service delivery system.

9.3 PARADIGMS IN SERVICE MARKETING

Services have increasingly assumed an important role in the economic development of many countries including India. Most countries in the western world have entered what is called a service economy or service society or about to do so. An economy is called a service economy when the contribution of the service sector to the GDP of the nation is more than 50%. USA was the first economy to declare as service economy way back in 1948 with about 53 percent contribution of service sector to the GDP of the nation. Almost all the developed countries and many developing counties are emerging as service economies. There is an argument that the statistics of service sector's contribution in many countries is a gross underestimation of the truth since services produced by manufacturers of goods in the industrial sector are not included. As such, there is large 'hidden service sector' which is not classified under service sector.

Services are becoming a critical source of wealth in many ways to the economies. Economies experienced increased in wealth and employment with the growth in service sector. While employment in manufacturing sector is receding year by year the employment in service sector is rising at a higher level. Even in times of economic recession unlike in manufacturing sector, the service sector has kept employment up. There is a substantial contribution of the service sector to the economy in other respects as well:

1. People value services at least as highly as manufactured goods. Services are not something one looks at after the good needs have been met.
2. The value added produced by service firms is very well comparable to, and even higher than, the value added produced by manufacturers of goods.
3. The service sector is at least as capital intensive as the goods sector, and many service industries have a high technology impact.
4. Service industries tend to be just as concentrated as manufacturing, and service firms tend to be sufficiently big in scale to be important and sophisticated buyers.
5. Service industries develop productivity increases that are big enough to support continuing real growth in per capita income.
6. The most traded services internationally are Tourism, Transportation, Financial services (Banking and Insurance) educational training, and business services.

Services are economic activities offered by one party to another.

Reasons for Growth of Service Sector

The reasons for the growth of service sector can be broadly categorized into two. They are:

1. Growth in intermediate demand from firms
2. Growth in final demand from customers.

Growth in Intermediate Demand from Firms

Manufacturing firms realized the importance of staff function when line mangers sub-optimal performance in decision-making relating to operational activities as well as the growth of the business as the manufacturing firms started bundling with number of service functions like selling, marketing research advertising labour welfare, HRD, financial advisers, strategic advisers, etc. with the growth of competition, the pace of change in consumer exposure and expectations forced the organisations to look for specialized services. They started unbundling the organizations and tasking the services from outside where highly professional and specialized services are available at relatively low price. As a result large number of service organisations has come up throughout the world.

Growth in Final Demand from Customers

There is growth in direct demand from customers from a variety of services. The changes in society make the people to develop a different attitude toward life. The marginal utility from goods diminishes, at least in a relative sense, and services grow in importance. People spend more and more on services. The following are the reasons identified or the growth in demand for services directly from customers:

1. **Increase in affluence:** Majority population in the developed economies and significant groups in developing economies are becoming affluent year by year. The 250 million strong middle income households of India attracting many multinational companies to the country with their growing affluence to have a variety of products and services. The demand for personal services, travel, tourism, entertainment, clubs and he like greatly depends upon the affluence of the society. If a traveller is tight with money, he will carry his luggage himself. If he has financial affluence he will engage a porter for the same job. The affluence reduces the scope of self-service and creates opportunities for many service people and organisations.

2. **More leisure time:** The tendency of the people throughout the world is to gain more leisure time so as to attend to their personal and family activities. There is a significant change in defining the holidays or leisure period even in semi-urban and rural pockets of India. Instead of eating stomachful with delicious food, resting on bed for extra hours, playing cards and chitchatting, the people are now spending time on education, training, skill development for themselves as well as for children, touring, entertainment; personal care, etc.

3. **Working women:** The percentage of women in employment is increasing year by year in many economies. They no longer can be viewed as just housewives and inferior to men. They proved beyond doubt in many areas that they are equal and in some areas more competent and suitable than men. The working women are burdened with household activities as well as office activities. They are looking for services that can reduce their burden significantly. As they belong to double income group, they have more affluence to spend on services. As a result the demand for crèches, babysitting, household domestic help, health services, fitness services, special education services, etc. has gone up.

4. **Growth in DINKS population:** DINKS are double income group with no kids. It is not that the couple cannot have children due to physical problems. The couple do not try to have a children may be because of the reason that both are careerists. Generally they may postpone having children for the first few years of marriage, after that due to pressures in employment with possible promotions, transfers and time pressure. The postponement continues until they

reach to the conclusion of not having children. In some societies where divorce rate is high, marriage is perceived as a short-term relationship. In such societies either the male or female prefer not to have the children whose future will be at stake when marriage becomes a failure. In many developed societies DINKS population is on the rise. The DINKS have greater affluence and no savages require for future generations. Hence they spend liberally on services.

5. **Greater life expectancy:** The economic prosperity and the increasing standard of living of the people have resulted in greater life expectancy. As a result, there is a significant growth in the old age population. If you take India as an example the population above the age of 60 years has increased from 14.13 million in 1981 to 54.69 million in 1991. It has reached 75.7 million by 2001. While the expected growth in 0-14, 15-34, 35-59 years of age groups is 6.26, 20.07 and 29.75%, respectively, the above 60 age group growth is about 38.42%. There would be greater demand for nursing homes and health care services with the increasing old age population.

6. **Greater complexity of products:** The rapid pace of change in technology offering more and more new products to the society. The human begins now are identifying a very large spectrum of needs compared to the earlier generations. The present generation is using number of products with technological complexities in day-to-day life. They need skilled specialists for maintenance of such complex products as computers, automobiles, television, kitchen appliances, etc. Therefore, the demand for such services is growing day-by-day.

7. **Greater complexity in life:** In the modern society the people are feeling that they are living ninety nine lives as they are required to play a number of roles in each day-to-day life. There is a demand for such service, which can share the burden or reduce the burden. As such there is an increased demand for income tax consultants. Legal consultants, counseling, employment services, labor supply services, baby care centers, etc.

8. **Greater concern for resource scarcity and ecology:** For majority of the population financial resources are scarce or limited but they are desirous to have a number of services. Owning a tangible for various services require financial strength. On the other hand, many of them may not be usable to the optimum capacity by the individuals. Hence, there is a demand for leisure services such as car rentals, computer hardware rentals, accommodation, door-to-door service, etc. In the recent years many economies manifested their concern towards environment and ecological balance. Large numbers of public organisations were promoted by governments of various countries to protect the environment from pollution and other hazards and to maintain the ecology through conservation of forests, protection of animals, birds, insects and other important

species. They have been using various media for campaigning and taking up several programs to make people participate in the process. The schemes like Van Mahotsav, water conservation, etc. are examples for this.

9. **Increasing number of new products:** The consumers are exposed to a wide variety of choice in the recent years. The span of life of products and services is reducing due to the entry of new or improved products at after pace. The consumer is unable to have a total comprehension before taking a purchase decision relating to a product or a service, as they are busy with a number of activities. As such consultancy services are enjoying increased demand. For example, if a person wants to invest in shares, the complex information inputs of the share market will certainly drive him to confusion and uncertainty. The broker or consultancy service facilitates the process to go smoothly.

10. **The new youth/young:** It is observed that the younger generation tends to use more and more services than the older generations. The older generation depends on self for a number of activities. The younger generation could able to cope up with that peace of change only through consumption of number of services. For example, a graduate in computers can teach himself the new languages but it takes lot of time. By the time he develops expertise in that there is danger that the program may be outdated or may be lagging far behind his competitors. Therefore, they prefer to take training through institution to be competitive.

India has been pursuing a planned approach for achieving economic growth and development. The economic activities that were to be developed were categorized into three sectors, in the order of priority. They are primary sector, secondary sector and the tertiary sector. The primary sector includes agriculture, animal husbandry, fishing and forestry. These areas are considered fundamental and the foundation for further development of the economy. The secondary sector includes manufacturing industry and construction. The tertiary sector covers services, including distributor. The allotment of funds and the focus of development have been given to these three sectors in a phased manner. The first three Five Year Plans gave greater focus to the primary sector and the next two focused on the secondary sector. As a result the services sector started growing.

Growth of Service Sector in India

One of the key measurements of growth of the services sector is its contribution to the Gross Domestic Product (GDP) of the country. While considering services for this purpose, there are two important dimensions that need special attention. They are the hidden services and the services in the unorganized sector. Hidden services are the services that are used internally by the manufacturing organisations. The output value of such services becomes part of the output of the tangible goods. As such the value of such services are hidden and taken as the value of tangible goods for the purpose of ascertaining the GDP. There are large numbers of services that are not accounted for output assessment for the purpose of GDP calculation. Personal services, maid services and a host of professional services such as the barber, carpenter, washer man, goldsmith, priest, and nurse, in semi-urban and rural India have their roots going back several centuries. These services are predominant in almost all parts of the country, but a proper accounting system to assess the value of output is conspicuously absent.

Barring these two important dimensions, the service output is valued for the purpose of GDP. The share of the agricultural sector in the GDP of the country was 57.1 per cent in 1950-51, that is, in the beginning of the planned era. Services occupy second position with 28.6 per cent and the contribution of industry to the GDP was 14.3 per cent there has been a significant change in the proportions of these three sectors by the end of 2000-01. The share of agriculture has gone down to 24.7 percent, the services sector became the major contributor with 48.8 per cent share in the GDP, and the contribution of industry to the GDP was 26.4 per cent. The share of service sector is increasing year-by-year. In 2006-07, the shares of the three sectors are; Services 61.8 per cent, Industry 19.7 per cent and Agriculture 18.5 per cent.

Reasons for Growth of Services in India

Several developments in the economy and society are attributable for the growth and development of service sector in India. K. Rama Mohan Rao in his book on Services Marketing identified the following vital factors that contributed significantly for the growth of service sector in India:

- Economic Affluence
- Changing role of women
- Cultural changes
- IT Revolution
- Development of markets
- Unbundling Corporations
- Increased consciousness of healthcare
- Economic liberalization
- Export potential
- Retail revolution
- Real estate and construction services.

9.4 LET US SUM UP

This unit attempts to give an overview of the functions in as simple manner as possible.

- In stage four a return to roots can be seen, which not a bad thing is. This will add new depth and grounding to the literature on service management.
- In operations it will allow us and encourage us to undertake research and make strong statements about things which we understand (quality, design and improvement, for example).
- But somehow we need to add this depth and focus without losing the richness that has developed as different functional areas have come together to share areas of common interest.
- Services sector is playing the role of growth driver in many developed and developing economies.
- The value of service output in many economies crossed 50 per cent in GDP and such economies became service economies.
- If services output in the unorganized sector and the value of hidden service sector also are taken in the GDP calculation, there may not be any economy in the world that cannot be called as service economy. Services sector registering consistent growth over other sectors of the economies.
- The reasons for such growth are basically two fold. One is from the industry and the other is forming the final consumers. Services growth supports manufacturing industry as well as services sector for further growth besides providing quality life to the consumers.
- Therefore, services sector is the engine for the growth and development of any economy.
- The service sector in India has grown significantly during the last three decades.
- The major reasons for growth are Economic Affluence, changing role of women, cultural consciousness of healthcare, economic liberalization, export potential, retail revolution knowledge process out sourcing, and real estate and construction services year by year service sector is improving its position in the economy and signaling tremendous growth potential in future.

9.5 EXERCISES

1. Explain the paradigms in service marketing.
2. Define the concept of Service Encounter.
3. What do you mean by service technology?
4. Discuss the reasons identified or the growth in demand for services directly from customers.

5. Give some specific definitions of the service concept.
6. Describe the process of Service Operation Management.
7. "This growing awareness of the need to re-operationalize service management material has led to an attempt to develop an agenda." Elaborate this statement.
8. The reasons for the growth of service sector can be broadly categorized into two. What are they?
9. Discuss the impact of growth of service sector on India.

9.6 SUGGESTED READING

- Operations & Supply Chain Management by Chase, Shankar, Jocaobs
- Operations Management (6th Edition) by Nigel Slack, Stuart Chambers, Robert Johnston
- Theory & Problems in Production & Operations Management- S N Chary, Tata McGraw Hill
- Production & Operations Management -Kanishka Bedi, Oxford University Press
- Operations Management for competitive advantage-Chase & Jacob, McGraw-Hill/Irwin
- Production and Operations Management- Chunawalla & Patel, Himalaya Publishing

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10

WORK STUDY AND METHOD STUDY

Unit Structure

10.0 OBJECTIVES

After studying this unit, you will be able to understand the concepts of:

- Method Study and Time Study
- Foundation of Work Study
- Main Components of Method Study
- Time Study Standards
- Involvement of Workers' Unions
- Predetermined Motion Rime Systems (PMTS)
- Work Sampling
- Application of Work Study to Office Work.

10.1 METHOD STUDY AND TIME STUDY

Work Study concerns itself with better ways of doing things and control over the output of those things by setting standards with respect to time. Productivity which is, generally speaking, a ratio of output to input, is of great importance for the smooth running of any organization; it assumes particular importance for developing countries like India who have to compete favourably with other countries in the international market and make optimal use of scarce resources.

Although usually the concepts of **Work Study** relate to a manufacturing organization, they are equally valid for other than manufacturing situations where services—if not goods—are generated. The means of improving ways and means of doing things is called **Method Study**. The primary purpose of improving methods is to save time, and therefore, effort of labour and machinery.

Hence a measurement of the work involved in any job and the setting up of standards (for control purposes) of the time normally expected and the effort involved will be necessary. This aspect of setting work standards for comparison, control and other managerial action purposes is termed as Work Measurement. Since the standards are mentioned in time units required to perform a job, given a particular work setting and method, Work Measurement is also alternatively called **Time Study**. Method Study and Time Study together comprise Work Study.

The study of methods of accomplishing a job by the movement of human limbs and eyes, etc. is termed as Motion Study. **Motion Study is a part of Method Study**.

10.2 FOUNDATION OF WORK STUDY

In fact, early researchers in the field of management were concerned with Motion Study. Frederick W. Taylor, Frank B. Gilbreth and Lillian M. Gilbreth were some of the pioneers in the field of Work Study. Dr. Taylor's conclusion was: "The greatest production results when each worker is given a definite task to be performed in a definite time in a definite manner." This is the foundation on which modern Work Study stands today.

The implication in the above statement of the interrelationship between Methods and Time Studies is important. By knowing the method you may improve the overall time, and by the study of the time taken for the different component tasks involved in the method you may get leads to improve the method.

Subdivision of Work—Therbligs

For a detailed and useful study of method or time, a subdivision of the work into its component elements is necessary. Taylor's division was broader as compared to the subdivision suggested by Gilbreth, although the latter's study concentrated only on the human body. Gilbreth's elementalization was 'general' in the sense that any work done by hand and body movements could be classified into a few or all of 17 (later 18) 'Therblig' (Gilbreth spelt backwards) work elements.

These fundamental motions are given in Table below:

Therblig	**Description**
Search	: When a hand or body member tries to find or locate an object.
Find	: Different from Search as it involves finding an object by eye movement.
Select	: To locate a specific object from a group of objects.
Grasp	: Gaining control over an object.
Hold	: Holding an object in a fixed position and location; it may amount to prolonged Grasp.
Transport Loaded	: Changing the location of an object.
Position	: Causing a part/object to line-up or orient.
Assemble	: To put two or three parts together.
Use	: Applying a tool or manipulating control.
Disassemble	: Taking objects apart (or causing separation of objects).
Inspect	: Determining the quality of an object by feeling the object.
Pre-position	: Same as Position except that this occurs when the line-up is previous to the use of part or tool in another place.
Release Load	: Letting go of an object.
Transport Empty	: Reaching for something.
Rest for over-coming Fatigue	: Idleness, necessary to overcome fatigue from previous working.
Unavoidable Delay	: Idleness, of a body member, where it is a part of the method.
Avoidable Delay	: Idleness or some movement of a body member, where it is not a part of the method.
Plan	: Deciding on a course of action.

(Adapted from Handbook of Industrial Engineering and Management, by Ireson and Grant, 3rd edition, Prentice-Hall of India)

For instance, picking up a glass of water kept on the table in front would involve the Therbligs of: Find, Transport Hand Empty, Grasp, and Transport Loaded (to the mouth).

When both the hand motions are detailed in therbligs, the idle time, the unnecessary motions of hands, the long transports, etc. are automatically highlighted for suggesting possible improvements in the methods and implements used for that job.

The general principles of motion economy are given in Table below:

Principles of Motion Economy

Use of the Human Body	**Arrangement of the Work Place**	**Design of Tools and Equipment**
The two hands should begin as well as complete their motions at the same time. The two hands should not be idle at the same time except during rest periods. Motions of the arms should be made in opposite and symmetrical directions and simultaneously. Hand motions should be confined to the lowest classification with which it is possible to perform the work satisfactorily. Momentum should be employed to assist the worker wherever possible, and it should be reduced to a minimum if it must be overcome by muscular effort.	There should be a definite and fixed place for all tools and materials. Tools, materials, and controls should be located close to and directly in front of the operator. Gravity feed bins and containers should be used to deliver materials close to the point of use. Drop deliveries should be used wherever possible. Materials and tools should be located to permit the best sequence of motions. Provisions should be for adequate conditions for seeing. Good illumination is the first requirement of satisfactory visual perception.	The hands should be relieved of all work that can be done more advantageously by a jig, a fixture, or a foot-operated device. Two or more tools should be combined wherever possible. Tools and materials should be pre-positioned whenever possible. Where each finger performs some specific movement, such as in typewriting, the load should be distributed in accordance with the inherent capacities of the finger.

Principles of Motion Economy…

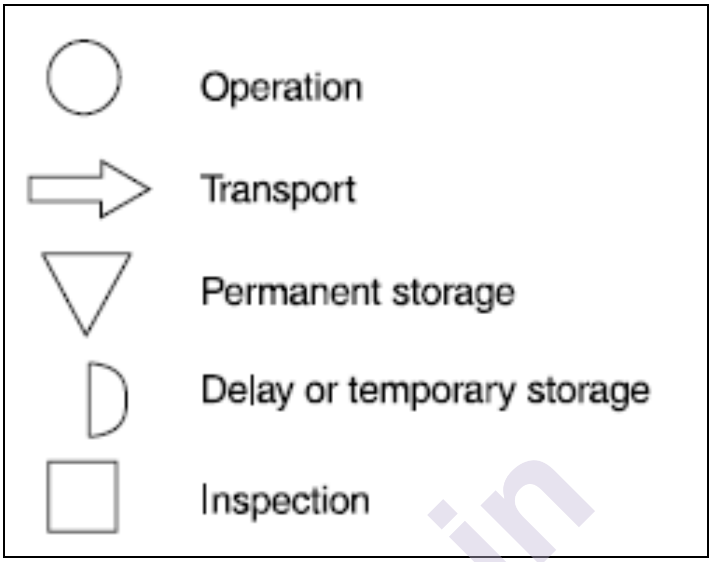
Use of the Human Body	Arrangement of the Work Place	Design of Tools and Equipment
Smooth continuous motions of the hands are referable to zigzag motions or straight-line motions involving sudden and sharp changes in direction. Ballistic movements are faster, easier and more accurate than restricted or 'controlled' movements. Rhythm is essential to the smooth and automatic performance of an operation, and the work should be arranged to permit easy and natural rhythm wherever possible.	The height of the workplace and the chair should preferably be arranged so that alternate sitting and standing at work are easily possible. A chair of the type and height to permit good posture should be provided for every worker.	Handles, such as those used on cranks and large screwdrivers, should be designed to permit as much of the surface of the hand to come in contact with the handle as possible. This is particularly true when considerable force is exerted in using the handle. For light assembly work the screwdriver handle should be so shaped that it is smaller at the bottom than at the top. Levers, crossbars, and hand wheels should be located in such positions that the operator can manipulate them with the least change in body position and with the greatest mechanical advantage.

An Example of Application of Motion Economy Principles: These principles can be applied to a simple situation (an example) of assembling a nut and a bolt to form an assembly.

If the nuts and bolts are kept on the work table on the two sides of the worker, so that they are kept within easy reach, facilitating smooth curved symmetrical motion of both hands (to be done simultaneously), are stacked or kept in such a way as to eliminate search, a fixture provided to eliminate grasp by a hand while assembling, a chute provided to eliminate transport and release by hand, then we have used some of the above principles to improve the method and productivity.

Process Flow Charts

Just as the motion of hands are studied by classifying into certain fixed categories of micro-motions, any job or process can be studied for methods improvement by recording all the events. For the study of the process, therefore, process-charts are used giving the sequence of event occurring in the process from the beginning to the end. The ASME symbols which are universally accepted are:



An example of a Process Chart is given in the next Fig.

Process charts are generally drawn for the material which goes from the raw material stage to the finished goods stage. Sometimes they may refer to the activities performed by the worker in getting a certain process done; in such a case the 'transport' refers to the movement of the man, the 'delay' refers to his waiting involved, etc. Process charts do not refer to the material and man or machine simultaneously.

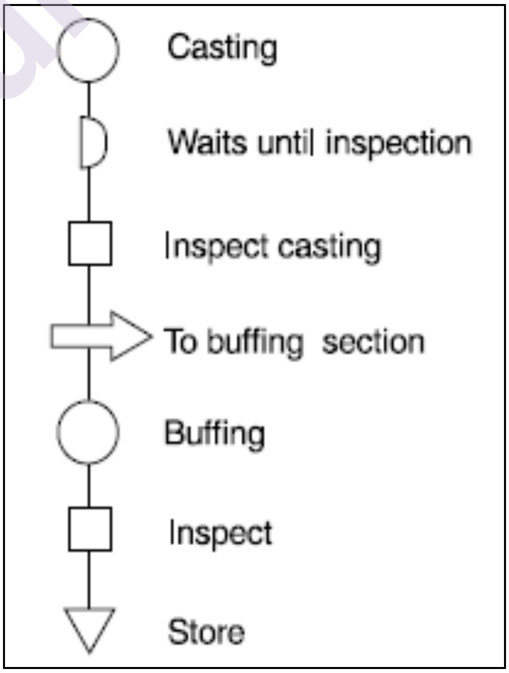


Fig. Simple Example of Process Chart

Such charts give a clear picture of the process and help in analyzing whether the efforts are utilized in accomplishing the job or whether they are wasted. Each one of the activities can then be analyzed to find whether it could be:

- eliminated, or
- reduced in time, or
- substituted by some other activity, or
- put elsewhere in the sequence of activities, etc.

The ultimate goal is to simplify the procedure to minimize the man/machine effort and reduce avoidable wastage of time resulting in minimization of the process costs.

Man-Machine Diagrams

Other types of charts used are the man-machine charts, which on a vertical time scale indicate the various activities done by man and machine both on the same chart, for carrying out a certain operation by the man-machine team. An example is given in Fig. below:

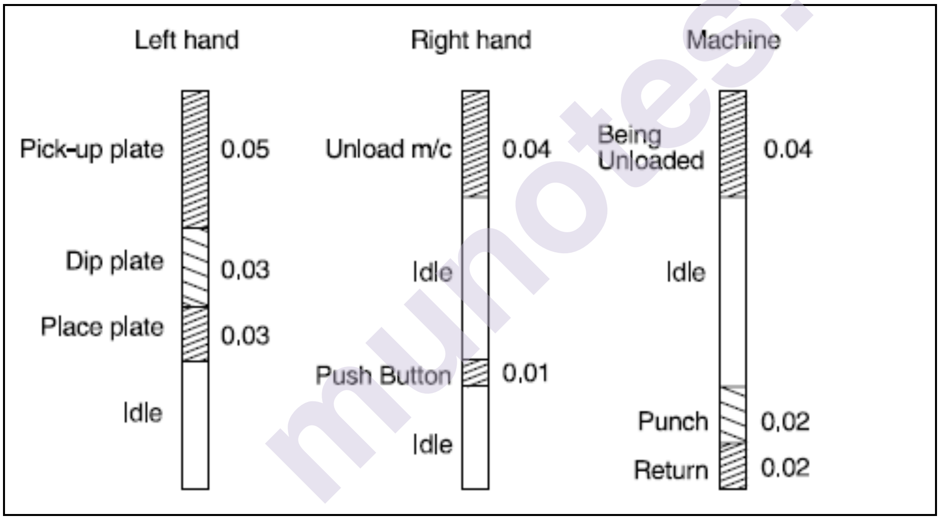


Fig: An Example for Constructing a Man-Machine Chart, Showing Left and Right Hand and Punching Machine Activities

Similar graphic charts are sometimes constructed for multi-man-machine situations and some to purely show the coordination (or lack of it) between the left and right hands of the operator (called Simo Charts). The basic idea behind such charts is to visually aid in highlighting the possibility of:

- better coordination between man and machine,
- reduction/elimination of idle times of man and machine to improve the utilization, and
- exploration of alternative man-machine arrangements suitable to the plant conditions.

10.3 MAIN COMPONENTS OF METHOD STUDY

The main components in the method study are:

1. Gaining information about and understanding the process, men carrying out the process and their work, machines carrying out the work, the tools, and the working conditions.

2. Information and understanding is to be sought in detail (as much as it makes sense) about the various components of process, and human, material and machine movements. This is preferably put in a graphic or visually simple-to-understand fashion for further analysis.

3. Analyzing critically:

   (a) What? (operations, delays, inspections, Why so? Alternatives, if any or hand-and-body motions, etc.)

   (b) Who? (number and skills of person/s Why so? Alternatives, if any doing it)

   (c) When? (sequence or time schedule of Why so? Alternatives, if any operations)

   (d) Where? (work place) Why so? Alternatives, if any

   (e) How? (use of tools, raw materials, etc.) Why so? Alternatives, if any

The questions are to be asked in that order.

4. After the critical examination, chalk out improved alternative methods which might be acceptable to the labour and the management.

5. Check acceptance and follow-up implementation to iron out wrinkles if any in the improved methods.

6. Much after the production is undertaken, a reevaluation and maintenance of the method.

Criteria for Methods Improvement

The improvement in method refers to criteria which are relevant to the organization, such as

- Improved cost performance
- Improved time or delay performance
- Improved worker satisfaction
- Improved standardization of operations and products.

The last two aspects, although mentioned last, are not of less significance; in fact, sometimes the Method Study has much to do with improving the always important industrial relations and with changes in product design (in consultation with marketing and other appropriate departments).

10.4 TIME STUDY STANDARDS

Once the method is established, the next thing to do would be to set the standard times for the work. This aspect of work study is called the 'time study'. The 'standard time' by its very meaning should be a consistent and truthful measurement of the time required to perform the job or components of the job with the established method, incorporating established number of adequately skilled and healthy human beings, their actions, machines, materials and work place conditions. The consistency of the time standard should hold good for the same job done day after day without any harmful physical effects.

Uses of Time Study

The utility of the time study comes in:

a) determining the work content and thereby setting wages and incentives;

b) arriving at cost standards per unit of output for the various jobs used for cost control and budgeting for deciding on sales price;

c) comparing the work efficiency of different operators;

d) arriving at job schedules for production planning purposes;

e) manpower planning;

f) aiding in the method study

- to appropriately sequence the work of an operator and the machines or that of a group of workers,
- to highlight time consuming elements, and
- to compare costs of alternative methods.

g) product design by providing basic data on costs of alternative materials and methods required to manufacture the product.

Three Basic Systems of Time Study

The setting of time standards is done basically by following three methods:

(a) Using a stop-watch

(b) Using synthetic time standards

(c) Using statistical sampling.

In the first, the actual performance is studied by collecting data while the worker/s are working, and the data so obtained are synthesized into the time standard. In the second, any work is subdivided into certain standard components for which the standard times are available from previously established time-studies; and these predetermined times are totaled, with appropriate allowances to compute the standard time for the job as a whole. Much of the skill of the time study man lies here in identifying the standard components of a job; the rest is arithmetical computation on paper. The third method is different from the previous two in that it relies on statistical sampling.

Steps Involved in a Stopwatch Time Study

Stopwatch Time Study makes direct observations by means of a simple stopwatch measuring, generally, to the precision of 0.01 minute. The observation equipment consists of the stopwatch, the recording board, the observation sheet and a pencil. The steps involved in such a study are:

1. Subdivide the job into observable and distinct elements.
2. Choose 'acceptable' operator/s for study.
3. Make direct observations of the work elements (while the operator is actually performing the job) and record the time of each element. Make a statistically adequate number of repeated measurements and record each time.
4. Performance rate each element and record.
5. Calculate the 'normal' time.
6. Establish 'allowances'.
7. Compute the 'standard' time.

The key step in a stopwatch time study is that of subdividing the job into component elements. One should take care that the elements are distinct or well defined and therefore amenable to repeated measurements. Also, the elements should be as short as possible without losing accuracy of measurement; the practical minimum is generally 0.02 or 0.03 minute the time required to read and record being 0.027 minutes or 45 TMU (Time Measurement Unit which will be explained subsequently in this chapter).

The following are the uses of this breakdown into elements:

(a) It helps in separate performance rating of each of the job elements, instead of performance rating the whole job (which may lead to much error in the Time Standard).

(b) If a job method changes in terms of only one or two elements, the revised time standard can be easily established in the future. Unnecessary time studies are, therefore, eliminated. Standards for similar or related jobs can also be easily established.

(c) It highlights the work element which consumes excessive time, and this can then be subjected to a critical examination to eliminate/substitute the element.

(d) Element/s with large variation in time can be examined for necessary changes in the job design or method.

(e) It highlights the inconsistency in working conditions.

(f) Such division into elements provides a detailed method description which can be used for training new workers.

A few points may be mentioned regarding elementalization:

1. One must separate the machine time from the worker time. At certain times the worker may appear to be working slow, but in actuality he may be waiting for a machine element to complete. Obviously, the worker cannot be performance rated low for this element.

2. While studying a job, elements of work other than the usual cycle may be encountered frequently. For instance, once in every 10 cycles the operator may clean the tool; or once in every 40 cycles the operator may have to replace the tray filled with finished work-pieces with an empty tray; or he may get the raw material once in a few cycles. These elements have got to be included in the time analysis since they are an integral part of the work. But since these elements are outside the routine cycle, they are called 'foreign' elements. There may be some genuine foreign elements such as when the worker is talking to a fellow employee or some other interruption which is not a part of the work. The Work Study analyst must note all the foreign elements as and when they occur.

3. It may also help if the analyst separates the constant elements from the variable elements.

4. Also, there is no unique method of subdividing a job into elements. Much depends upon the particular job being studied, the type of jobs encountered in the plant, and finally the judgment of the analyst. Only the precautions of distinctiveness and appropriate shortness of elements and of differentiating between constant and variable elements and man or machine elements need to be observed.

For the Time Study one has to choose an 'acceptable' operator. He is one amongst many operators who are trained sufficiently in the job to be performed and are healthy and skilled or capable of performing the job at an acceptable pace day-in and day-out. He is not an abnormally fast or slow worker but one amongst the many who fall in between who might qualify for doing the job. The theme is to:

(i) eliminate the extraordinary (in either sense), and

(ii) to time study only those jobs that have received sufficient learning or training (reaching saturation in terms of 'learning) and in general all the working conditions are well established/ settled.

Two Methods of Stopwatch Reading The observation and recording of the element times are done by two methods:

(a) Continuous

(b) Snap-back.

In the continuous method the stopwatch is allowed to run continuously and observations on successive elements are recorded. The times for individual elements are obtained later by successive subtractions. The 'snapback' method involves measuring each element separately and snapping the watch back to zero for timing the next element.

One of the criticisms of the snap-back method is that the analyst may forget to take into account any foreign elements. Also the direct recording of the individual elemental times may make the analyst tend towards recording more uniform readings. Moreover, the error due to observing a job and reading a watch simultaneously is not small enough to be ignored in the snap-back method. It is of the extent of 3 to 9% on an element of 0.06 minute duration and the error could be larger, if the elemental time is shorter.

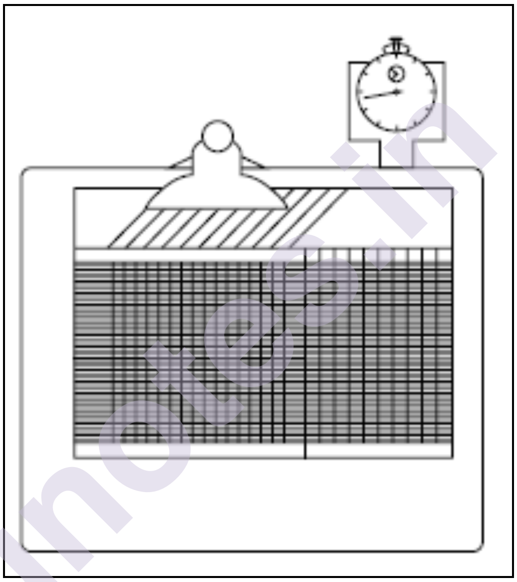


Fig. Stopwatch Time Study Equipment

Performance Rating Each of the elements is performance rated. For this, the analyst's concept of what is the 'normal' pace of working is important. Although this may sound very judgmental, speed rating techniques as used in the Society for Advancement of Management (SAM) rating films and in the Lowry, Maynard and Stegemerten (LMS) system are available to adjust/improve the judgment towards more uniformity amongst various raters. The LMS system gives weights to Skill, Effort, Conditions and Consistency on a Super, Excellent, Good, Average, Poor scale. Of course, the judgmental element or mental concept of what is 'average' is always there.

Each element should be timed repeatedly a number of times before arriving at the usable figure for the elemental times. For this, generally, an arithmetical average of the readings is taken. But, how many such readings should be taken? Or, what is the adequate sample size from which to take an average? This question has been answered by statistical principles. The formula (not derived here; the reader may refer to books on statistics) for having 95 chances out of 100 that observed average will be within (+/-) 5% of the true average for the element for the pace at which it was performed, is

$$N_{reqd} = \left(\frac{40 \cdot \sqrt{N_{taken} \sum X^2 - \left(\sum X\right)^2}}{\sum X} \right)^2$$

where N_{reqd} = Required number of readings or sample size

N_{taken} = Number of readings taken based on which data, the sample size is being determined.

X = Individual reading or elemental time

$\sum$ = Sum of

The sample size computations are done for each element and the element having highest degree of variability, will determine the sample size required for that job.

Computation of Normal Time and Standard Time

The 'normal time' for the job is the sum of the 'normal times' for all of its elements. The normal time for an element is given by:

$$\begin{pmatrix} \text{Arithmetical Average of} \\ \text{the Recorded Times} \end{pmatrix} \times \begin{pmatrix} \text{Performance Rating expressed} \\ \text{in percentage with 100\% as} \\ \text{the 'accepted' performance} \end{pmatrix} \div (100)$$

Thus, if an element is rated as 120% and the actual readings are (in minutes):

0.05 0.06 0.05 0.05 0.05 0.06 0.06 0.05 0.06 0.06

(Arithmetical average = 0.055)

Normal Time for the element = {(0.55 X 120) / 100} = 0.066 min

This is so, provided the sample size of 10 is the proper one (statistically required).

We can check this.

$$N_{reqd} = \left(\frac{40\sqrt{10 \times 305 - 3025}}{55} \right)^2$$

$$= 12.2 \approx 13$$

Therefore, if we take three more readings we have the adequate sample size. Let these be 0.06, 0.06, 0.05 min.

Now, arithmetic average of the 13 readings = 0.0554 min

Normal Time for the element = {(0.0554 X 120) / 100)}

= 0.06648 = 0.066 min

Allowances: ‘Standard times’ are derived from the normal times by applying appropriate ‘allowances’ for Personal Time, Fatigue and Unavoidable Minor Delays (outside the control of the worker).

A worker needs time to attend to personal physical needs such as drinking water, etc. which is reflected in the Personal allowances added to the Normal Time. These are generally not less than 5%.

At the end of the day a worker tends to work at a slower pace which is due to muscular as well as mental fatigue caused by noise, vibration, need for concentration, rapidly changing directions of motion, heat, etc. This allowance normally is given to the extent of 5 to 10%, but much depends upon the particular conditions of work prevailing.

During the day there are usually some interruptions in the operator’s activity over which the operator has no control, for example a delay in the availability of material.

Work Study analyst must analyze the extent of such time losses and add appropriate allowance to the Normal Time.

Although to some extent these allowances can be estimated by a proper and extended analysis, these need to be agreed to by the workers’ unions.

10.5 INVOLVEMENT OF WORKERS’ UNIONS

Workers’ Unions must be involved in the entire work study activity. New methods cannot be implemented without the cooperation of the workers. Proper time study cannot be done and implemented unless the workers understand and accept the logic behind the division into elements, the performance rating, the allowances provided, etc. Every step in time study can cause doubts in the minds of workers if their confidence is not won. Even the times recorded may not be acceptable.

One may say that a good industrial engineer is first a good Industrial Relations person and next a good industrial engineer. The standard time is calculated from the normal time by the following:

$$\text{Standard Time} = \frac{\text{Normal Time}}{\left(1 - \begin{array}{l}\text{Total Allowance} \\ \text{expressed as a} \\ \text{fraction}\end{array}\right)}$$

Thus, if the total allowances (personal time, fatigue and unavoidable minor delay) are agreed upon as 16% and if the Normal Time is 0.210 minutes, then

$$\text{Standard Time} = \frac{0.210}{(1-0.16)} = 0.250 \text{ min.}$$

Illustrative Problem: Continuous Stopwatch Time Study figures for a job are given below. Calculate the Standard Time for the job assuming that the sample size is adequate, and total allowances are 15%.

Element No.	Description	Cycle	Cycle Time, min										Performance Rating
			1	2	3	4	5	6	7	8	9	10	
1			0.09	0.49	0.89	1.31	1.70	2.09	2.50	2.88	3.29	3.71	90
2			0.16	0.56	0.95	1.38	1.76	2.16	2.57	2.95	3.36	3.78	110
3			0.28	0.67	1.07	1.49	1.88	2.28	2.68	3.07	3.40	3.90	120
4			0.41	0.80	1.21	1.61	2.00	2.41	2.80	3.20	3.62	4.03	100

Solution:

The above are the 'continuous' Watch Study figures. The following is derived from them.

Element No.	Cycle	Element Time, min										Arithmetic Average	'Normal' Time for Element, Minutes
		1	2	3	4	5	6	7	8	9	10		
1		0.09	0.08	0.09	0.10	0.09	0.09	0.09	0.08	0.09	0.09	0.089	0.080
2		0.07	0.07	0.06	0.07	0.06	0.07	0.07	0.07	0.07	0.07	0.068	0.075
3		0.12	0.11	0.12	0.11	0.12	0.12	0.11	0.12	0.13	0.12	0.118	0.142
4		0.13	0.13	0.14	0.12	0.12	0.13	0.12	0.13	0.13	0.13	0.128	0.128
													Total = 0.425 min.

$$\text{Standard Time} = \frac{0.425}{(1-0.15)} = 0.500 \text{ Minutes}$$

10.6 PREDETERMINED MOTION RIME SYSTEMS (PMTS)

So far we have discussed the Stopwatch Time Study. The other way of establishing time standards is by making use of synthetic time standards for elements of motion. Many such Predetermined Motion Time Systems (PMTS) are available. Some of the important PMTS are MTM standards (Methods Time Measurement) and Work Factor. We shall limit our discussion mainly to MTM, which is used extensively in USA, Canada and other advanced countries and which is gaining some interest in Indian industries in recent times.

Methods Time Measurement (MTM)

MTM was developed by the MTM Association for Standards and Research which now has its headquarters at Ann Arbor, Michigan, and various Chapters and Cooperating National Associations in countries such as England, France, West Germany, Holland, Japan, Norway, Sweden, Switzerland, and various Industrial and Consultant members in Australia, Columbia, Argentina and South Africa. The basic principles of MTM were first put forth by Maynard, Stegemerten and Schwab. The start of MTM application may be put around the year 1948.

The basic MTM approach is to classify the human work motions into certain fixed standard categories such as reach, move, turn, apply pressure, grasp, release, position, eye motions, bodyleg and foot motions, etc. In each of these categories again there are different subclasses or cases of motion. The MTM Association has done extensive and exhaustive studies on the hand and body motions and arrived at normal times for each of these sub-classes of motions. These times or predetermined times for motions are used to synthesize a time standard for a job. A job is therefore observed or visualized to consist of a series of micro-motions from the MTM inventory of standard micro-motions, the times for each of these are looked up from the MTM tables, they are totalled and appropriate allowances added (as in Time Study by Stopwatch) and the result is the standard time for the job.

Since much of the earlier MTM research on the basic elements of motion was done by means of a movie camera with a speed of 16 frames per second, the minimum time that could be observed was 1/16 of a second or 0.0625 second, i.e. 0.00001737 hour. Most of the wage calculations in USA and Canada are done in $ per hour. Taking this also into considerations, it is understandable that the originators of MTM used the smallest or basic time measurement unit as 0.00001 hour. This basic unit is called the Time Measurement Unit (TMU).

1 TMU = 0.00001 hour = 0.0006 minute = 0.036 second

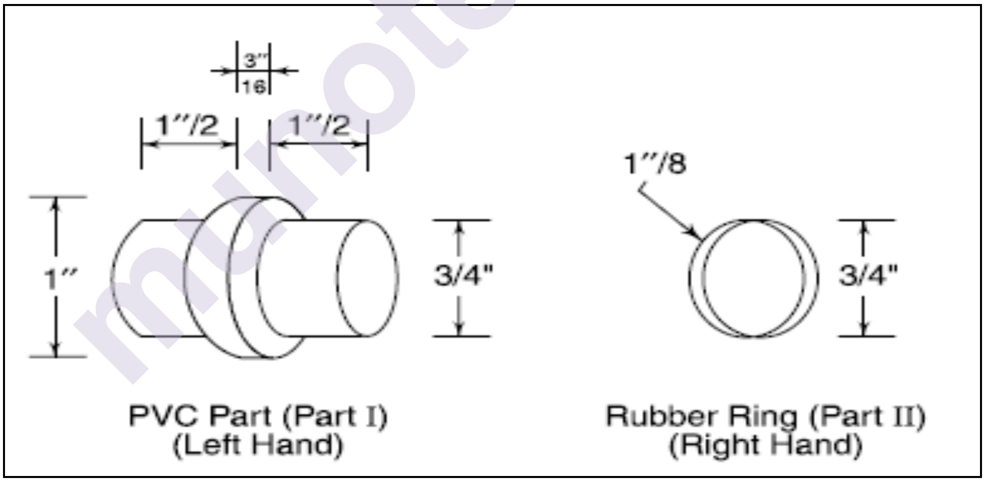


Fig. MTM Application to the Simple Fitting of Part II on Part I

Example: An example of MTM application is given below. The case is that of fitting a rubber ring (3/4 inch dia) into a plastic part cylindrical in shape. The operator has a stock of each of those parts piled on the table on his left and right hand sides. The assembly is dropped into the centre bin when it is complete. Figure above will aid the reader.

Solution:

MTM Elements			*MTM Elements*		
Left Hand	*TMU*		*Right Hand*		*TMU*
RB 12	12.9		RB 12		12.9
G 4 B	9.1		G 4 B	—	9.1 + 9.1*
—	—		G2	—	5.6
MB 12	13.4	...	MB 12	—	13.4
P2SE	16.2	...	P2 SE	—	16.2 + 16.2*
—	—	...	AP2	—	10.6
RL 1	2.0	...	RL 1	—	2.0
			Total		95.1 TMU

Given that 'allowances' are 16%,

$$\text{Standard Time} = \frac{95.1}{1-0.16} = 113.2 \text{ TMU}$$

$$= 3.47 \text{ sec}$$

Merits and Demerits of MTM

The skill of the work study man lies in consistently and accurately identifying the MTM motions involved in a job. A motion may raise doubts as to whether it belongs to Move or Reach? Position or Move? Whether a Move and a Turn are done combined or consecutively? Whether a motion is partly Reach and partly Move or only Move? Whether the Move is of A category or B category? etc. All such cases need a consistent approach besides being as truthful / accurate as possible.

The advantages of MTM over stopwatch time study are:

- It avoids performance rating thereby eliminating this subjective part
- It can be used for jobs that are yet in the planning stage since it can dispense with direct observation.
- It is a method which has definite breakdown of motion elements thereby enhancing the understandability or verify-ability by two or more analysts.
- It does not have the effects of sample size coming into picture, unlike the stop watch method.
- It offers the advantage of the detailed method study and time study combined into one.

One must also mention its disadvantages:

- It is applicable only for the hand, eye and body motions of an individual worker (not for group work or for anything other than hand-eye-body motions). Process times and/or machine times if any, may have to be established by other means.
- Although it offers the advantages of clarity of comprehension for trained analysts, it may baffle the ordinary worker with too lengthy details.
- Allowances for other ordinary working conditions become very important / critical in the calculation of the standard times. The

Stopwatch Time Study implicitly takes care of a major fraction of these allowances due to its direct observation technique.

- Jobs involving extreme high degree of control cannot be measured by it.
- The detailed analysis consumes much time and therefore, the economies may not favor measurement of non-repetitive work with this method.

Work Factor System

Another PMTS is the Work Factor system, developed by Quick, Shear and Koehler and now a proprietary system of the Work Factor Company Inc. This system, as different from MTM, classifies movements in terms of finger movements, arm movement, leg movement and trunk movement.

The movements will take longer times as the difficulty factors of precision of movement, resistance due to weight, directional control or steering, changes in direction, stopping effort by the operator are included. In addition to the distance moved, the analyst has also to estimate the number of difficulty (or work) factors (1, 2, 3 or 4 as the case may be) and read corresponding time from the Work Factor tables. The time measurement unit here is 0.0001 minute. Many industrial corporations in USA have adopted this system.

Data Block from PMTS

The logical extension of PMT systems is to combine elemental movements commonly encountered in not only one plant or an organisation but also common across several industries and organisations.

For example, typing a sheet of paper of running matter is common to any organisation anywhere, or changing a gasket for a given size of centrifugal pump is another example. Special Data Blocks have been developed for various such situations. Some of the special Data Systems (a number of such pertinent data blocks making a Data System) are:

(i) Master Clerical Data

(ii) Universal Maintenance Standards (UMS)—both of which are developed by H.B. Maynard & Co., USA

(iii) Standard Sewing Data—used in the garment industry

(iv) Universal Office Controls—developed by Birn Company of USA.

10.7 WORK SAMPLING

Besides Stopwatch Time Study and PMTS, Work Sampling is another useful technique for Work Study. This technique is particularly useful to estimate the proportion of delays or stoppages occurring in a plant and attributing the cause for it such as supply failures/delays, machine breakdowns, machine cleaning, manpower idling, etc.; or to give another example, estimating the proportion of time spent by an engineer on telephoning, reading, writing, attending meetings, etc. The same estimation by the Stopwatch method is extremely time-consuming and therefore not feasible; and PMTS also would not be feasible.

Besides this, the Work Sampling technique can also be satisfactorily used to set production standards like those resulting from the Stopwatch Time Study. As the name suggests, it is a statistical sampling method. It estimates the proportion of time devoted to a given type of activity over a certain period of time by means of a large number of random 'spot' observations.

For example, a sufficiently large number of spot observations at random time intervals throughout a week of a Personal Assistant's (PA) work would give a fair estimate of the time spent by the PA on contacting people on telephone. Of course, the larger the number of observations the better (more accurate) is the estimate. Therefore, what should be the adequate sample size (or number of observations)?

If the true proportion of phoning in the entire range of activities (population) is p, and if the sample size is n, then,

$$\text{Standard Deviation (SD)} = \sqrt{\frac{p(1-p)}{n}}$$

Let U denote the mean of the sampled observation. If sampling procedure is undertaken repeatedly: 95% of the values of U will fall between p (+/-) 2SD; 99.7% of the values of U will fall between p • } 3 SD; and 67% of the values of U will fall between p (+/-) 3SD. Since the U will have to represent for true p there will be an error and for 95% confidence limits this error, E = 2 SD maximum:

i.e. $$E = 2\sqrt{\frac{p(1-p)}{n}} \text{ maximum}$$

i.e. $$n = \frac{4p(1-p)}{E^2} \text{ minimum}$$

Note that the error E is expressed here as a fraction of the population.

Problem: A preliminary study indicates that the proportion of idle time of a machine is 30%; rest of the time it is working. To get a good estimate of the idle time (as a fraction) with a precision of (+/-) 1% at 95% confidence level what should be the sample size?

Solution:

Required sample size n

$$= \frac{4(0.30)(1-0.30)}{(0.01)^2} = 8400$$

Therefore, there should be a minimum of 8400 observations. Based on these 8400 observations, the idle fraction of time of the machine can be calculated.

Say, if 2400 observations are in the category of 'machine idling', the ratio of idle time to total time available is 2400/8400 = 0.29 approximately. If the ratio was found to be significantly different from the earlier estimated 0.30, then the sample size would need to be recalculated to check if additional number of observations are warranted.

Production Standards from Work Sampling

The production standards can be established from Work Sampling as follows:

Normal Time for an activity per unit of output

$$= \frac{(\text{Total time of the Study}) \times \begin{pmatrix}\text{Ratio of the number}\\ \text{observations of the activity}\\ \text{to total sample size}\end{pmatrix} \times \begin{pmatrix}\text{Average performance rating}\\ \text{for the activity}\end{pmatrix}}{(\text{Total Output of the activity, in measurable units, during the total time of study})}$$

The above may be illustrated by means of a simple example.

Problem: An activity sampling study was undertaken to study the cutting, sealing, finishing and packing operations involved in the money-purse section of Kartik Plastic Works. There are three workers in this section, and the data collected for the finishing operation is as under:

Employee Name	Rama	Bharata	Laxmana
Total hours	40	30	40
Total observations	400	360	340
No. of observations of finishing operation	80	90	85
Average Rating	110	120	80

If 4000 purses equivalent is the output, what is the standard time for the finishing operation? Assume 16% allowances.

Solution: Applying the earlier given formula for this case, we have:

$$\text{Normal Time} = \frac{\left(\frac{40\times 80}{400}\times\frac{110}{100}\right)+\left(\frac{30\times 90}{360}\times\frac{120}{100}\right)+\left(\frac{40\times 85}{340}\times\frac{80}{100}\right)}{4000}$$

= 0.00645 hours = 23.22 sec

Standard Time for the finishing operation

= 23.22 / (1- 016) = 27.64 sec.

Whether it is time study by Stop-Watch, PMTS or Work Sampling, each has its own merits and should be used in appropriate situations.

10.8 APPLICATION OF WORK STUDY TO OFFICE WORK

The principles and techniques of Work Study have been applied to office work also, although with some difficulties. The difficulties are arguably attributed to the following:

(a) Office work involves a significant portion of “mental work”. This refers to the decision making process involved and ‘creative thinking’ involved in problem-solving which is difficult to measure in terms of time.

(b) Office work is irregular and non-repetitive in nature, unlike the manufacture of a product in a factory. It is possible to visualize an Office Assistant or a Secretary doing a variety of jobs in a variety of permutations and combinations at different times. At one time he/she is making a decision, at another leafing through an office communication, and at yet another talking to a potential customer, etc.

In short, it is argued, and justifiably so, that office work is less amenable to accurate measurement. But much accuracy may not really be necessary and generally ball-park standards of work may be quite adequate. Moreover, not all the above arguments hold much water on closer scrutiny.

For instance, in the work of a clerk, the mental work component or decision-making component may not be considerable. For this much of the irregular office work can be made more regular by proper planning and supervision. Work measurement is usually required to investigate whether a section of the office is understaffed or over-staffed and to provide guidelines for future manpower planning; for this purpose a rather broad-based and less precise work measurement would be adequate.

Work sampling has much application; this technique will take care of the irregular or random nature of the office working. Sometimes, PMTS systems such as Master Clerical Data and Universal Office Controls have also been found useful. Stopwatch Time Study per se may not be very useful. A system unique to office work is sometimes found useful: making the office personnel maintain a log of their daily work which forces them to record briefly the work done at every 15 minutes or so time interval and therefore to record the work as truthfully as possible.

Organisation and Methods (O&M)

Work Study in an office is usually given a different name, Organisation and Methods. The 'Methods' study principles are very much the same as were discussed for the manufacturing situation. Instead of studying and charting the flow of materials, the analyst may chart the flow of papers and forms and that of a complete office procedure. For this purpose, Procedure flow chart forms flow charts, and sometimes combined forms and procedure flow chart are used. Since much of the office work involves the flow of communication, the methods study in an office in large measure amounts to designing a suitable management information system. Of course, the physical part of the office working can be compared to its counterpart in the manufacturing situation. Improving the information system involves a study and possibly redesign of the organisation and decision making structure. For this reason, the work study in an office was given the name of organisation and methods. Many organisations in India have O&M cells. However, in most cases, the activities of the cell are confined to the simpler variety of methods improvement rather than studies on information requirements or organizational restructuring. Also, the head of the cell does not rank high in the organizational hierarchy.

Work Study forms the basis of determining job content, changing the job content if necessary, evaluating performance, devising salary and wage structures, designing incentive schemes, and the entire wage and salary administration

10.9 LET US SUM UP

In this unit we have studied the definition of method study and time study. We saw the foundation of work study in terms of subdivision of work—therbligs and principles of motion economy. We discussed process flow charts and man-machine diagrams. Main components of method study and time study standards have also been explained. Steps involved in stop watch time study and involvement of workers in the entire work study activity have been explained. Predetermined motion time systems (PMTS) and work sampling techniques have been discussed. At the end application of work study to office work is discussed with examples.

10.10 EXERCISES

1. Explain the relationship between method study and time study.

2. Get the pen from your shirt pocket and start writing your answer to Question 1 on a sheet of paper. What are the 'therbligs' involved?

3. You are to sign a stack of copies of the same letter. What principles of motion economy might you apply?

5. Take any simple office procedure, such as the sanctioning of a medical reimbursement claim, and write the process flow chart for the same.

6. What is the purpose of dividing a job into elements?

7. How can work study be used for arriving at (i) Manufacturing Budget, (ii) Production Plan, (iii) Personnel Policies, (iv) Materials Planning? Explain your answer.

8. Are there any similarities / commonalities between work study and time study? If so, what are they?

9. Method Study is mostly, commonsense applied systematically. What are these 'systematic' elements?

10. Good industrial engineering begins with good industrial relations. Do you agree with this statement? Explain why.

11. Can time study be applied to indirect labour such as cleaners or sweepers? Explain. Can it be applied to Supervisors?

12. A good work study should be followed by good supervision, for getting good results. Can you explain or elaborate on this statement?

10.11 SUGGESTED READING

- Operations & Supply Chain Management by Chase, Shankar, Jocaobs
- Operations Management (6th Edition) by Nigel Slack, Stuart Chambers, Robert Johnston
- Theory & Problems in Production & Operations Management- S N Chary, Tata McGraw Hill
- Production & Operations Management -Kanishka Bedi , Oxford University Press
- Operations Management for competitive advantage-Chase & Jacob, McGraw-Hill/Irwin
- Production and Operations Management- Chunawalla & Patel, Himalaya Publishing

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11

QC AND SQC

Structure

11.0 OBJECTIVES

After studying this unit, you will be able to understand the concepts of:

- Quality as a Corporate Strategy
- What is Quality?
- Statistical Methods
- Statistical Process or Quality Control
- Control Charts
- Diagnostic Value of Control Charts
- Process Capability
- Use of Statistical Process control (SPC) in services

11.1 QUALITY AS A CORPORATE STRATEGY

Quality is an important dimension of production and operations management. It is not enough to produce goods or services in the right quantity and at the right time; it is important to ensure that the goods and services produced are of the right quality. The consumer of the final product of a company needs a certain quantity of products of a quality appropriate to his needs. Without quality, the other dimensions of quantity and time have little relevance.

Quality management, which includes ensuring proper quality for a company's output, is important not only for its survival in the market, but also to expand its market or when it wants to enter into a new product-line and various other marketing ventures. If a country' products are to make an impact in the international market, it is vital that the quality of its exports should be at par with, if not better, than similar products from other nations. Quality management is thus an important long-term marketing strategy as well. For developing countries, such as India, this aspect assumes greater importance since in the international market they have to compete with products of advanced countries with established brand names and brand loyalties. To make a dent on such a market, it might sometimes be necessary for our products to be one step better than the already established products of other advanced countries.

Looking at it from another angle, it is necessary that we try to improve the quality of our products and services for even domestic consumption, so that Indian consumers get better service in terms of improved products. This is the social aspect of quality.

11.2 WHAT IS QUALITY?

Although we have described the virtues of good quality, one basic question needs to be answered: What is quality and who decides what the quality should be?

1. Quality is the performance of the product as per the commitment made by the producer to the consumer.

The commitment may be explicit such as a written contract or it may be implicit in terms of the expectations of the average consumer of the product.

'The performance of the product' relates to the ultimate functions and services which the final product must give to the final consumer. For instance, a watch should show accurate time or a ball point pen should write legibly on a piece of paper or the paper should be capable of retaining the pen-or-pencil marks made on it. Quality may be measured in terms of performance tests. A product is called a quality product only when it satisfies various criteria for its functioning for the consumer. In addition to the physical criteria, there is also a service and time dimension to quality. The same quality of physical performance should be available over a reasonable length of time. Thus, time is also an essential aspect of quality.

2. Quality is either a written or non-written commitment to a known or unknown consumer in the market. Since the market or the target-market itself is decided by the company, that is to which type of consumer or customer to cater to, quality is a strategic marketing decision taken by the company itself at the outset. We may broaden this concept by saying that the quality of products to be produced by a corporation is a corporate level decision. It is a decision based on various marketing considerations, production constraints, manpower or personnel constraints, and equipment or technology constraints. The decisions regarding quality are not really in the realm of one functional manager as this involves overall strategic decisions for the running of the business of a corporation.

3. Once such a strategic decision regarding the quality is taken, it is the job of all functional managers, including the production and operations manager, to see that such strategic objectives and goals are implemented. In this, the purchasing department has as much contribution to make to the quality as the production department that produces the goods, and the warehousing department that stores the goods, and the transport department that ensures the proper shipment of the goods to the customers. Quality implementation is also a 'total organisation effort.'

11.3 STATISTICAL METHODS

Statistics and quantitative methods are helpful in the implementation of quality. Though these quantitative and statistical methods are not a panacea for the problems of quality implementation, they are nevertheless helpful in this implementation process. There are three aspects of assuring quality, as shown in Fig. below:

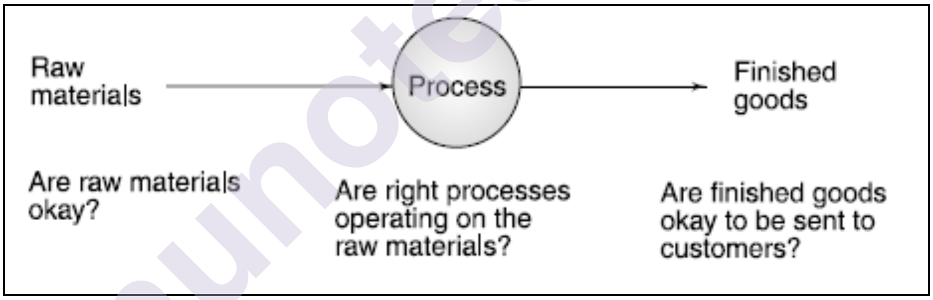

Fig: Basic Aspects of Assuring Quality

Acceptance Sampling

The task of exercising control over the incoming raw materials and the outgoing finished goods is usually called 'Acceptance Sampling'. Here, one is concerned about accepting or rejecting the supplier's raw materials, and sending or not sending the finished goods out. This is why the control at the raw material and the finished goods point is called Acceptance Sampling. This is only one part of what is known as **Statistical Quality Control**.

Process Control

The control one exercises over the processes operating on the raw materials or the semi-finished goods is called Process Control. This is another aspect of statistical quality control. It is assumed that if controls are exercised at the above-mentioned three points, quality will be appropriately maintained.

Mass Production

At the outset itself we must be clear, that Statistics is a science of averages, and therefore, statistical methods are useful for mass-production and mass-purchase or procurement of raw materials and mass shipment of the finished goods. The statistical methods depend on a large population for their accuracy and relevance, and of course, being a science of averages, these methods have their own special drawbacks (which we need not elaborate at this point).

Sampling

Since in all the statistical methods we shall be dealing with small samples taken from a large population, these statistical methods are of a great help in ensuring adequate quality for the total population or mass of products by checking only a few. These methods, in addition to reducing the labour involved in the implementation of quality, also give us an adequate amount of confidence on a scientific basis. They tell us to what extent we might fail or succeed in our efforts to maintain quality. Quality management has been given a scientific basis with the advent of the **statistical quality control methods**.

11.4 STATISTICAL PROCESS OR QUALITY CONTROL

The premise in process control is that if the processes (chemical reactions, mechanical working by men and or machines) are operated within a tolerable range, the product produced will be of the desired quality. This assumes that the incoming raw materials are of the right quality to start with. The objective of process control is to set a proper procedure to work or shape the raw materials into finished goods and then monitor the processes operating on the raw material frequently and any deviations from the said procedures should be corrected when required. Process control is nothing but the monitoring of the various physical variables operating on the materials and the correction of the variables when they deviate from the previously established norms.

Variations

But, we know that most things have a variable component to them. The processes which operate on the raw materials will also have variations due to causes inherent in them or otherwise. In any case, the causes responsible for the deviation of the processes from the established norms have to be rectified. The causes responsible for the deviation could be such that can be traced or spotted and, therefore, rectified and such that cannot be traced and rectified easily. In statistics, anything that we do not understand or we are not capable of understanding is called 'random'. The variations which are inherent in nature to a particular process and which are random since they are not traceable to any particular cause, are labeled to be due to 'random causes' or 'chance causes'. For instance, a machine filling toothpaste in tubes may not fill all tubes with exactly the same amount of paste; there will be some variations. This is due to the inherent nature of the process. In process control, we would be concerned only with those causes which can be rectified, i.e. the assignable causes. We can do nothing about the chance causes. But, anytime there is an assignable cause it is preferable to rectify it. The difficulty arising in this approach, of course, is to know when a particular deviation in the process is occurring due to the chance causes and when it is occurring due to assignable causes.

Monitoring the Process

We can control the process by **(a)** actually measuring the variables operating on the raw materials, or by **(b)** measuring the characteristics of the output product. When a number of variables are operating on the product, it becomes easier to monitor the processes by observing the quality of the product coming out of the processes, rather than monitoring the various variables operating. Moreover, we are interested in the final quality of the product rather than in the process variables operating on the materials. Therefore approach 'b', which is to monitor the output of the process and based on that to make inferences regarding the processes operating on the raw materials, is preferable. This is particularly so when a large number of variables are operating on the raw materials.

The statistical process control would, thus, seek to monitor the output of the processes and thus control the processes by locating the causes for the deviations (if any) and rectifying the same.

Specification Limits for the Output

When the quality of a particular product is being described, one usually refers to the appropriate range of performance of this product. We do not say that the diameter of the shafts have to be 3 centimeters exactly. Rather we would say that it should be 3 centimeters plus or minus 0.002 centimeters. Similarly, we do not say that the pH of baby powder has to be 5.7 exactly. Rather we say that it has to be between 5.2 and 6.2. Every quality performance requirement is usually expressed within a certain range. This range, narrow or wide, of the performance requirement in terms of quality of a product is called the specification range or specification limits.

Control Limits

Naturally, in exercising process control by monitoring the product from the processes, we should not exceed these specification limits. In fact, we should exercise control over the processes before the product quality goes beyond the specification limits. Therefore, the limits for our process control purposes should be narrower than the specification limits. These limits should be such that when exceeded, a danger signal is given, but as yet it is only a signal, and the product is not harmed. This is the philosophy behind the design of control-limits vis-a-vis the specifications limits (which have been already set in the Quality planning process).

Cost Aspects in Designing Control Limits

In addition to the above, while designing the control limits or the danger signals one should keep in mind the cost aspects as well. There is no point in worrying over every small variation in the output and wasting our efforts in rectifying the processes operating on the materials. We must give the process its inherent free play as well. We must also allow for certain margin of error even if the error is assignable or locatable. Such should be the design of the process control limits.

Central Tendency and Dispersion: Variations in any process can be described in general in terms of two parameters:

1. Central tendency, and

2. Dispersion.

The former has to do with accuracy and the latter with the precision. To understand these two concepts, let us consider the following example.

Example: Suppose I weigh 150 pounds (lb). There are two machines and they show the following readings for my weight:

Machine No. 1	Machine No. 2
140, 151, 159 lb	139, 139.5 140 lb

Machine No. 1 gives an average of 150 lb and therefore, this is an accurate machine. Its central tendency does not show deviation, but it has a lot of 'dispersion'. Machine No. 2 is precise, but it is not accurate because, its central tendency is 139.5 lb which is far removed from the actual weight, whereas, its dispersion is quite low, ranging from 139 to 140.

The above example shows that in controlling errors one has to control not only the central tendency, but also the dispersion. Both controls are necessary. We need to control the mean and also amplitude of the variations. We need to check whether a process has gone out of control in terms of either the central tendency, or in terms of the dispersion, or both.

11.5 CONTROL CHARTS

In process control, we keep a check on both the above-mentioned aspects by a constant monitoring device; which is graphical; the graphs which are used for such monitoring are called control charts. Process control relies mostly on such graphical or visual representations, and monitoring thereby.

If we were to monitor the process by measuring the characteristics of output from the process, the continuous measurement will interfere considerably with the manufacturing activities. We need to measure, but intermittently. Moreover if we were to continuously monitor the quality characteristics of the output of the process, the population of all such observations may not be amenable to easy statistical methods. If we were to plot distribution of the total population, it could be rectangular or it could be something else more abnormal.

Normal Distribution

The above told suggest that we resort to a sampling procedure for process control purposes. This has also another advantage by virtue of what is known as the Central Limit Theorem in statistics. The theorem states that the means of samples tend to follow a simple statistical distribution, viz. Normal distribution.

Therefore, the procedure will be: to take a few samples at a time; measure their quality characteristics; find the mean of the sample; measure the range of dispersion in the sample; and gather statistics for the ranges and the means of the various samples taken over frequent or regular intervals of time. These statistics, when plotted appropriately on a graph paper, will guide us as to when a particular process needs to be rectified and in what manner.

Statistical Relationships for Sampling

Based on the sample-size, there is a definite relation between the standard deviation of the population and the standard deviation of the sample means.

$$\sigma_{\bar{x}} = \frac{\sigma \text{ population}}{\sqrt{n}} \qquad (1)$$

$$\mu_{\bar{x}} = \mu_{\text{population}} \qquad (2)$$

where $\sigma \equiv$ Standard deviation

$\mu \equiv$ Mean

$x \equiv$ Value of the measured characteristic

$\bar{x} \equiv$ Mean of 'x' s observed of the sample (x_1, x_2, x_3, etc. individual values in the sample)

$n \equiv$ Sample size

The sampling distribution (of $\bar{x}$) being normal, the computation of $\mu_{\bar{x}}$, $\sigma_{\bar{x}}$ and Confidence Levels is quite easy.

x̄-Chart

Now to keep a watch on the 'central tendency' we have to fix limits which are called 'control limits' for the values of $\bar{x}$. Any time the sample mean exceeds the control limits, we say that the process has gone out of control—that is, there are certain 'assignable causes' which should be looked into immediately. It may not be that every time the control limits are exceeded the process has really gone out of control. The overshooting may simply be due to chance causes; and when this is the case, our investigation into finding the assignable causes will mean an unnecessary burden of cost. Therefore we would like to limit the number of times we look for assignable causes for the variations. Depending upon the precision that is involved, we would be setting up the control limits on the + and the – side of the mean of the sample means. Usually (+/--) 3σ limits are established. Since means of the samples are distributed normally, the 3σ limits will mean that when the process is under control we will investigate into the assignable causes 3 out of 1000 times. Incidentally, when we look for the assignable cause when none exists, it is called the Type 1 error; and when we are not looking for assignable causes, when these causes do exist, it is called Type 2 error. We would like to find a proper balance between the Type-1 and the Type-2 errors, and based on this particular balance we can fix the + and – control limits on the 'central tendency' (mean of the sample means). As we said, in many cases, we fix these limits at (+/--)3σ level. The control chart for the 'central tendency' is called the $\bar{x}$-chart and is presented in Fig. below:

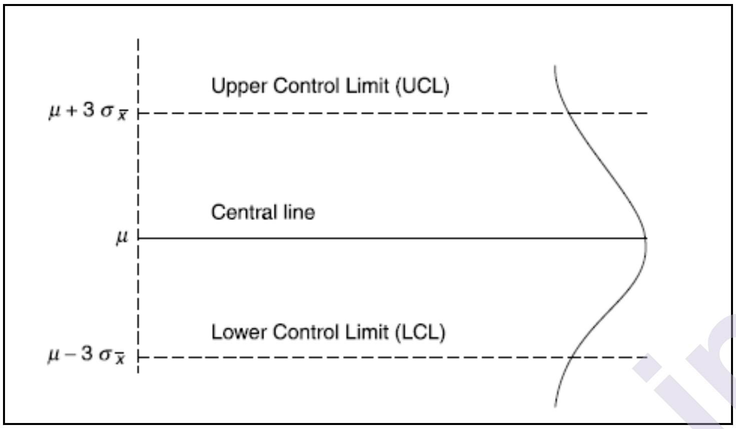

Fig. $\bar{x}$-Chart for Process Control

Any time the sample-mean overshoots the upper control limit or undershoots the lower control limit, we give a red signal; that means, we look for assignable causes by checking the machine or equipment or process that is producing the particular product.

R-Chart

The $\bar{X}$-Chart is for keeping a control on the 'central tendency'. Now we look for the control for the 'dispersion'. The standard deviation as well as the Range will give an indication of the Dispersion.

The range is the difference between the maximum value and the minimum value of the observations in a sample. We use the sample's range for controlling the 'dispersion' of the population as it is simpler to use.

The distribution of the range for the samples is shown in Fig. below:

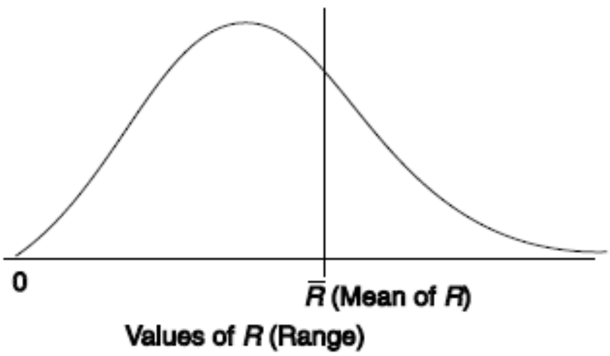

Fig: Frequency Distribution of Range

$\bar{R} = d_2 * \sigma$ population

where, d_2 is a constant whose value depends upon the sample size n. The mean of the samples ranges or $\bar{R}$ will represent for σ_{pop} which is the standard deviation for the population. By maintaining $\bar{R}$ within limits we can maintain σ_{pop}. Although the frequency distribution of the sample's ranges appears as given in Fig on Frequency Distribution of Range, it can still be approximated to a normal distribution and 3σ limits would be established for the upper and lower control limits. The resulting R-chart is presented in Fig. R-Chart for Controlling Dispersion.

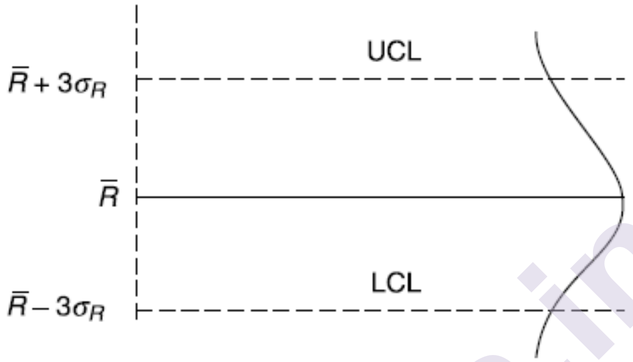

Fig. R-Chart for Controlling Dispersion

σ_R = Standard Deviation of the Ranges = $d_3 * \sigma_{pop}$

where, d_3 is a constant whose value depends upon the sample size n.

When the R values fall below the central line, it indicates that the process at that point of time is having less dispersion than the average values of the same. This may be desirable, and so we may ask the question why one should be concerned about the undershooting of the lower control limit in an R-chart. If the narrowing down of the dispersion is a permanent feature, it should be incorporated by having a revised R-chart. Moreover, we should ask whether this desirable result is due to some uneconomical methods which might have been employed, or whether it is due simply to the inspection error. These aspects need to be investigated, and hence the need for having a lower control limit even in R-charts.

Simple Relationships for $\bar{X}$ and R Chart

For $\bar{X}$ -chart: UCL and LCL

$$= \mu \pm 3\,\sigma_{\bar{x}}$$

$$= \mu \pm \frac{3\sigma_{pop}}{\sqrt{n}}$$

$$= \mu \pm \frac{3}{\sqrt{n}} \cdot \frac{\bar{R}}{d_2} = \mu \pm A_2 . \bar{R}$$

Where

$$A_2 = \frac{3}{d_2 \cdot \sqrt{n}}$$

; the values of A2 can be read off from standard Statistical and Quality Control tables, corresponding to a sample size.

For R-chart: UCL and LCL = $\overline{R} \pm$• 3 σ_R

$$= \overline{R} \pm 3.d_3.\, \sigma_{pop}$$

$$= \overline{R} \pm 3.d_3.\frac{\overline{R}}{d_2}$$

$$= \overline{R}\left[1 \pm 3\frac{d_3}{d_2}\right] = D_4\overline{R} \text{ and } D_3\overline{R}$$

$$\text{where } D_4 = 1 + \frac{3d_3}{d_2} \text{ and } D_3 = 1 - 3\frac{a_3}{d_2} \;;$$

the values of D_4 and D_3 can be read off from standard Statistical and Quality Control tables, corresponding to a sample size.

Thus, by looking for assignable causes which result in abnormal deviations in the means of the samples and in the ranges of the samples, we try to control the process and the quality level of a product.

Solved Problems

1. Shubha & Company (SAC) is an automobile ancillary and manufactures piston rings amongst several other products. Since quality is very important in a highly competitive market, SAC wants to introduce statistical quality control on its shop-floor. Sample checks on the diameter (critical dimension for quality) of the piston rings are taken as they are produced. Samples are taken in a bunch of five items, i.e. five rods produced would constitute one sample. The results on 20 such samples yield the following: μ = 0.2244 cm and $\overline{R}$ = 0.0023 cm.

What should be the control limits for the process control charts?

Solution:

$\bar{X}$-chart:

For the $\bar{X}$— chart the control limits are:

UCL= $\mu + A_2.\bar{R}$

and

LCL= $\mu - A_2.\bar{R}$

Now, the value of A_2 corresponding to a sample size of 5 can be read off from the statistical table on (Factors for Computing Control Chart Lines).

It is: $A_2 = 0.577$

Hence, UCL = 0.2244 + (0.577)(0.0023) = 0.2244 + 0.0013 = 0.2257 cm

and LCL = 0.2244 – (0.577)(0.0023) = 0.2244 – 0.0013 = 0.2231 cm.

R –chart

For the R-chart, the control limits are:

UCL = $D_4.\bar{R}$

and LCL = $D_3.\bar{R}$

Again, the values of D_4 and D_3 can be read off from the same table.

These are: $D_4 = 2.115$ and $D_3 = 0$

Hence,

UCL for the R-chart = (2.115)(0.0023) = 0.0049 cm and

LCL for the R-chart = (0)(0.0023) = 0.0000 cm.

2. In the above company, if the sample size was 10 (i.e. if they were taken in a bunch of ten) how would the process control charts have been different?

The factors A_2, D_4 and D_3 would have been different.

The new factors would have been: $A_2 = 0.308$, $D_4 = 1.777$ and $D_3 = 0.223$

Hence,

UCL for $\bar{X}$-chart =0.2244 + (0.308)(0.0023) = 0.2244 + 0.0007 = 0.2251 cm

LCL for $\bar{X}$-chart = 0.2244 - (0.308)(0.0023) = 0.2244 – 0.0007 = 0.2237 cm

UCL for R-chart = (1.777)(0.0023) = 0.0041 cm and

LCL for R-chart = (0.223)(0.0023) = 0.0005 cm.

We observe that the process control limits in this case (sample size of 10) have become narrower compared to the previous one (when the sample size was 5). Why is it so? The reason is that in the present case, even with twice the number of items (i.e. 10 instead of 5) in a sample, the mean range is the same (0.0023). The process is, therefore, tighter and hence the control limits also need to be tighter. A sample size is chosen with the rationale that the units within a sample have the greatest chance of being alike and the units between the samples have the greatest chance of being different. This being so, a larger sample size presumes that the variation is expected to be lower.

p-Charts or Fraction Defective Charts

So far, we have dealt with the control charts where measurements of the samples were taken in terms of the particular characteristic, for example, the diameters of the shafts being produced or the thickness of the plates being produced, etc. But, not in all cases can we describe the samples in terms of their measurable characteristics. Many a time, the inspection is of the go/no-go, or accept/reject type. In such a case, the particular sample is either defective or it is not defective. Control charts for such inspection procedures have been named p-charts where p stands for the fraction defective in a sample. The procedure of constructing the p-chart is as follows:

Suppose we take about 25 samples. We find the average fraction defective, $\overline{p}$. This is the central line. We assume normal distribution for the fraction defective data of these 25 samples. Note that though this is a typical case for the application of the Binomial distribution, we can approximate the distribution to a normal distribution when $np \geq 10$. If this requirement is met, then based on the normal distribution assumption, we set the limits for the upper and lower control:

$$\overline{p} \pm 3\sqrt{\frac{\overline{p}(1-\overline{p})}{n}}$$

$$\left(\text{Note that the variance for the fraction defective is: } \overline{p}\,\frac{(1-\overline{p})}{n}.\right)$$

c-Charts or Number of Defects Chart

Many a time a part or product is considered defective not just based on one measurement like the go and no-go gauges would indicate, but on the basis of a number of defects present in a sample. For instance, a welded joint will have a number of defects all of which have to be taken into account before a decision to accept or reject it can be arrived at. Similar examples can be given of cloth produced which may have a number of defects per metre length. It is the total number of defects in the sample which would render a sample either acceptable or rejected. For process control measures in such situations where the number of defects is the criterion for acceptance or rejection, a special kind of chart called the c-chart is used. The procedure is to take a sample of fixed size, count the defects in the sample (suppose the number of defects is equal to c); then plot the distribution of c's for all samples. The approximation of a Poisson distribution with a mean of $\bar{c}$ and a standard deviation of $\sqrt{\bar{c}}$ will be suitable. Therefore our control limits will be $\bar{c} \pm 3\sqrt{\bar{c}}$ and the chart would look as given in Fig. below.

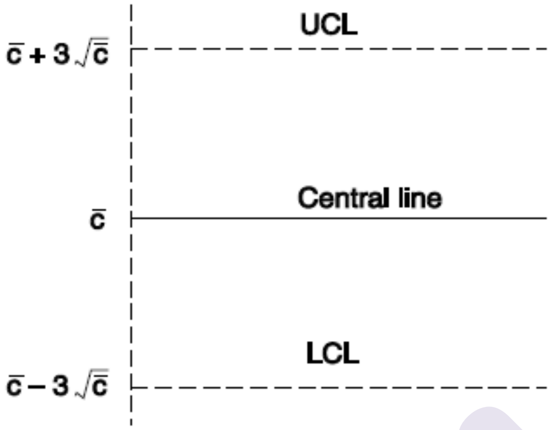

Fig: 6 Control Chart for Defects

3. In a production process of precision washers, a sample of 100 washers is checked every hour. The outer and inner diameters and the thickness are the three dimensions that are checked. However, after the check, the washer is categorized as either 'defective' or 'good'. The readings of this quality control process on particular day (24 hours) are as follows:

Hour No.	*Percent Defectives*	*Hour No.*	*Percent Defectives*
1	2	13	4
2	4	14	1
3	2	15	1
4	4	16	3
5	3	17	4
6	1	18	2
7	3	19	1
8	3	20	4
9	3	21	2
10	2	22	2
11	3	23	4
12	4	24	2

(i) Draw the control chart for the above.

(ii) Is the process currently in control?

(iii) If the Manager-Quality desires that there are no more than 5 per cent chances that percentage defectives in a sample exceeds 5 per cent, would the current process meet the Manager's desires?

(iv) If the Manager's requirement is not met, what should be the action plan to meet the requirement? Will the control chart be different?

Solution:

(i) The above process calls for a p-chart or Fraction Defectives chart.

There are 24 hourly points and the average fraction defective is (0.64) / (24) = 0.0267

The variance of the fraction defective is = (0.0267)(1– 0.0267) / 100 = 0.0002599

Standard deviation is = √ (0.0002599) = 0.01612

The Upper Control Limit would be: 0.0267 + (3)(0.01612) = 0.0765 = 7.65%

The Lower Control Limit would be: 0.0267 – (3)(0.01612) = 0 = 0%

(ii) The process has not crossed the control limits during the 24 hours and hence it is in control.

(iii) 5 per cent or 0.0500 fraction defectives correspond to:

(0.0500 – 0.0267) / (0.01612) = 1.445 standard deviations.

Referring to the Standard Normal Distribution table, it corresponds to an area of 0.4258 between the mean (centre line) and the value of 0.05 per cent defectives.

That means, the point of 0.05 will be exceeded with a chance of (0.5 – 0.4258) (100) per cent = 7.42 per cent.

Current process does not meet the Manager's requirement (although it is 'in control'.

Note that 'in control' only means that the process is functioning as usual).

(iv) If the Manager's requirements have to be met, then he will have to:

a) Investigate each of the variables, viz. outer diameter, inner diameter and thickness.

b) Investigate the reasons for the quality lapses in the variable/s that may be responsible for the lower quality. The reasons could be in the inputs or in the processes or in the measurement itself.

c) The detected reasons have to be attended to, i.e. have to be corrected.

d) The output quality has to be checked once again after carrying out the above corrections.

Basically, one has to reduce the average fraction defectives of the process by means of the above suggested actions. Hence, the centre line (average fraction defectives) and the control limits (+/- 3 std. deviations) will be different in the new statistical process control chart for fraction defectives.

4. Surgical tape is being coated in a coating range. The process is to continuously coat a surgical grade cloth with medicated masticated rubber solution and pass it through an oven in order to cure it. The cured tape is wound at the other end to be slit later into required sizes and rewound. The tape is inspected for a number of flaws such as black specs, loose threads, foreign particles, adhesive clots and uneven ends among others. Half-hourly quality checks are done on a random two meter length and the number of flaws is counted. The readings during a particular shift of 8 hours have been as furnished below.

What is the appropriate process control chart and what may be the control limits for the same?

Reading No.	*No. of Defects Detected*	*Reading No.*	*No. of Defects Detected*
1	10	9	5
2	2	10	12
3	9	11	14
4	14	12	3
5	12	13	10
6	1	14	4
7	10	15	2
8	10	16	10

Solution:

The appropriate statistical process control chart for this process would be the ‘number of defects’-chart or ‘c’-chart.

Using the data given above, the total number of defects in the 16 readings is 128.

The average number of defects = 128 / 16 = 8.

For a ‘c’-chart, the centre line is the average number of defects $\bar{c}$.

Upper Control Limit UCL = $\bar{c} + 3\sqrt{\bar{c}} = 8 + 3\sqrt{8} = 8 + (3)(2.8284) = 16.49$

Lower Control Limit LCL = $\bar{c} - 3\sqrt{\bar{c}} = 8 - 3\sqrt{8} = 8 - (3)(2.8284) = 0$

Note tha since LCL is negative, it is taken as zero.

Check that the process is in control. We see that all the sixteen readings are within the UCL and LCL. Hence, the process is in control and we have a stable control chart.

11.6 DIAGNOSTIC VALUE OF CONTROL CHARTS

It may not always be necessary for the sample point to cross the Control Limit in order to indicate trouble brewing in the process. Many a time the trend of the sample values provides diagnostic information regarding some real trouble in the process. If a series of successive points fall on the upper side of the control limits, although within the band of control limits, it may mean a particular type of trouble in the process. If the successive points keep falling on alternate sides of the centre line, it may mean another kind of process problem. The upward or downward trend of successive points may mean a particular process change and sudden shift of the successive points on the chart may mean another category of process trouble. Such situations are depicted in Fig below:

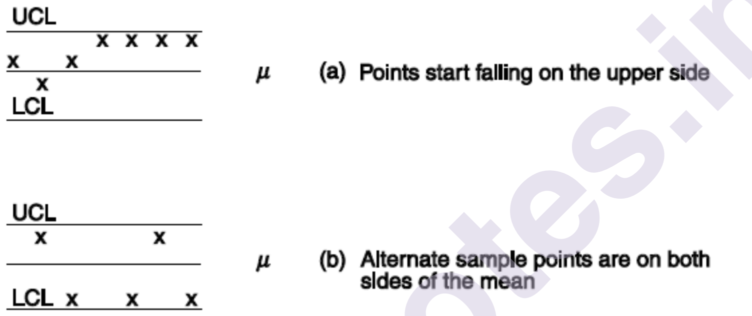

Fig: Behaviour of Control Charts and Diagnostic Information

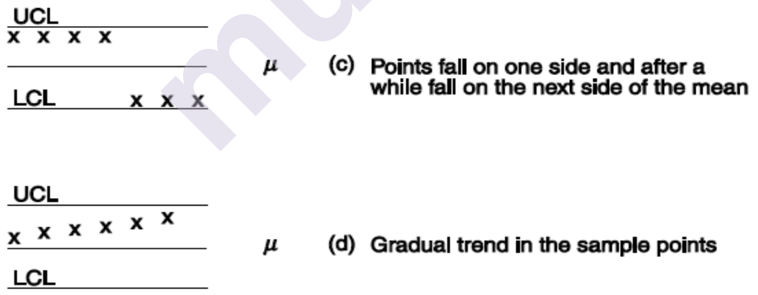

Fig: Behaviour of Control Charts and Diagnostic Information

11.7 PROCESS CAPABILITY

Mass production is controlled for quality by controlling the means operating on the raw materials entering into the process. By controlling the means of production it is assumed that the quality of the product will be controlled. The quality of the product will be as good as the ability of the process to produce the same. Based on the ability of the process or 'process capability' we can ensure by means of process control, as described above, only the capable (possible) stability of the processing system operating on the raw materials. The quality of the product will depend upon the capability of the stable system.

11.8 USE OF STATISTICAL PROCESS CONTROL (SPC) IN SERVICES

Whether it is manufacturing or services, there are common concerns regarding costs, quality and effectiveness. Hospitals, other healthcare facilities, hotels and similar hospital industry, transport, tourism, banking, telecommunications, and other service industries need tools to help the service providers monitor and assess the quality of service being provided and guide them to make better decisions. Just as in manufacturing, the SPC helped in identifying the variation that needs to be addressed; in service industry too; the SPC can be quite useful in determining as to which aspect of service is out of control. Large deviation/s hint that an aspect is out of control, so that there is a need to determine the source/s of the variation and identify the best method of correction. The difference, in production and service situations, is mainly in the particular variable/s that is monitored.

Just as manufacturing/production has a process; the service production also has a process. For instance, if it is a community health project, e.g. polio eradication, it has a process. In large hospitals with heavy patient load, the process aspect is quite evident. The quality of care delivered to the patients can have several measurable parameters. When these are in control, the service delivery can be expected to be of the desired quality. The statistical concepts of mean, standard deviation, range, and distributions like normal and Poisson are equally applicable for several service situations. As long as there is a standardized process with identifiable and measurable variables, SPC can be a very useful tool for improving quality of the service outcomes or service delivery. The point to note is the requirement of a standardized process to be in a place. This requirement can be met in most service situations. The concept of 'special cause' and 'common cause' of variation is, then, of as much utility as in the manufacturing situation. $\bar{x}$ -chart, p-chart and c-chart can, therefore, be useful.

11.9 LET US SUM UP

Quality is an important dimension of production and operations management. It is not enough to produce goods or services in the right quantity and at the right time; it is important to ensure that the goods and services produced are of the right quality. In this unit we have discussed the definition of quality, concepts of statistical process control, control limits, $\bar{x}$-chart, p-chart and c-chart. Diagnostic value of the control chars and their applications in services are also explained. Factors for computing control chart lines are presented below in the form of a table:

Factors for Computing Control Chart Lines

	Chart for Averages			Chart for Standard Deviations						Chart for Ranges						
Number of Observations in Sample, n	Factors for Control Limits			Factors for Central Line		Factors for Control Limits				Factors for Central Line			Factors for Control Limits			
	A	A_1	A_2	c_2	$1/c_2$	B_1	B_2	B_3	B_4	d_2	$1/d_2$	d_3	D_1	D_2	D_3	D_4
2	2.121	3.760	1.880	0.5642	1.7725	0	1.843	0	3.267	1.128	0.8865	0.853	0	3.686	0	3.276
3	1.732	2.394	1.023	0.7236	1.3820	0	1.858	0	2.568	1.693	0.5907	0.888	0	4.358	0	2.575
4	1.501	1.880	0.729	0.7979	1.2533	0	1.808	0	2.266	2.059	0.4857	0.880	0	4.698	0	2.282
5	1.342	1.596	0.577	0.8407	1.1894	0	1.756	0	2.089	2.326	0.4299	0.864	0	4.918	0	2.115
6	1.225	1.410	0.483	0.8686	1.1512	0.026	1.711	0.030	1.970	2.534	0.3946	0.848	0	5.078	0	2.004
7	1.134	1.277	0.419	0.8882	1.1259	0.105	1.672	0.118	1.882	2.704	0.3698	0.833	0.205	5.203	0.076	1.924
8	1.061	1.175	0.373	0.9027	1.1078	0.167	1.638	0.185	1.815	2.847	0.3512	0.820	0.387	5.307	0.136	1.864
9	1.000	1.094	0.337	0.9139	1.0942	0.219	1.609	0.239	1.761	2.970	0.3367	0.808	0.546	5.394	0.184	1.816
10	0.949	1.028	0.308	0.9227	1.0837	0.262	1.584	0.284	1.716	3.078	0.3249	0.797	0.687	5.469	0.223	1.777
11	0.905	0.973	0.285	0.9300	1.0753	0.299	1.561	0.321	1.679	3.173	0.3152	0.787	0.812	5.534	0.256	1.744
12	0.866	0.925	0.966	0.9359	1.0684	0.331	1.541	0.354	1.646	3.258	0.3069	0.778	0.924	5.592	0.284	1.719
13	0.832	0.884	0.249	0.9410	1.0627	0.359	1.523	0.382	1.618	3.336	0.2998	0.770	1.026	5.646	0.308	1.692
14	0.802	0.848	0.235	0.9453	1.0579	0.384	1.507	0.406	1.594	3.407	0.2935	0.762	1.121	5.693	0.329	1.671
15	0.775	0.816	0.223	0.9490	1.0537	0.406	1.492	0.428	1.572	3.472	0.2880	0.755	1.207	5.737	0.348	1.652
16	0.750	0.788	0.212	0.9523	1.0501	0.427	1.478	0.448	1.552	3.532	0.2831	0.749	1.285	5.779	0.364	1.636
17	0.728	0.762	0.203	0.9551	1.0470	0.445	1.465	0.466	1.534	3.588	0.2787	0.743	1.359	5.817	0.379	1.621
18	0.707	0.738	0.194	0.9576	1.0442	0.461	1.454	0.482	1.518	3.640	0.2747	0.738	1.426	5.854	0.392	1.608
19	0.688	0.717	0.187	0.9599	1.0418	0.477	1.443	0.497	1.503	3.689	0.2711	0.733	1.490	5.888	0.404	1.596
20	0.671	0.697	0.180	0.9619	1.0396	0.491	1.433	0.510	1.490	3.735	0.2677	0.729	1.548	5.922	0.414	1.586
21	0.655	0.679	0.173	0.9638	1.0376	0.504	1.424	0.523	1.477	3.778	0.2647	0.724	1.606	5.950	0.425	1.575
22	0.640	0.662	0.167	0.9655	1.0358	0.516	1.415	0.534	1.466	3.819	0.2618	0.720	1.659	5.979	0.434	1.566
23	0.626	0.647	0.162	0.9670	1.0342	0.527	1.407	0.545	1.455	3.858	0.2592	0.716	1.710	6.006	0.443	1.557
24	0.612	0.632	0.157	0.9684	1.0327	0.538	1.399	0.555	1.445	3.895	0.2567	0.712	1.759	6.031	0.452	1.548
25	0.600	0.619	0.153	0.9696	1.0313	0.548	1.392	0.565	1.435	3.931	0.2544	0.709	1.804	6.058	0.459	1.541
Over 25	$\frac{3}{\sqrt{n}}$	$\frac{3}{\sqrt{n}}$	-	-	-	†	*	†	*	-	-	-	-	-	-	-

Source: W.G. Ireson and E.L. Grant (Eds), Handbook of Industrial Engineering and Management, Prentice-Hall of India, New Delhi, 1977 (2nd edn.)

11.10 EXERCISES

1. What is the role of statistics in quality control? Give examples of the situations where statistics is applicable and where it is not applicable.
2. How would you control quality in a job-shop situation (where one customer's order may be different from another's). How would you control quality in a bank ? In a restaurant ? Discuss.
3. How would you perceive the role of the Quality Control Manager in an organisation? In a manufacturing organisation Should the quality control function be separate from the line function of manufacturing? If yes, why? If no, why not? (Give an example as to where it need not be separate.)
4. What is the difference between the specification limits and the control limits?
5. What is the implicit assumption when we say 'the control limits fall within the range of specification limits'? When is this possible and when is it not?
6. For what kind of industries and products do you feel that statistical process control may not be quite applicable? Describe the different situations.
7. We have introduced a sampling procedure in order to simplify the statistical computations. Is it always possible to adopt such a sampling procedure in all industries?
8. Give an example of how quality planning is a part of the corporate planning process. Give an example from the service industry.

11.11 SUGGESTED READING

- Operations & Supply Chain Management by Chase, Shankar, Jocaobs
- Operations Management (6th Edition) by Nigel Slack, Stuart Chambers, Robert Johnston
- Theory & Problems in Production & Operations Management- S N Chary, Tata McGraw Hill
- Production & Operations Management -Kanishka Bedi , Oxford University Press
- Operations Management for competitive advantage-Chase & Jacob, McGraw-Hill/Irwin
- Production and Operations Management- Chunawalla & Patel, Himalaya Publishing

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12

ISO SYSTEMS, VALUE ENGINEERING AND ANALYSIS

Unit Structure

12.0 OBJECTIVES

After studying this unit, you will be able to understand the concepts of:

- ISO Systems - Quality Management Systems (ISO 9001:2015)
- Value engineering and Analysis.

12.1 ISO SYSTEMS

What is quality all about?

A quality management system (QMS) is a set of policies, processes and procedures required for planning and delivering (production/development/service) in the core business area of an organization of any kind and size.

The ISO standard 9001 is a set of requirements that define the implementation and maintenance of a quality management system for a company.

Above all, ISO 9001 is a management tool for improving customer satisfaction and for assisting organizations to be more efficient. At the same time an important characteristic of the food industry is that, in order to cope with market needs as well as legal requirements, it has to satisfy both safety and quality criteria for it products.

A quality management system (QMS) is a set of policies, processes and procedures required for planning and delivering (production/development/service) in the core business area of an organization of any kind and size.

The ISO standard 9001 is a set of requirements that define the implementation and maintenance of a quality management system for a company. Above all, ISO 9001 is a management tool for improving customer satisfaction and for assisting organizations to be more efficient. At the same time an important characteristic of the food industry is that, in order to cope with market needs as well as legal requirements, it has to satisfy both safety and quality criteria for it products.

Therefore, in order to cope with those tasks, the top management of any company must assure a high "degree to which a set of inherent characteristics fulfills requirements" (ISO 9000, 2005), in terms of maintaining a standard quality of products and services.

As Govind Ramu, chair of the ISO 9001:2015 U.S., quotes "ISO 9001:2015 is not a giant, scary monster. It's a commonsense approach to running any organization.

Historic Review of the ISO 9000 Standards

The ISO 9000 family of quality management systems standards is designed to help organizations ensure that they meet the needs of customers and other stakeholders while meeting statutory and regulatory requirements related to a product or program. ISO 9000 deals with the fundamentals of quality management systems, including the seven quality management principles upon which the family of standards is based.

The ISO 9000 family includes standards such as:

- The ISO 9001:2015-that covers the requirements of a QMS.
- The ISO 9000:2015-that includes the basic concepts and language.
- The ISO 9004:2009-that focuses on improving the efficiency and effectiveness of a QMS.
- The ISO 19011:2011-that includes guidelines for the conduction of internal and external audits of QMSs.

ISO 9001 deals with the requirements that organizations wishing to meet the standard, must fulfill.

ISO 9000 was first published back in 1987. It was based on the British Standard, BS 5750 series of standards from BSI that were proposed to ISO in 1979. Actually it was back in 1959, when the US Department of Defense (1959) issued a specification for quality – Quality Program Requirements (MIL-Q-9858) (US Department of Defense, 1959), and later in 1973, the UK Defence Standards DEF STAN 05-21/1 – "Quality Control System Requirements for Industry" (Ministry of Defence, 1973) was published and based on earlier North Atlantic Treaty Organization (NATO) quality standards issued at the end of the 1960s.

Practically, all these standards changed the emphasis from post-production quality inspection and control to ensuring that quality was built into the manufacturing processes from the beginning, thus introducing the concept of quality assurance.

Year	Conformance Standard	Title
1979	BS 5750: 1979	Quality systems: Part 1. Specification for design, manufacture and installation
1987	BS 5750: 1987; ISO 9001: 1987; EN 29000; ANSI/ ASQC Q91	ISO title: Quality systems – Model for quality assurance in design/ development, production, installation and servicing
1994	ISO 9001: 1994: ANSI/ASQC Q9001-1994	Quality systems – Model for quality assurance in design, development, production, installation and servicing
2000	ISO 9001: 2000	Quality management systems Requirements
2015	ISO 9001: 2015	Quality management systems – Requirements

Source: "Developing a knowledge management policy for ISO 9001: 2015", John P. Wilson, Larry Campbell, Journal Of Knowledge Management, Vol. 20 No. 4 2016, Page 831

Recent Years

The 2000 version of the standard (ISO 9001:2000) sought to make a radical change in thinking. It placed the concept of process management at the heart of the standard, making it clear that the essential goals of the standard – which had always been about 'a documented system' not a 'system of documents' – were reinforced. The goal was always to have management system effectiveness via process performance measures. This third edition makes this more visible and so reduced the emphasis on having documented procedures if clear evidence could be presented to show that the process was working well. Expectations of continual process improvement and tracking customer satisfaction were also made explicit in this revision. A new set of eight core quality management principles, designed to act as a common foundation for all standards relating to quality management, were also introduced namely:

- Improved consistency with traceability
- Enhanced customer focus

- Focused leadership
- The involvement of people
- A system approach to management
- Continual improvement
- A factual approach to decision making
- Mutually beneficial supplier relationships.

The fourth edition of the standard (ISO 9001:2008) arrived on November 14th 2008. This revision contains minor amendments only. The aim of this revision is to clarify existing requirements and to improve consistency of approach with other management standards, like ISO 14001:2015.

During September 2015, a revised version – ISO 9001:2015 – was launched to bring the standard up to date, reflecting latest quality management good practice. Whilst some requirements have been tightened, the standard is now far less prescriptive and has even greater integration with other ISO management standard thanks to a common high-level structure.

THE SEVEN (7) QUALITY MANAGEMENT PRINCIPLES

According to the ISO, ISO 9000, ISO-9001 and related ISO quality management standards are based on seven Quality Management Principles (QMPs). The achievement of those QMPs, is essential for the efficient and successful management of any organization worldwide.

The revised version of ISO 9001:2015 Standard is based on the following Seven principles of Quality management:

- QMP 1 – Customer focus.
- QMP 2 – Leadership.
- QMP 3 – Engagement of people.
- QMP 4 – Process approach.
- QMP 5 – Improvement.
- QMP 6 – Evidence-based decision making.
- QMP 7– Relationship management.

QMP 1 - Focus on your customers and their needs

Developing a strong customer focus is an excellent way of demonstrating your commitment to quality. Gathering customer feedback is key – whether good or bad – as this can help you to spot non-conformities and improve your processes so that your business can strengthen its performance even further.

As well as satisfying customers, your business should also consider the interests of other stakeholders, whether owners, employees, suppliers, investors or the wider community.

Sustained success is achieved when an organization attracts and retains the confidence of customers and other interested parties. Every aspect of customer interaction provides an opportunity to create more value for the customer.

Understanding current and future needs of customers and other interested parties contributes to sustained success of the organization.

Key benefits

- Increased customer value
- Increased customer satisfaction
- Improved customer loyalty
- Enhanced repeat business
- Enhanced reputation of the organization
- Expanded customer base
- Increased revenue and market share

Actions you can take

- Recognize direct and indirect customers as those who receive value from the organization.
- Understand customers' current and future needs and expectations.
- Link the organization's objectives to customer needs and expectations.
- Communicate customer needs and expectations throughout the organization.
- Plan, design, develop, produce, deliver and support goods and services to meet customer needs and expectations.
- Measure and monitor customer satisfaction and take appropriate actions.
- Determine and take actions on interested parties' needs and expectations that can affect customer satisfaction.
- Actively manage relationships with customers to achieve sustained success.

QMP 2 - Getting your team involved in the management system

Management systems such as ISO 9001 are not just for senior management – everyone within your organisation contributes towards its processes. Openly discussing issues and sharing knowledge and experience with your team is therefore key if you want to fully benefit from your quality management ISO. It is essential that everyone in your company understands their role and feels valued for their contribution to its success. This will not only help you to achieve certification but will also demonstrate your organization's commitment to improving quality.

To help raise awareness of ISO 9001 and its benefits, you may want to consider some awareness training.

Creation of unity of purpose and direction and engagement of people enable an organization to align its strategies, policies, processes and resources to achieve its objectives.

Key benefits

- Increased effectiveness and efficiency in meeting the organization's quality objectives
- Better coordination of the organization's processes
- Improved communication between levels and functions of the organization
- Development and improvement of the capability of the organization and its people to deliver desired results

Actions you can take

- Communicate the organization's mission, vision, strategy, policies and processes throughout the organization.
- Create and sustain shared values, fairness and ethical models for behaviour at all levels of the organization.
- Establish a culture of trust and integrity.
- Encourage an organization-wide commitment to quality.
- Ensure that leaders at all levels are positive examples to people in the organization.
- Provide people with the required resources, training and authority to act with accountability.
- Inspire, encourage and recognize people's contribution.

QMP 3 - Develop a strong management team

Strong leadership means you have a clear vision of your company's future. Communicating this vision effectively will ensure your whole team works towards the same objectives, giving your organisation a shared sense of purpose. This can then help to increase employee motivation and productivity.

To manage an organization effectively and efficiently, it is important to involve all people at all levels and to respect them as individuals. Recognition, empowerment and enhancement of competence facilitate the engagement of people in achieving the organization's quality objectives.

Key benefits

- Improved understanding of the organization's quality objectives by people in the organization and increased motivation to achieve them

- Enhanced involvement of people in improvement activities and enhanced personal development, initiatives and creativity
- Enhanced people satisfaction and enhanced trust and collaboration throughout the organization leading to increased attention to shared values and culture throughout the organization

Actions you can take

- Communicate with people to promote understanding of the importance of their individual contribution.
- Promote collaboration throughout the organization and facilitate open discussion and sharing of knowledge and experience.
- Empower people to determine constraints to performance and to take initiatives without fear.
- Recognize and acknowledge people's contribution, learning and improvement and enable self-evaluation of performance against personal objectives.
- Conduct surveys to assess people's satisfaction, communicate the results, and take appropriate actions.

QMP 4 - Create a process culture

The Plan Do Check Act (PDCA) principle of the ISO 9001 Standard will help you promote a process-driven culture across your organisation. This is a proven way of ensuring you plan, resource and manage your processes and their interactions effectively.

By managing the different areas in your business together as a whole, you will be able to align operations for greater efficiency, making it even easier to achieve your objectives. Measuring and evaluating these interrelated processes will also help you to identify areas for improvement.

The quality management system consists of interrelated processes. Understanding how results are produced by this system enables an organization to optimize the system and its performance.

Key benefits

- Enhanced ability to focus effort on key processes and opportunities for improvement
- Consistent and predictable outcomes through a system of aligned processes
- Optimized performance through effective process management, efficient use of resources, and reduced cross-functional barriers
- Enabling the organization to provide confidence to interested parties as to its consistency, effectiveness and efficiency

Actions you can take

- Define objectives of the system and processes necessary to achieve them.
- Establish authority, responsibility and accountability for managing processes.
- Understand the organization's capabilities and determine resource constraints prior to action.
- Determine process interdependencies and analyses the effect of modifications to individual processes on the system as a whole.
- Manage processes and their interrelations as a system to achieve the organization's quality objectives effectively and efficiently.
- Ensure the necessary information is available to operate and improve the processes and to monitor, analyze and evaluate the performance of the overall system.
- Manage risks that can affect outputs of the processes and overall outcomes of the quality management system.

QMP 5 - Drive continual improvement

Continual improvement is essential to the ISO 9001 quality management system and should be your organization's core objective. Implementing processes for identifying risks and opportunities, spotting and solving non-conformities, and measuring and monitoring your efforts means that you will be able to find ways to improve and make your business even stronger.

Improvement is essential for an organization to maintain current levels of performance, to react to changes in its internal and external conditions and to create new opportunities.

Key benefits

- Improved process performance, organizational capabilities and customer satisfaction
- Enhanced focus on root-cause investigation and determination, followed by prevention and corrective actions
- Enhanced ability to anticipate and react to internal and external risks and opportunities
- Enhanced consideration of both incremental and breakthrough improvement
- Improved use of learning for improvement
- Enhanced drive for innovation

Actions you can take

- Promote establishment of improvement objectives at all levels of the organization.
- Educate and train people at all levels on how to apply basic tools and methodologies to achieve improvement objectives.
- Ensure people are competent to successfully promote and complete improvement projects.
- Develop and deploy processes to implement improvement projects throughout the organization.
- Track, review and audit the planning, implementation, completion and results of improvement projects.
- Integrate improvement considerations into the development of new or modified goods, services and processes.
- Recognize and acknowledge improvement.

QMP 6 - Base your decisions on facts

Accurate and reliable data is essential for making informed decisions. For instance, to solve the root cause of non-conformity you need the right evidence. Make sure information is available to those who need it and keep communication channels open.

Decision making can be a complex process, and it always involves some uncertainty. It often involves multiple types and sources of inputs, as well as their interpretation, which can be subjective. It is important to understand cause-and-effect relationships and potential unintended consequences. Facts, evidence and data analysis lead to greater objectivity and confidence in decision making.

Key benefits

- Improved decision-making processes
- Improved assessment of process performance and ability to achieve objectives
- Improved operational effectiveness and efficiency
- Increased ability to review, challenge and change opinions and decisions
- Increased ability to demonstrate the effectiveness of past decisions

Actions you can take

- Determine measure and monitor key indicators to demonstrate the organization's performance.
- Make all data needed available to the relevant people.
- Ensure that data and information are sufficiently accurate, reliable and secure.

- Analyze and evaluate data and information using suitable methods.
- Ensure people are competent to analyze and evaluate data as needed.
- Make decisions and take actions based on evidence, balanced with experience and intuition.

QMP 7 - Develop mutually beneficial relationships with suppliers

Your suppliers can be a source of competitive advantage but this requires a relationship built on trust. Creating such lasting relationships with suppliers and other interested parties means balancing short-term financial gains with long-term, mutually beneficial strategies.

Interested parties influence the performance of an organization. Sustained success is more likely to be achieved when the organization manages relationships with all of its interested parties to optimize their impact on its performance. Relationship management with its supplier and partner networks is of particular importance.

Key benefits

- Enhanced performance of the organization and its interested parties through responding to the opportunities and constraints related to each interested party
- Common understanding of goals and values among interested parties
- Increased capability to create value for interested parties by sharing resources and competence and managing quality-related risks
- A well-managed supply chain that provides a stable flow of goods and services

Actions you can take

- Determine relevant interested parties (such as suppliers, partners, customers, investors, employees, and society as a whole) and their relationship with the organization.
- Determine and prioritize interested party relationships that need to be managed.
- Establish relationships that balance short-term gains with long-term considerations.
- Pool and share information, expertise and resources with relevant interested parties.
- Measure performance and provide performance feedback to interested parties, as appropriate, to enhance improvement initiatives.
- Establish collaborative development and improvement activities with suppliers, partners and other interested parties.
- Encourage and recognize improvements and achievements by suppliers and partners.

Benefits of the Quality Principles

Implementing these seven quality principles during your ISO 9001 certification process can help you to meet key requirements of the Standard. This will then help you to improve customer satisfaction and loyalty, increase employee motivation and productivity, and your use of resources.

Continually strengthening your processes will also help you to improve your cost-efficiency and enable you to build market share by responding rapidly to new opportunities.

12.2 VALUE ENGINEERING AND ANALYSIS

Though the two terms are used synonymously and philosophy underlying is same unnecessary cost elimination, there is a difference between the two. The difference lies in time and the phase of product life-cycle at which the technique is applied.

Value Analysis is applied to the existing product with a view to improve its value. It is analysis after the fact and it is a remedial procedure. Value engineering is applied to the design stage and thus ensures prevention rather than elimination.

Value Engineering

Value Engineering (VE) is concerned with **new products**. It is applied during product development. The focus is on reducing costs, improving function or both, by way of teamwork-based product evaluation and analysis. This takes place before any capital is invested in tooling, plant or equipment. Value engineering should be considered a crucial activity late on in the product development process and is certainly a wise commercial investment, with regard to the time it takes. It is strongly recommended you build value engineering into your new product development process, to make it more robust and for sound commercial reasons.

Value Analysis

Value Analysis (VA) is concerned with **existing products**. It involves a current product being analyzed and evaluated by a team, to reduce costs, improve product function or both. Value Analysis exercises use a plan which step-by-step, methodically evaluates the product in a range of areas. These include costs, function, alternative components and design aspects such as ease of manufacture and assembly. A significant part of VA is a technique called **Functional Analysis**, where the product is broken down and reviewed as a number of assemblies. Here, the function is identified and defined for each product assembly. Costs are also assigned to each one. This is assisted by designing and viewing products as assemblies (or modules). As with VE, VA is a group activity that involves brainstorming improvements and alternatives to improve the value of the product, particular to the customer.

Origins of Value Engineering

The technique of value engineering had gained considerable momentum, during the Second World War. During the year 1947, Lawrence Miles, who was working for the American General Electric Company (GEC) became increasingly aware of the limitations of traditional cost reduction techniques. As a design engineer involved in cost reduction activities, was able to distinguish between what is good value and bad value and realized that very few people had a real grasp of good and bad value. He established that this is because of altogether a different approach. He evolved a set of tests that could be applied to any product either projected or being currently produced. Then he persuaded the management to try this technique which was already subjected to cost reduction exercises many times. The result was encouraging and soon the G. E. Company started using this to their products.

The technique soon spread to other American companies and later to Europe. It is now generally accepted by management as a powerful tool to ensure that unnecessary costs are not built into their products. The principle behind value analysis is that it is a functionally oriented method for improving product value by relating the various elements of product worth to their corresponding elements of cost. Thus value analysis allows the required functions to be performed at the minimum cost. To apply principles of value analysis effectively it is recommended that a systematic and rigorous approach is to be followed to ensure that no steps are omitted. Value engineering is a team approach. A team of people drawn from various specialist areas is found to be the best way to handle V. E. projects. The participating team members are drawn from design, purchase, production, accounts and marketing coordinated by an engineer belonging to any one of the above departments.

Uses of Value Engineering

- It is a cost prevention as well as cost elimination technique thus reducing cost of the product.
- Helps employees for better understanding of their jobs and oriented then towards creative thinking.
- Balance the cost and performance.
- Prevents over design of components.
- Motivates employees to come out with creative ideas.
- Increases the profits and deflates costs.
- Helps to satisfy the customer with company's products.

Steps in Value Analysis

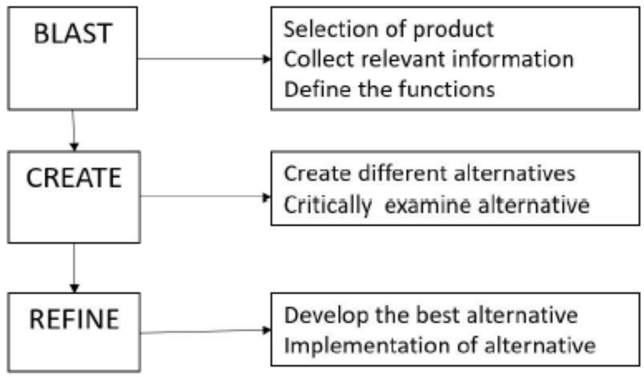

Fig.: Steps in Value Analysis

When to apply Value Analysis

One can expect very good results from application of value analysis at the proper time and correct phase of product life cycle. Value Engineering should be applied in case of the following indications:

- Company's products are losing in the market and there is a decline in sales.
- Company's products are priced higher than the competitors.
- New design of products being undertaken.
- Symptoms of disproportionate increase in cost of production.
- Decreasing profitability and return on investment.
- Company failing to meet its delivery commitment.

Benefits of Value Analysis

Value analysis is a methodical approach to sharpening the efficiency and effectiveness of any process. Often, businesses apply it to the processes used in product creation or service delivery. Paramount to the value analysis is the practice of breaking down a process into each individual component and considering ways to improve that component's value as measured by cost and importance to the process. General Electric developed value analysis during the late 1940s.

Eliminating Costs

A critical advantage to using value analysis is its potential for reducing costs, which is a benefit that permeates all advantages of the system. Because value analysis breaks down a product or service into components, it enables you to analyze each component on its own, evaluating its importance and efficiency. A value analysis correctly implemented and applied allows you to identify components that are not worth the cost they require and that can be eliminated or replaced with an alternative. In this manner, the process for the product or service being analyzed is refined to be done at less expense.

Modernizing

The value analysis process often allows users to root out practices that have grown out of date and can be replaced with more modern approaches. This is particularly beneficial when something has been done the same way for an extended period of time. Because the old way works and was new when it was instituted, you have had little impetus to make changes. However, a value analysis, which calls for questioning every step of a process, can reveal new methods that are cheaper, more efficient and sometimes more effective.

Design Flaws

Value analysis can uncover design flaws that not only operate inefficiently but also create problems. In the case of a product, this could mean a high rate of malfunctioning items, creating customer complaints and warranty claims that put a strain on personnel and inventory. It also can lead to bad publicity and damage to the product brand and the company producing it. Similarly, in the case of a service, value analysis can help pinpoint design flaws in the customer support system that causes service to fall short of customer expectations.

Customer Service

Value analysis is oriented to weigh costs and the benefit to customers of a product or service. It forces you to consider every aspect of a process in the context of how it serves the customer, which could be a consumer or another business. This means that each step in the process is scrutinized and questioned from the perspective of the benefit that it provides the customer. If the benefit to the customer is small and the step is not necessary for the product or service as a whole, it can be eliminated, allowing you to streamline your operation and to reduce the use of resources.

Ten Commandments of Value Analysis

i. Do not use a component or part that does not contribute to the value of the product.

ii. Do not use a component or part whose cost is not proportional to its usefulness.

iii. Do not provide any features to the component or finished product that are not absolutely necessary.

iv. Accept the change if part of the required quality can be made out of cheaper and easily available material.

v. If the part of required quality is made by a process or method costing less, then do use the alternative process or method.

vi. Use standard parts wherever possible.

vii. Use proper tooling and manufacturing methods taking into consideration the quantities,

viii. The cost of the component used should be proportional to its use or function.

ix. Use the material, part best suited for the purpose.

x. Purchase the part instead of manufacturing in house, if suitable supplier can provide the part of good quality at the reasonable price.

12.3 LET US SUM UP

In this unit, the concept of a quality management system (QMS) as a set of policies, processes and procedures required for planning and delivering (production/development/service) in the core business area of an organization of any kind and size is explained and the ISO standard 9001 as a set of requirements that define the implementation and maintenance of a quality management system for a company is discussed in detail/

Value Engineering and Value Analysis is the systematic application of recognized techniques by a multi-disciplined team which identifies the function of a product or services; establishes a worth for that function; generates alternatives through the use of creative thinking; and provides the needed functions to accomplish the original intent of the project, reliably and at the lowest life-cycle without sacrificing project requirements for safety, quality, operations, maintenance and environment.

12.4 EXERCISES

1. Give historical review of ISO 9000 family of standards.
2. Discuss seven principles of quality management.
3. Differentiate between value analysis and value engineering.
4. Explain the steps in value analysis.

12.5 SUGGESTED READING

- Operations & Supply Chain Management by Chase, Shankar, Jocaobs
- Operations Management (6th Edition) by Nigel Slack, Stuart Chambers, Robert Johnston
- Theory & Problems in Production & Operations Management- S N Chary, Tata McGraw Hill
- Production & Operations Management -Kanishka Bedi , Oxford University Press
- Operations Management for competitive advantage-Chase & Jacob, McGraw-Hill/Irwin
- Production and Operations Management- Chunawalla & Patel, Himalaya Publishing

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13

INTRODUCTION TO SUPPLY CHAIN MANAGEMENT

Unit Structure

13.0 OBJECTIVES

After studying this unit, you will be able to understand the concepts of:

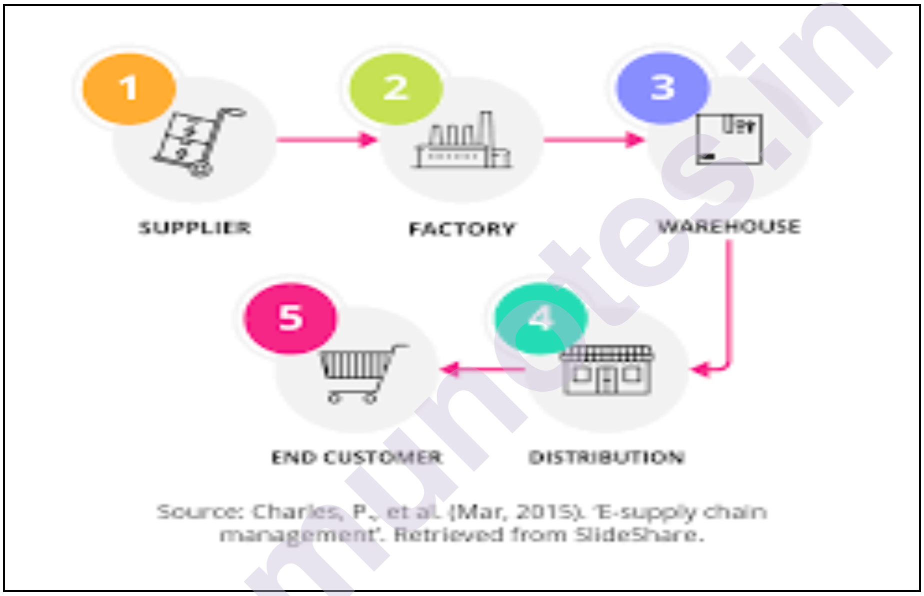
- What is supply chain management?
- Stages/ Key components in supply chain management
- Key Decision Areas in Supply chain Management
- Importance of supply chain management
- Pull v/s Push supply chain
- The Bullwhip Effect
- External Drivers of Supply Chain Performance
- Logistics system analysis

13.1 WHAT IS SUPPLY CHAIN MANAGEMENT?

The network created amongst different companies producing, handling and/or distributing a specific product is called supply chain. Specifically, the supply chain encompasses the steps it takes to get a good or service from the supplier to the customer. Supply chain management is a crucial process for many companies, and many companies strive to have the most optimized supply chain because it usually translates to lower costs for the company. Quite often, many people confuse the term logistics with supply chain. In general, logistics refers to the distribution process within the company whereas the supply chain includes multiple companies such as suppliers, manufacturers, and the retailers.

Supply chain management (SCM) is the management of the flow of goods. It includes the movement and storage of raw materials, work-in-process inventory, and finished goods from point of origin to point of consumption. Interconnected or interlinked networks, channels and node businesses are involved in the provision of products and services required by end customers in a supply chain.

Supply chain management has been defined as the "design, planning, execution, control, and monitoring of supply chain activities with the objective of creating net value, building a competitive infrastructure, leveraging worldwide logistics, synchronizing supply with demand and measuring performance globally.



13.2 STAGES/ KEY COMPONENTS IN SUPPLY CHAIN MANAGEMENT

Supply chain management (SCM) is a process used by companies to ensure that their supply chain is efficient and cost-effective. A supply chain is the collection of steps that a company takes to transform raw components into the final product. The following are five basic components of SCM.

- Plan
- Develop (Source)
- Make
- Deliver
- Return.

1) **Plan**

The first stage in supply chain management is known as plan. A plan or strategy must be developed to address how a given good or service will meet the needs of the customers. A significant portion of the strategy should focus on planning a profitable supply chain.

This is the strategic portion of SCM. Companies need a strategy for managing all the resources that go toward meeting customer demand for their product or service. A big piece of SCM planning is developing a set of metrics to monitor the supply chain so that it is efficient, costs less and delivers high quality and value to customers.

2) **Develop (Sourcing/ suppliers)**

Develop is the next stage in supply chain management .It involves building a strong relationship with suppliers of the raw materials needed in making the product the company delivers. This phase involves not only identifying reliable suppliers but also planning methods for shipping, delivery, and payment.

Companies must choose suppliers to deliver the goods and services they need to create their product. Therefore, supply chain managers must develop a set of pricing, delivery and payment processes with suppliers and create metrics for monitoring and improving the relationships. And then, SCM managers can put together processes for managing their goods and services inventory, including receiving and verifying shipments, transferring them to the manufacturing facilities and authorizing supplier payments.

3) **Make (production and operations)**

At the third stage, make, the product is manufactured, tested, packaged, and scheduled for delivery. This is the manufacturing step. Supply chain managers schedule the activities necessary for production, testing, packaging and preparation for delivery. This is the most metric-intensive portion of the supply chain - one where companies are able to measure quality levels, production output and worker productivity.

4) **Delivery (distribution/ logistics)**

Then, at the logistics phase, customer orders are received and delivery of the goods is planned. This fourth stage of supply chain management stage is aptly named deliver.

This is the part that many SCM insiders refer to as logistics, where companies coordinate the receipt of orders from customers, develop a network of warehouses, pick carriers to get products to customers and set up an invoicing system to receive payments.

5) **Return (customer service)**

The final stage of supply chain management is called return. As the name suggests, during this stage, customers may return defective products. The company will also address customer questions in this stage.

This can be a problematic part of the supply chain for many companies. Supply chain planners have to create a responsive and flexible network for receiving defective and excess products back from their customers and supporting customers who have problems with delivered products.

13.3 KEY DECISION AREAS IN SUPPLY CHAIN MANAGEMENT

To ensure that the supply chain is operating as efficient as possible and generating the highest level of customer satisfaction at the lowest cost, companies have adopted Supply Chain Management processes and associated technology. Supply Chain Management has three levels of activities that different parts of the company will focus on: strategic; tactical; and operational.

1. **Strategic**

   At this level, company management will be looking to high level strategic decisions concerning the whole organization, such as the size and location of manufacturing sites, partnerships with suppliers, products to be manufactured and sales markets.

   Strategic activities include building relationships with suppliers and customers, and integrating information technology (IT) within the supply chain.

2. **Tactical**

   Tactical decisions focus on adopting measures that will produce cost benefits such as using industry best practices, developing a purchasing strategy with favored suppliers, working with logistics companies to develop cost effect transportation and developing warehouse strategies to reduce the cost of storing inventory.

   Studying competitors and making decisions regarding production and delivery would fall under the tactical category.

3. **Operational**

   Decisions at this level are made each day in businesses that affect how the products move along the supply chain. Operational decisions involve making schedule changes to production, purchasing agreements with suppliers, taking orders from customers and moving products in the warehouse.

   The operational category includes the daily management of the supply chain, including the making of production schedules.

13.4 IMPORTANCE OF SUPPLY CHAIN MANAGEMENT

To remain competitive, small firms have to offer superior quality goods at the lowest prices possible. The need to minimize product costs makes effective supply chain management vital. There are costs involved in every process of the product life cycle, and it is the responsibility of management to ensure that these costs are kept low, so the company can continue to pass along these savings to the consumer.

1. **Reduced Costs**

   Supply chain management involves identifying those processes that increase cost without increasing the value of the final product. These processes are wasteful and do not add value, and should be eliminated whenever possible.

2. **Increased Efficiency**

   Resource wastage is a common source of increase production costs. Often this is due to improper planning. A company that employs supply chain management is able to achieve efficiency of its operations since only that value adding activities are encouraged. This ensures that the organization's processes flow smoothly and output keeps inline with the company's needs.

3. **Increased Output**

   A company that employs supply chain management can foster close-knit relationships with its suppliers and customers, ensuring the timely fulfillment of orders. A company known for its timeliness and responsiveness will attract more customers, and will grow as a result of increased output and sales.

4. **Increased Profits**

   Businesses exist to make profits. One of the most efficient ways of increasing a company's profits is by ensuring that costs are kept as low as possible. The application of supply chain management by a small company leads to cost reductions due to elimination of wasteful processes. Since these are operating costs for the company, the savings on these costs reflect increased profits by the company.

13.5 PULL V/S PUSH SUPPLY CHAIN

Under pull supply chain, products are manufactured or procured based on specific customer requests. We also know it as "Built to Order" or "Configured to Order" model. We often see this model operating in IT/High Tech Industries, where customization is the competitive advantage. Briefly, we have seen this model in automotive industry and it is being used in high end luxury market segment. The objective of this model is to minimize the Inventory carrying and optimize supply. Pull model is as a response to growing uncertainty in demand and short product cycle.

Some of the characteristics of this model include:

1. Volatile demand situation
2. High rate of Customization
3. Minimal Inventory Carrying
4. Not a off the shelf product
5. Highly dynamic and effective distribution network.

Under Push model, products are manufactured or procured based on anticipated customer orders (speculative). This model is also known as Built to Inventory or Built to Stock. The name itself reveals its functionality. Products are manufactured in anticipation of customer needs. There are no prizes for identifying industries that use push model, it is obvious that retail heavily uses push model. Even though direct to store or cross docks are implemented, overall retail supply chain is based on push model. Some of the big names in the retail industry are trying to adopt the hybrid model which is a combination of pull and push.

Some of the key challenges and characteristics could include:

1. High inventory costs,
2. Challenging working capital requirements due to low inventory turns;
3. Huge warehousing and distribution costs;
4. Inability to meet dynamic market conditions and
5. Seasonal demand and off the shelf product.

13.6 THE BULLWHIP EFFECT

The bullwhip effect can be explained as an occurrence detected by the supply chain where orders sent to the manufacturer and supplier create larger variance then the sales to the end customer. These irregular orders in the lower part of the supply chain develop to be more distinct higher up in the supply chain. This variance can interrupt the smoothness of the supply chain process as each link in the supply chain will over or underestimate the product demand resulting in exaggerated fluctuations.

Causes of the Bullwhip Effect

Sources of variability can be demand variability, quality problems, strikes, plant fires, etc. Variability coupled with time delays in the transmission of information up the supply chain and time delays in manufacturing and shipping goods down the supply chain create the bullwhip effect.

The following all can contribute to the bullwhip effect:

1. Overreaction to backlogs
2. Neglecting to order in an attempt to reduce inventory
3. No communication up and down the supply chain

4. No coordination up and down the supply chain
5. Delay times for information and material flow
6. Order batching: larger orders result in more variance. Order batching occurs in an effort to reduce ordering costs, to take advantage of transportation economics such as full truck load economies, and to benefit from sales incentives. Promotions often result in forward buying to benefit more from the lower prices.
7. Shortage gaming: customers order more than they need during a period of short supply, hoping that the partial shipments they receive will be sufficient.
8. Demand forecast inaccuracies: everybody in the chain adds a certain percentage to the demand estimates. The result is no visibility of true customer demand.
9. Free return policies

How to reduce Bullwhip Effect?

While the bullwhip effect is a common problem, many leading companies have been able to apply countermeasures to overcome it. Here are some of these solutions:

1. **Countermeasures to order batching** - High order cost is countered with Electronic Data Interchange (EDI) and computer aided ordering (CAO). Full truck load economics are countered with third-party logistics and assorted truckloads. Random or correlated ordering is countered with regular delivery appointments. More frequent ordering results in smaller orders and smaller variance. However, when an entity orders more often, it will not see a reduction in its own demand variance - the reduction is seen by the upstream entities. Also, when an entity orders more frequently, its required safety stock may increase or decrease; see the standard loss function in the Inventory Management section.

2. **Countermeasures to shortage gaming** - Proportional rationing schemes are countered by allocating units based on past sales. Ignorance of supply chain conditions can be addressed by sharing capacity and supply information. Unrestricted ordering capability can be addressed by reducing the order size flexibility and implementing capacity reservations. For example, one can reserve a fixed quantity for a given year and specify the quantity of each order shortly before it is needed, as long as the sum of the order quantities equals to the reserved quantity.

3. **Countermeasures to fluctuating prices** - High-low pricing can be replaced with everyday low prices (EDLP). Special purchase contracts can be implemented in order to specify ordering at regular intervals to better synchronize delivery and purchase.

4. **Countermeasures to demand forecast inaccuracies** - Lack of demand visibility can be addressed by providing access to point of

sale (POS) data. Single control of replenishment or Vendor Managed Inventory (VMI) can overcome exaggerated demand forecasts. Long lead times should be reduced where economically advantageous.

5. **Free return policies are not addressed easily**. Often, such policies simply must be prohibited or limited.

13.7 EXTERNAL DRIVERS OF SUPPLY CHAIN PERFORMANCE

Inventory

1. All of the raw materials, work in process (WIP), and finished goods within the supply chain. Inventory policies can dramatically alter a supply chain's efficiency and responsiveness.
2. Why hold inventory?(3 reasons)

   >Unexpected changes in customer demand (always hard to predict, and >uncertainty is growing)

   >Short product life cycles

   >Product proliferation

   >Uncertain supply
3. Inventory's Impact Inventory can increase amount of demand that can be met by increasing product availability. Inventory can reduce costs by exploiting economies of scale in production, transportation, and purchasing. Inventory can be used to support a firm's competitive strategy. More inventory increases responsiveness, less inventory increases efficiency (reduces cost).

Transportation

1. Faster transportation allows a supply chain to be more responsive but generally less efficient. Less than full truckloads allow a supply chain to be more responsive but generally less efficient.

2. Transportation can be used to support a firm's competitive strategy. Customers may demand and be willing to pay for a high level of responsiveness.

3. Mode of transportation is the manner in which a product is moved (air, truck, rail, ship, pipeline, electronic). Each mode differs with respect to speed, size of shipments, cost, and flexibility.

4. Routes are paths along which a product can be shipped.

5. In house or outsource the transportation function. Many companies use third-party logistics providers (3PL) to perform some or all of their transportation activities.

Facilities

1. Places within the supply chain where inventory is stored, assembled, or fabricated. Decisions on location, capacity, and flexibility of facilities have a significant impact on performance.
2. Facilities Impact: Facilities either store inventory between supply chain stages (warehouses, distribution centers, retailers) or transform inventory into another state (fabrication or assembly plants).
3. Centralization of facilities uses economies of scale to increase supply chain efficiency (fewer locations and less inventory) usually at the expense of responsiveness (distance from customer)
4. Facility Decisions Location: Centralize to gain economies of scale or decentralize to be more responsive. Other issues include quality and cost of workers, cost of facility, infrastructure, taxes, quality of life, etc. Capacity. Excess capacity allows a company to be more responsive to changes in the level of demand, but at the expensive of efficiency.

Information

1. Data and analysis regarding inventory, transportation, facilities, and customers throughout the supply chain. It is potentially the biggest driver since it affects all the other drivers.
2. Information's Role: Information connects various supply chain stages and allows them to coordinate activities. Information is crucial to the daily operations of each stage of the supply chain. An information system can enable a firm to get a high variety of customized products to customers rapidly .An information system can enable a firm to understand changing consumer needs more.

Dimensions of logistics -Macro Perspective& macro dimension

- Logistics impacts and has relationship with economy
- Cost of business logistics increasing
- Percentage of GDP decreasing
- Transportation largest percentage of logistics costs (rising due to inventory management practices)
- Logistics adds value to a product
- Place utility - moving goods to points where demand exists
- Time utility - moving goods to points at a specific time
- Allows for economic development and specialization
- Affects land values due to increased accessibility

13.8 LOGISTICS SYSTEM ANALYSIS

Logistics analysis has been viewed as an important element in the corporate strategy of many organizations. Logistics refers to a process that is associated with flow of information, goods, and services offered to suppliers and customers from the point of origin to the point of destination. It is commonly the complete process that starts from raw materials to the final disposal or sale of the finished goods.

An effective and efficient logistics system is created to meet the requirements of the customers for timely responsiveness, quality and creating value for products and services.

The modern day competitive environment has encouraged firms to reformulate their corporate strategies concerning supply chain management. Global orientation is often favored by many firms for handing the complexities of relationships around the supply chain management when it comes to maintaining relationships with customers and suppliers from different geographic locations. There is an urgent need for striking a balance between the costs of servicing customers with the need to generate customer value, and logistics analysis can help to define that balance point.

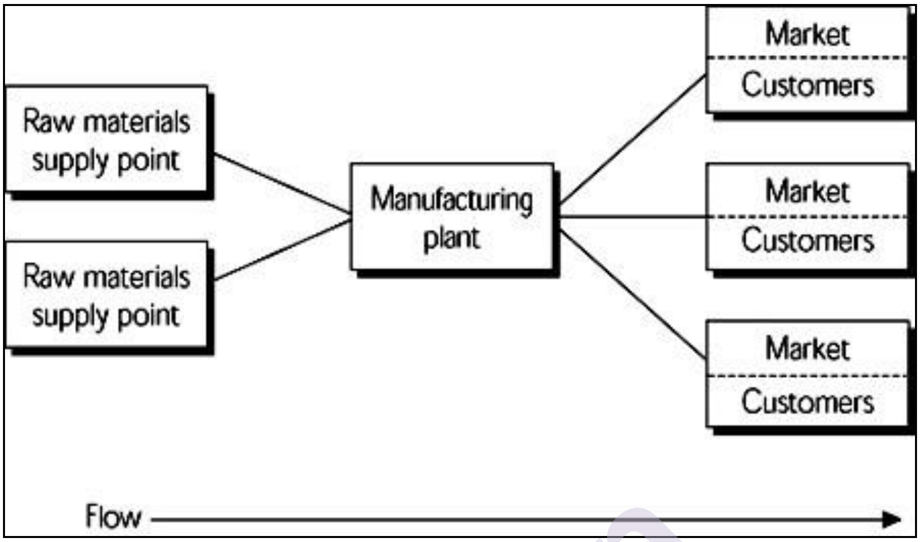
The optimization of plans and procedures paves the way for creating an everlasting and sustainable competitive advantage for the organization throughout the supply chain. There is a need for the integration of the business processes of the organization with its technological systems for the purpose of enhancing speed, organizational responsiveness, and flexibility in the networks of customers and suppliers.

Logistics analysis involves the use of numerous quantitative techniques on the part of the organization while still giving importance to operational research. It involves logistical aspects such as network design, forecasting, inventory control and warehousing. The purpose of the analysis is planning and managing of the efforts to measure the logistics impact of the changes proposed by logistics management.

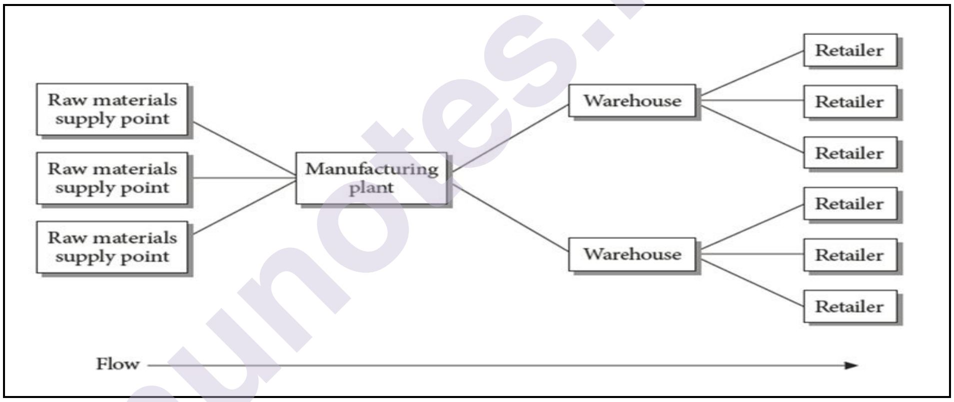
Logistics analysis consists of the integration of inventory, facility location, transportation, packaging activities, and informational flow for the purpose of managing an effective physical movement of outbound and inbound goods and services in a competitive environment. The complete cost and system approach are developed for planning and managing the various logistical functions that are prevalent within the organization. It may be dependent on the techniques of basic sampling and data analysis. This may involve the use of questionnaires and online or electronic ways of gathering information.

This is all based on an application of several tools that are beneficial in the field of logistics analysis. It also includes examination of several features of the logistical system and the development of skills helpful in analyzing numerous technical logistical issues.

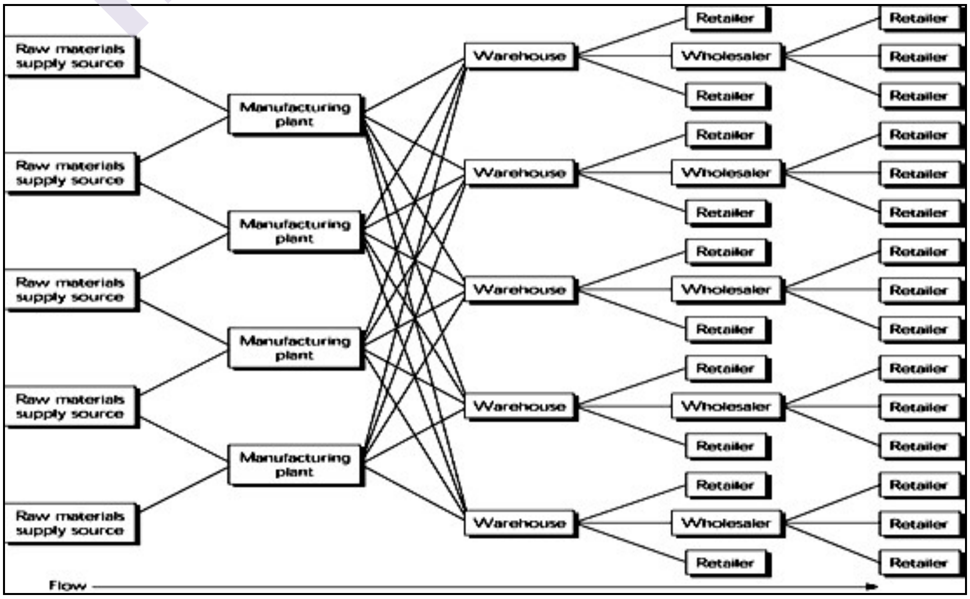
Simple Logistics Channel



Multi-Echelon Channel



A Complex Logistics Channel



13.9 LET US SUM UP

In this unit the concepts of SCM, its key decisions and components, external drivers of change, dimensions of logistics and logistics system analysis are discussed.

13.10 EXERCISES

1. What do you understand by supply chain management? Explain with one example.
2. Discuss the stages or key components in supply chain management.
3. What are the key decision areas in supply chain management
4. What is a Pull v/s Push supply chain? Explain with one example.
5. Discuss The Bullwhip Effect.
6. Explain the external drivers of supply chain performance.
7. Discuss the importance of logistics system analysis

13.11 SUGGESTED READING

- Operations & Supply Chain Management by Chase, Shankar, Jocaobs
- Operations Management (6th Edition) by Nigel Slack, Stuart Chambers, Robert Johnston
- Theory & Problems in Production & Operations Management- S N Chary, Tata McGraw Hill
- Production & Operations Management -Kanishka Bedi , Oxford University Press
- Operations Management for competitive advantage-Chase & Jacob, McGraw-Hill/Irwin
- Production and Operations Management- Chunawalla & Patel, Himalaya Publishing

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