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OPERATIONS MANAGEMENT

STRUCTURE

1.0 INTRODUCTION

The origins of Operations Management can be traced back to the Industrial Revolution, the same as Scientific Management and Operations Research. In the past centuries human beings have been creating utilities to meet their requirements through conversion process. These conversion processes take input as labour, material, machinery, equipment, energy, and management, etc,. to create products and services.

Adam Smith (1776), a Scottish economist revealed scientific operations management by incorporating division of labour in his book "The Wealth of Nations". He advocated specialization of work or tasks to improve production efficiency and save time (Smith, Adam, 2002). Charles Babbage (1835) followed the specialization concept of Adam Smith and published his book "The Economy of Machinery and Manufacture" to explain raw material control, power regulation, labour division, lot size manufacture, inventory control, division of labour, time study, and replacement of machinery for better handling of production problems (Charles Babbage, 1835). Frank Gilbreth, an American Engineer, also known as the father of work study published his books, "Motion Study" and "Applied Motion Study" to explain the link between physical effort and output. He classified motions in 17 categories, known as Therbligs. Many pioneers have also contributed extensively to the field of operations management like Henry Ford (1913) discovered assembly line balancing, Henry Gantt (1913)-Gantt Charts, F.W. Harris (1914)-Economic Order Quantity, Walter Shewhart (1924)- Statistical Quality Control, F.H. Doge (1931)-Statistical Sampling Tables, and L.H. C. Tippet (1937)-Work Sampling, Maynard, Schwab and Stegemerten (1940)-Method -time measurement (Sheldrake, John, 2003).

However, the formulas regarding input-output relations remained unexplored before Frederic W. Taylor. In his early work Taylor conducted series of measurements, experiments to develop formulas to deal with cutting of metals to produce products or create utilities. He extensively focused on "differential piece-rate system" to rate worker performance on the fronts of efficiency and effectiveness. The efficiency focused on higher productivity whereas higher quality focused on effectiveness (Taylor, 1906, 1903). In 1911 Taylor has published a book on "The Principles of Scientific Management" advocating scientific management as a means to find solution to the production related problems. Frank and Gilbreth discovered "time and motion study" for better efficiency, safety and satisfaction of workers. With the addition of "standard time" the work methods were improved. The "methods engineering" has integrated these approach to be applied today to the service as well as service sectors (Krick, 1962). During the Second World War many researchers have contributed and evolved the field of operations research such as Dantzig (1947)-Simplex Method, Taiichi Ohno (1943)- Just-in-Time, Deming, Juran and Feigenbaum (1950)-Total-Quality Management (TQM), Kaoru Ishikawa (1968)-Quality Management Systems and present era is of quality management systems (QMS) and quality standards.

The need of operations Management is originated because of the competitive measures like cost, quality, time and variety. Because till 1960, the focus was on cost but after 1980's the shift has been changed to delivery, flexibility and customization which ultimately took the shape of disciple called operations management. The meaning of the term "Production" and "Production management" should be noted carefully. "Production" involves the step-by-step conversion of one-form of materials into another through chemical or mechanical processing to create or enhance the utility of the products or services. These days therefore both manufacturing and service organizations fall into the scope of production management. Thus production management which was formerly considered as- manufacturing management' only, now after inclusion of services into its scope, is broadly known as operations management. Many non- manufacturing organizations providing services like hospitals, banks, transportation, farming, warehousing etc. are now covered by operations management. Operations management is an area of business that is concerned with the production of goods and services, and involves the responsibility of ensuring that business operations are efficient and effective. It is the management of resources, the distribution of goods and services to customers, and the analysis of queue systems. An operation by formal definition is a process of changing inputs into outputs, with the creation or adding of value to some entity. The process of alteration or transportation or storage or inspection or “any combination thereof t6add value to an entity is rightly called operations. The growth of service in (industry has brought with it the term 'operations management'.

Operations in the services organizations have some unique features, different from those which has manufacturing base. These are :

(1) Non-inventoriable output of service, since generally no stock is produced.

(2) Variable demand.

(3) Labour-intensive operations mostly.

(4) Location of service is dictated by the location of the users.

Production and Operations Management-("POM") is about the transformation of production and operational inputs into "outputs" that, when distributed, meet the needs of customers.

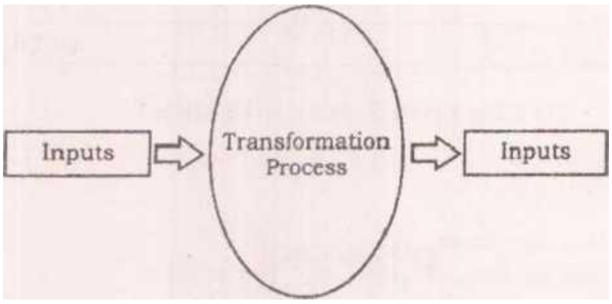

Figure 1.1: Conversion process

The process in the above diagram is often referred to as the "Conversion Process".

1.1 SCOPE OF OPERATIONS MANAGEMENT

Basically, this discipline has to decide about a production/operation system to generate customer satisfaction at optimum cost. As such, there are certain long-term strategic decisions involved, influencing substantially the whole system. Mostly these decisions are with respect to the Design and Planning aspects.

Product Selection and Design : The product mix makes our system either efficient or inefficient. Choosing the right products, keeping the mission and overall objectives in mind is the key to success. Design of the product, which gives it enough functional and aesthetic value, is of paramount importance.

It is the design of the product which makes us competitive or non-competitive. Value engineering does help us to retain enough of features, while eliminating the unnecessary cost increasing features.

Process Selection and Planning : Selection of a process involves taking decisions about technology, machines and equipment. We have to optimize the output from a given process. Process planning, detailing the stages of the process, gives us an idea of optimum automation and mechanization.

Facilities Location : Where can we locate our operations/production? It commits us ala location for a long time. So a wrong decision may prove disastrous. Location should as far as possible cut down on production and distribution cost. Therefore, from the alternatives open to us, we have to evaluate and judge a suitable location for us. While evaluating, there are diverse factors to be considered.

Facilities Layout and Materials Handling : Plant layout deals with the arrangements of machines and plant facilities. The machines should be so arranged that the flow of production remains smooth. There should not be over-: lapping, duplication or interruption in production flow. Product layout, where machines are arranged in a sequence required for the processing of a particular product, and process layout, where machines performing the similar processes are grouped together - are two popular methods of layout. The departments are laid out in such a way that the cost of material handling reduced. There should be proper choice of materials handling equipment. These days, computer software is available for planning the process lay-out (e.g. Craft, CORELAP etc.). Group Technology (GT.), Cellular Manufacturing Systems (CMS) and Flexible Manufacturing Systems (FMS) have made our concepts of layout planning undergo a tremendous change.

Capacity Planning : This deals with the procurement of productive resources. Capacity refers to a level of output of the conversion process over a period of time. Full capacity indicates maximum level of output. Capacity is planned for short-term as well as for long-term. Process industries pose challenging problems in capacity planning, requiring in the long run, expansion and contraction of major facilities in the conversion process. Some tools that help us in capacity planning are marginal costing (BEA), learning curves, linear programming, and decision trees.

1.2 OPERATIONS MANAGEMENT AS INTER FUNCTIONAL IMPERATIVE

Operations management draws upon ideas from engineering, management and mathematics and is closely related to several other fields in the decision sciences - applied mathematics, computer science, economics, industrial engineering, and systems engineering.

Production Management and Engineering : Mostly production engineering and management are confused with each other; Production management, as we. have observed at the beginning of this chapter, is involved in a conversion process, and its management. Production engineering is an advisory function. It provides expert support to run the equipments and carry out process technologies. Production management is a business function, and is not just an engineering function. In small businesses, perhaps both function may merge with each other, but it is just an exception. Production management provides business orientation to the organization.

Operations Management and Operations Research : Both operations management and operations research have a common term 'operations'. It is also true that most of the operations research techniques are used in the area of operations management. Operations research techniques are optimising techniques e.g., linear programming and are used extensively in production function. Though they have been treated in books of production management in pre-1980 period, their role and relevance have now been questioned in production management area, though a few of these techniques still cast their shadow on this area.

Operations Management and Strategic Planning : In the late forties and early sixties, planning was more or less production-oriented, since the output that was available would be easily sold off. During late sixties to early eighties, marketing occupied the centre stage, as companies experienced that selling products have become increasingly difficult. Planning thus became marketing-oriented. By early 80's and during the concluding decade of this century, both marketing and finance started to drive the strategy formulation. There are corporate failures, and financial problems. This led to finance contributing a great deal to strategy formulation. Operations Management and Sales Management: Production interfaces with several other departments. Sales department provides the present demand position and the future sales forecast to form the basis of production planning. Design gives an idea as to how the product should look like.

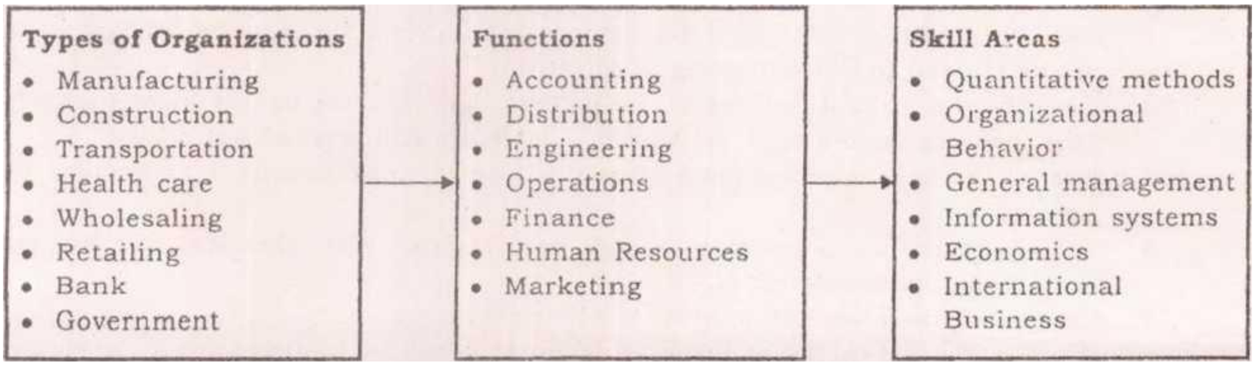

Figure 1.2: Organizations, functions and skill areas

Operations management focuses on the transformation of input into outputs. These outputs shall be products or services. It is defined as systematic design, direction, and control of processes to transforms inputs into outputs to satisfy demands of internal and external customers for products and services. The transformations process can be linked to one another to form a supply chain. These supply chain focus on integration of upstream (supplier-side) and downstream (customer-side) business activities to better serve customers. Various functions of operations management are as follow:

1. Operations planning: This function is foundation of operations management. It mainly focuses on production planning, monitoring, controlling and keeping teams informed, and motivated. Operations managers focus on operational efficiency using effective and efficient operations strategy to remove bottlenecks in the flow of production processes.

2. Financial planning: Financial resources availability and planning is also an important function of operations management. The major focus here is on the budget planning for allocation of resources to meet operational objectives.

3. Product design & development: Product design and development function helps in providing better utilities to the customers considering cost, quality, availability, etc. to compete in the market. Product design refers to designing a new product where as product development focuses on the modification or development of existing products. Product managers need to consider market trends and communicate to product design team to capture better market share. Data analyst can help product design team to know more about customer preferences and products available in the market.

4.Quality control: Quality control function focuses on the standards to produce products or provide services. Operations function focuses on risk, quality standards, quality testing, recording deficiencies and control defects.

5. Demand forecasting: Demand forecasting function helps to know in advance the requirements of products or services as well as internal operational needs. Operations managers also conduct market analysis for specific product or market segment demands. Knowing demands in advance operations managers plan internal business operations to produce as per demand.

6. Strategy development: Operations strategy is a mean to achieve goals and objectives of the operations function. Managers can collaborate, improve, control costs, control inventory, prioritize process to gain competitive advantage.

7. Supply chain management: Supply chain function focuses on the integration of upstream and downstream business activities by focusing on suppliers, raw materials, transformation processes, distribution and customers receipts as well as returns.

Operations management plays an important role in the success of business. It plays a vital role to motivate, develop, and keep team members informed. Here, the focus is to fit the right person at the right time on the right job for successful completion of work packages. The operations managers manage resources to meet various timely operational need at minimum cost, mitigating wastages to improve productivity.

1.3 OPERATIONS STRATEGY

Operations strategy focuses on the means by which operations implement the firm's corporate strategy. Basically, operations strategy links long and short term operations decisions to corporate strategy. Developing a customer-driven operations strategy begins with corporate strategy which coordinates the firm's overall goals with its core competencies. It determines which customers the firm will serve, which new products or services it will produce, which responses it will take to changes in its business and socioeconomic environment. Based on the corporate strategy, a market analysis categorizes the firm's customers, identifies their needs and assesses competitors' strength. The competitive priorities and the directives from corporate strategy provide input for the functional strategies, or the goals and long term plans of each functional area. The input along with the current status and capability of each area, is fed back into the corporate strategic planning process to indicate whether corporate strategy should be modified.

An operations strategy includes all the strategic decisions made by operations managers. It defines the overall policies for operations and gives the framework for more detailed operations management decisions. The operations strategy forms a link between the more abstract strategic plans and the final products. While the corporate and business strategies describe general aims the operations strategy designs the products and processes that can achieve these. The operations strategy is really concerned with matching what the organization is good at with what the customer wants. It answers questions such as the following :

- What type of products do we make?
- How wide a range of products do we offer?
- What types of process do we use?
- What technology do we use?
- How do we maintain high quality?
- What geographical areas do we work in?

1.3.1 DESIGNING AN OPERATIONS STRATEGY

A reasonable approach in designing an operations strategy includes following steps :

1. Analyze the business strategy and other strategies from an operations viewpoint. This gives the context and overall aims of the operations strategy.

2. Understand the market in which the operations strategy must work. This shows the kind of product that customers want as well as the volume, range and flexibility.

3. Find the factors that will lead to success in this market and the importance of each one. This defines the qualifying factors, and shows the general features that products need in order to compete effectively.

4. Describe the general features of the process that can best deliver these products. This includes factors such as capacity, flexibility and level of technology.

5. Design the best organizational structure, controls and functions to support the process.

6. Define measures to compare actual performance with planned, optimal and competitors' performance.

7. Continually monitor and improve actual performance.

Continuous cross-functional interaction must occur in implementing operations strategy. For example, operations need feedback from marketing to determine how much capacity to allocate to various product lines, and operations must work with finance regarding the timing and funding of increased capacity. Thus, in identifying the operational capabilities needed for the future, the operations manager must work closely with the managers of other functional areas.

1.4 TYPES OF MANUFACTURING SYSTEMS

One of the first decisions a manager makes in designing a well-functioning process is to choose a process type that best achieves the relative importance placed on quality, time, flexibility and cost. Manufacturing processes can be classified as core processes and support processes. Core processes focuses on external users or customers of products and services. Managers interact with external customers for developing new products, management of orders, and better customer and supplier relations to identify, attract, retain and delight customers. Customer reviews and feed-backs are incorporated for better customer value to the price paid. Support process play a vital role in the management of business to achieve its goals. Operations managers need support of human resources, accounting, finance, marketing and management information system for efficient execution of operations. These business functions support operations by searching and allocating right job to the right person at the right time.

The best way of classifying processes is by the frequency with which products change. At one extreme are continuous flows, like an oil refinery or electricity supply, which make the same product without any changes and at other extreme are projects that make a single unique product like shipbuilding or writing a book.

The types of processes are as follows :

- Project
- Job shop
- Batch
- Line, and
- Continuous

These types of processes are found in manufacturing and services organizations alike. The best choice for a process depends on the volume and degree of customization required of the process. A process choice might apply to an entire process or just one sub-process within it. The production process used to manufacture a product moves through a series of stages, much like the stages of products and markets, which begins with a highly flexible, high-cost process and progresses toward increasing standardization, mechanization, and automation, culminating in an inflexible but cost-effective process. The process life cycle dimension describes the process choice (job shop, batch, assembly line, and continuous flow) and process structure (jumbled flow, disconnected line flow, connected line flow and continuous flow) while the product structure/product life cycle describes the four stages of the product life cycle (low volume to high volume) and product structure (low to high standardization).

1.4.1 PROCESS CHOICES

Project: A project process is characterized by a high degree of job customization, the large scope of each project, and the release of substantial resources once a project is completed. The sequence of operations and the process involved in each are unique to the project, creating one-of-a-kind products or services made specifically to customer order. Project processes are valued on the basis of their capabilities to do certain kinds of work rather than their ability to produce specific products or services. Projects typically make heavy use of certain skills and resources at particular stages and then have little use for them the rest of the time. These include large-scale, one-time, unique products such as civil-engineering contracts, aerospace programs, construction, etc. They are also customer-specific and often too large to be moved, which practically dictates that project is the process of choice.

Job Shop: If a manufacturer had broken a large cog on an outdated (i.e., replacement parts are no longer available) but still useful machine, he would take the broken cog to a machine shop where they would manufacture a new one from scratch. This machine shop (along with tool and 'die manufacturers) is probably the primary example of manufacturing job shops. A job shop is the producer of unique products; usually this product is of an individual nature and requires that the job shop interpret the customer's design and specifications, which requires a relatively high level of skill and experience. Once the design is specified, one or a small number of skilled employees are assigned to the task and are frequently responsible for deciding how best to carry it out. Generally, resources for processing have limited availability with temporary in-process storage capability needed while jobs wait for subsequent processing. If the product is not a one-time requirement, it, is at least characterized by irregular demand with long periods of time between orders. Efficiency is difficult since every output must be treated differently. In a job shop, the outputs differ significantly in form, structure, materials and/or processing required. Each unique job travels from one functional area to another according to its own unique routing, requiring different operations, using different inputs, and requiring varying amounts of time. This causes the flow of the product through the shop to be jumbled, following no repetitive pattern. Job shops and batch operations (upper-left quadrant of the matrix) are usually organized around the function of the individual machines. In other words, machinery is grouped according to the purpose it serves or the capabilities it possesses. For example, in a machine shop, hydraulic presses would be grouped in one area of the shop, lathes would be grouped into another area of the shop, screw machines in another area or chemical treatment in still another, and so on (also contributing to the jumbled flow). This is labeled a process layout.

Batch: Firms utilizing batch processes provide similar items on a repeat basis, usually in larger volumes than that associated with job shops. Products are sometimes accumulated until a lot can be processed together. When the most effective manufacturing route has been determined, the higher volume and repetition of requirements can make more efficient use of capacity and result in significantly lower costs. Since the volume is higher than that of the job shop, many processes can be utilized in repetition, creating 'a much smoother flow of work-in-process throughout the shop. While the flow is smoother, the work-in-process still moves around to the various machine groupings throughout the shop in a somewhat jumbled fashion. This is described as a disconnected line flow or intermittent flow. Examples of batch processing operations include printing and machine shops that have contracts for higher volumes of a product. Services utilizing batches could be some offices (processing orders in batches), some operations within hospitals, classes within universities (how many classes have only one pupil?), and food preparation.

Line: When product demand is high enough, the appropriate process is the assembly line. Often, this process (along with continuous) is referred to as mass production. Laborers generally perform the same operations for each production run in a standard and hopefully uninterrupted flow. The assembly line treats all outputs as basically the same. Firms characterized by this process are generally heavily automated, utilizing special-purpose equipment. Frequently, some form of conveyor system connects the various pieces of equipment used. There is usually a fixed set-of inputs and outputs, constant throughput time, and a relatively continuous flow of work. Because the product is standardized, the process can also, follow the same path from one operation to the next. Routing, scheduling, and control are facilitated since each individual unit of output does not have to be monitored and controlled. This also means that the manager's span of control can increase and less skilled workers can be utilized. The product created by the assembly line process is discrete; that is, it can be visually counted (as opposed to continuous processes which produce a product that is not naturally divisible). Almost everyone can think of an example of assembly-line manufacturing (automobile manufacturing is probably the most obvious).

Examples of assembly lines in services are car washes, class registration in universities, and many fast food operations. Because the work-in-process equipment is organized and sequenced according to the steps involved to produce the product and is frequently connected by some sort of conveyor system, it is characterized as flowing in a line. Even though it may not be a straight line (some firms utilize a U-shaped assembly line) we say that it has a connected line flow. Continuous manufacturing involves lot-less production wherein the product flows continuously rather than being divided. A basic material is passed through successive operations (i.e., refining or processing) and eventually emerges as one or more products. This process is used to produce highly standardized outputs in extremely large volumes. The product range is usually so narrow and-highly standardized that it can be characterized as a commodity. Considerable capital investment is required, so demand for continuous process products must be extremely high. Starting and stopping the process can be prohibitively expensive. As a result, the processes usually run 24 hours a day with minimum downtime (hence, continuous flow). This also allows the firm to spread their enormous fixed cost over as large a base as possible. The routing of the process is typically fixed. Labor requirements are low and usually involve only monitoring and maintaining the machinery. Typical examples of industries utilizing the continuous process include gas, chemicals, electricity, ores, rubber, petroleum, cement, paper, and wood.

Table 1.1 : Features of different types of processes

Process Type	**Project**	**Job Shop**	**Batch**	**Line**	**Continuous**
Volume	One	Low	Medium	Very high	Continuous
Product variation	One-off	High	Some	Little	None
Product changes	n/a	Frequent	Some	None	None
Equipment	General	General	Some specialized	Specialized	Very specialized
Employee numbers	Many	Many	Medium	Few	Few
Skill Level	High	High	Medium	Low	Low
Capital cost	Low	Low	Medium	High	Very high
Unit cost	High	High	Medium	Low	Low

The types of process are suited to different production quantities and variety of products. Some important differences between the types of process are suggested in the **Table 1.1.** In addition to above mentioned process, managers can also use **cellular manufacturing process**. It is a combination of JIT and lean manufacturing using group technology. A cellular cell is created to for specific products to be produced using assembly lines to quickly manufacture wide variety of similar products. The cells arrange machinery in the U shape for minimum movements and add flexibility to manufacture products.

1.4.2 CHOOSING THE BEST TYPE OF PROCESS

The best type of process depends on many factors, primarily the overall demand, including the following :

- **Product Design:** to a large extent, the product's design will be set the best overall type of process. A very high quality suit to specifications given by a customer, the process is fixed as a hand-made project rather than mass production.
- **Overall Demand :** the number of units made clearly affects the best type of process. Painters use a project process to make very small numbers, while film processors use mass production for very large numbers. Higher demands allow an organization to use lower-cost processes.
- **Changes in Demand :** if the number of units made has to change continually to meet a variable demand, a more flexible process must be used. This must have enough capacity to meet peak demands, but still work efficiently during slacker times.
- **Product Flexibility :** this shows how quickly a process can stop making one product and start making another. Generally, the lower volume processes are more flexible to change in both demand and product.

- **Automation :** higher levels of automation are generally associated with expensive, specialized equipment making high volumes, so the level of automation used by the organization can affect its choice of process.
- **Finances :** the costs of setting up different processes vary widely, so the choice can be affected by the capital available and installation cost.

1.5 EXERCISE

1. An operations strategy is based on products that meet customer demands, and the process used to make these. Comment.

2. Explain the various characteristics of different types of production systems. What are the important factors required in choosing the best process?

3. A local hospital declares an emergency patient care in less than 10 minutes to turn away patients for further medical care. Identify the major implications for this commitment for strategic operations management of the hospital regarding capacity and workforce?

1.6 SUGGESTED READINGS

- Donald Waters, Operations Management, Pearson Education, 2nd Edition.
- Edward M. Knod, Operations Management : Meeting Customers' Demand, Tata McGraw-Hill Publishing Company Limited, New Delhi, 7th Edition, 2001.
- K. Aswathappa, Production and Operations Management, Himalaya Publishing House, Mumbai, Reprint 2007.
- Taylor, F. W., (1906). *On the Art of Cutting Metals*, American Society of Mechanical Engineers.
- Taylor, F. W. (1903). *Shop Management* (1903), a handbook read before the American Society of mechanical engineers, New York (this has been republished in 1911, https://archive.org/details/shopmanagement00taylgoog).
- Krick, Edward V. (1962). *Methods Engineering*, Millionbooks; universallibrary.
- Smith, Adam. (2002). The Wealth of Nations . Oxford, England: Bibliomania.com Ltd.
- Charles Babbage (1835).*On the Economy of Machinery and Manufactures*, C. Knight, Publishers, USA.
- Sheldrake, John (2003). "The Gilbreths and motion study". *Management Theory* (2nd ed.). Thompson Learning. pp. 27–34. ISBN 1-86152-963-5.

MBA-DISTANCE EDUCATION(First Year) **OM 204-B OPERATIONS MANAGEMENT**

Semester-II **Lesson No. 2**

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PRODUCT PLANNING AND DESIGN

STRUCTURE

2.0 OBJECTIVES

Product planning and design are important business decisions. In the modern competitive world, competitiveness of a firm is at times determined on its ability to come up with new products. This chapter is aimed at achieving the following learning objectives :

- To provide the basic understanding of product planning
- To explain the importance of product design in context of business
- To understand various dimensions of product design
- To provide the basic details of product reliability and methods for achieving a good design
- To explore the methods for developing a new product
- To understand in detail the process of developing a new product
- To understand the concepts leading to shorter development times

2.1 INTRODUCTION

Product planning and design are important activities both for goods and services. Product planning basically deals with new products and changes in existing products as per the market requirements. Presently, survival and success of a business enterprise depends up to a large extent on its ability to exhibit superior product planning and design skills and churning out new products in the market that suit the customer requirements. Traditionally, product planning has been defined as the activity of finding the optimal product mix in a situation where several products have different costs and resource requirements. Product mix is a selection of products that a business enterprise decides to produce in line with its business objectives. Product mix is an enterprise wide decision involving participation from a number of functional areas especially operations and marketing. Product planning decides the constitution of the product mix, therefore it is a strategic decision. It is important to provide a wide range of variety to customers but at the same time it is also important to keep a close watch on costs of production. Product planning is concerned with all decisions about the introduction of new products, changes to existing products and withdrawal of old products. Its aim is to make sure that an organization has a steady supply of products that customers want.

2.2 PRODUCT LIFE CYCLE (PLC)

The main difficulty with product planning is that customer demands change over time. Customers change their buying habits for many reasons, ranging from fashion to new legal requirements. As a result, the demand for any product changes continually. Sometimes the demand follows a pattern for which there is an obvious reason; for example, the seasonal demand for clothing. Another pattern comes from the product's life cycle, which describes the overall shape of demand, from a product's introduction through to its withdrawal.

PLC has four stages namely Start-up, Rapid Growth, Maturation and Commodity/ Decline phase. From the perspective of operations management important dimensions along PLC are product variety and volume. It has been seen that during the start-up phase great variety is available because the product is new to the market. Rapid growth stage witnesses increasing standardization and the product variety observes shrinkage. In the maturity phase, there is emergence of a dominant design and only few product options are available. In the decline or commodity phase, there is very high standardization and the product usually assumes commodity like characteristics. There is inverse relationship between volume and variety; hence as variety goes on reducing along PLC, there is a consistent increase in volume of the product. 'Low volume' can be associated with start up phase and 'high volume' is witnessed during the maturity phase.

2.2.1 Operations and the Life Cycle

The product life cycle affects operations in several ways, including the following :

Different types of operations during the life cycle

When the product is launched and moves into the introduction stage, initial demand is small. The initial designs of the product can be adjusted as customers give their reaction, so the operations must be flexible enough to deal with changes in both demand and specifications. In the growth stage, the product design becomes more stable, and operation managers look for improvements in the process, typically changing from a manual process to a more automated one. When the product reaches its mature stage, operations manger emphasize on cost reduction and improvement in productivity. During the design stage, there is likely to be excess capacity, and organizations change the product design and the process to try to extend its life.

Costs, revenues and profits during the life cycle

In the early stages of the life cycle, small scale operations result in high unit costs. However, the profit can also be high as customers are willing to pay a premium. Revenue rises when the product moves from introduction to the growth stage as fixed costs are recovered and the product starts to make an overall profit. During maturity stage revenue stops rising as competitors start making similar products and demand slackens so both the unit price and revenues begin to fall.

Entry and exit strategies

These strategies can be classified as follows :

• **Research-driven :** good at research, design and development; innovative with constant changes in product; high quality and high cost; low sales volumes; slow delivery.

• **New product exploiters :** Identifying new products with wide appeal; good at developing new processes for production; strong in marketing to create demand; high quality with reducing cost; moving to high volume.

• **Cost reducers :** High volume, low cost process; low innovation, concentrating on established products; low price and fast delivery; good at process design.

Range of products made

Any decision about the range of products must be weighed up against the following:

• If the range is narrow, the organization can use standard operations, but some customers are lost to competitors who offer more products or different ones.

• If the range is wide, the organizations can satisfy varied customer demands, but it loses the efficiency that comes with standardization.

2.3 PRODUCT DESIGN

Design means only the features of shape, configuration, pattern, ornament or composition of lines or colours applied to any article whether in two dimensional or three dimensional or in both forms, by any industrial process or means, whether manual, mechanical or chemical, separate or combined, which in the finished article appeal to and are judged solely by the eye; but does not include any mode or principle of construction or anything which is in substance a mere mechanical device. Product design broadly covers two aspects i.e. form and function. Form refers to shape, patterns, features and physical outlook of the product, while function refers to the working of the product as per intended objectives. Product design affects operations both with in the organization and outside the organization. Product design directly affects product quality, production cost, logistics costs as well as customer satisfaction. Products can be differentiated in the category by means of novel and distinct physical outlook stemming from design operations. Product design is crucial to success of any product as 80 percent of product cost is decided at the design phase of product development. Product design affects logistics and storage costs and is of strategic importance as frequent changes and modifications are not possible. A good product design is instrumental in carving out a number of advantages. Few of these advantages have been listed as follows :

Functionality : It refers to the manner in which product performs and deals with how well the product is functioning.

Conformance : It refers to the conformance of the product to predetermined standards and specifications.

Aesthetics : It refers to outlook of the product i.e. how attractive the product is in its physical appearance.

Features : It refers to the additional characteristics and functions performed by the product over and above the basic characteristics and functioning.

Reliability : It refers to consistent performance of the product in the desired manner during a certain given time period.

Innovative: A products should be innovative component to attract users with better features, appearance, shape and size etc. Managers need to consider requirements of end users, business goals and available technology for developing an innovative product.

Durability : It refers to long lasting use of the product without considerable decline in its functionality.

Serviceability : It refers to convenience in maintenance of the product over a number of repetitions.

Safety : It refers to less or negligible risk/hazards to users and those in vicinity of the product both at the time of using the product as well as after disposing off.

User-Friendliness : It refers to the degree of ease with which a user can operate the product so as to make it function up to a desired level.

Scope of Customization : It refers to the extent up to which the product can be modified so as to suit the needs of a particular customer.

Simplicity: Simplicity refers to ease to understand what product does and they can use it.

2.3.1 Product Reliability

At the time of purchasing any product apart from price, quality and aesthetics customers try to base their purchase decision on reliability of the product. Product reliability can be defined as the probability that the product will perform as intended for a prescribed lifetime under specified operating conditions. Unreliability of the product of the product is exhibited either by failure of the product in its expected lifetime by either complete breakdown of the product or by performance at sub-optimum level. According to 'Product Failure Curve' shown in Fig 1, there is high probability of product failure in the initial phase as well final phase of the lifetime of the product.

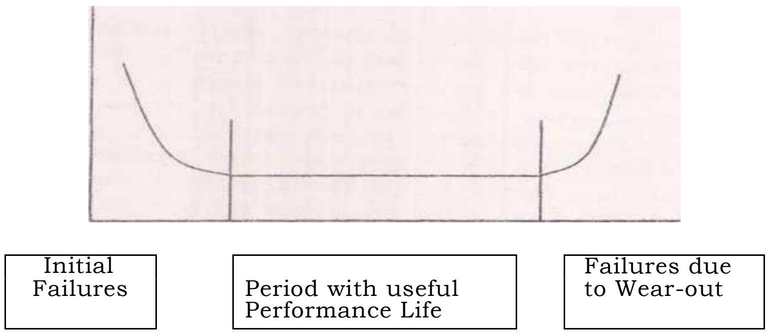


Fig. 1 : Product Failure Curve/ Bath Tub Curve

It can be seen from Product. Failure of Bath Tub Curve that rate of failures are quite high in the initial phase of lifecycle. These high failure rates can be attributed to the design faults, undetected faults in the components and damages occurred to product during shipping and transportation. Once this phase is over, one can expect a prolonged useful life of the product. It can be seen that after the initial phase there is sharp decline in the rate of product failure and the product failure curve hits the minimum height. Reliability engineers try to maximize the length of the curve at this minimum height. Depending upon the nature of the product, i.e. durable like TV, Refrigerator etc and non durables such as food, newspapers etc, an attempt is made to increase or decrease the length of the curve at its minimum height. Such decision is taken in light of financial, technical and consumer considerations. Towards the end of the curve, a steep rise is witnessed on account of wear and tear of the components.

2.3.2 Modular Product Design

Modular design means creating a product from a set of sub-components (modules).' For example a home computer is combination of a number of modules such as a monitor, CPU machine, mouse, keyboard etc. If there are 3 types of monitors, 2 types of machines, 3 types of mouse and 2 types of keyboards, then 36 (3*2*3*2) different home computers can be offered to customers. Modular design provides more variety to customers and increases the scope for customization. There are a number of advantages associated with the modular design :

- A wide range of product options for the customers.
- Ease of designing and manufacturing the components/modules of a product.
- Ease of diagnosing the product in case of problems.
- Ease of servicing the product.
- Economy in servicing and maintenance of the product.

• Easy replacement of modules without affecting the working of other modules.

• Better production planning as product is divided in sub parts.

• Efficient and economic materials management.

• Maintenance of lesser inventory for providing variety to the customers.

2.3.3 Standardization

Standardization is the process of developing and agreeing upon technical standards. A standard is a document that establishes uniform engineering or technical specifications, criteria, methods, processes, or practices. Standardization can be used to enhance productivity leading to benefits both for consumers and producers. Consumers can benefit from this concept as parts and components purchased from different producers are going to fit well. For example, irrespective of the producer, there will be a good fit between electric bulb and its holder. Common products such as screws, nut & bolts, sparkplugs, electric tube rods are produced in standardized fashion by different producers. There are a number of benefits associated with standardization. These have been mentioned as follows:

• Avoiding engineering designs as standard designs are already available.

• Simplified planning and control

• Price based competition benefiting the customers.

• Flexibility to the firms in hiring vendors.

• Easy availability of items

2.3.4 Quality Function Deployment

Quality Function Deployment (QFD) is an important tool for designing the products and services by which customers requirements can be included in the design specification of a product. Toyota Motors has successfully used this approach for reducing the costs of its cars by more than sixty percent apart from achieving significant reduction in design time of the products. QFD involves closer interaction among inter-functional groups such as marketing & sales, design engineering, and manufacturing so as to reflect customer requirements in product design. Initial step of QFD involves knowing customer preferences in context of superior product. This is accomplished by market research, focus groups and customer feedbacks on the product. Customers are asked to describe 'what they would like to see in a superior product'. Customers requirement are weighted according to the priority assigned to different requirements. Customers are also asked to compare the company products with that of the competitors and responses thus obtained are analyzed. This exercise helps the company having a good understanding of customer requirements as well as determining the product characteristics that are of prime importance to them. In the next step, customer requirements are used as base for developing a matrix called ’house of quality’. This matrix can be used by inter-functional team to understand the customer requirements. Further, efforts are made to translate the customer requirements into concrete design engineering goals. This process ensures that design engineers are able to understand the customer requirements in a better manner and are able to come up with a product that meets customers' expectations.

2.3.5 Design for Manufacture

Time is an important dimension while designing and developing a product. By reducing 'time to market' companies can enjoy first mover advantages and consolidate their market position. From perspective of manufacturing operations, a good design should take lesser time, operations and efforts for making the product. Design for manufacture will ensure efficiency in the following dimensions:

• Material handling and inventory management

• Material procurement

• Simpler machining processes permitting use of low cost machines

• Few changeovers leading to lesser set up costs

• Better quality control procedures

• Simpler assembly operations

The basic idea of DFM is to reduce the manufacturing time of a product without compromising the features and quality of the product. Design of existing products is modified under DFM so as to ensure lesser manufacturing operations effecting reduction in time. These time savings can be used by the companies to respond to changing market requirements in a quick manner. The basic theme of DFM is that design of the product affects the efficiency of manufacturing and attempts are made to enhance this efficiency by effecting minor modifications in the product design. The following DFM principles are found quite useful for assembly operations :

• Keep the number of parts in a product to minimum.

• Try to adopt standardized designs as far as possible.

• Redesign/modify the parts keeping in mind the simplification of assembly operations.

• Minimize the assembly operations.

• Adopt modular designs to the extent possible.

• Design the parts in a manner so that slots and grooves are helpful in right and fast assembly operations.

2.4 NEW PRODUCT DEVELOPMENT

Developing and launching new products is core activity of the business enterprise. To retain the existing customers and to attract new customers, companies go on developing new products that are aimed at serving the markets in an improved manner. Success of a business enterprise in modern and competitive world can be partly attributed to its ability to churn out new products periodically. Companies exhibit their competitive character by means of developing better products as compared to the competition as well as improving upon their existing products. In pursuit of differentiation, customers show a tendency to purchase the new products that are based on cutting edge technology and stand out of the crowd. Marketers understand this tendency and are always interested in providing new and latest products to their target markets. Developing new products assumes importance in light of hefty resources and future of business at stake. It is because of these two factors that new product development has always sought attention of top circles in the corporate world. Companies use new products not only to offload their competitors in the market but also try to change the rules of business. For example, Tata Motors is coming up with Nano, a product designed to change definition of car markets not only in India but abroad as well. The following discussion deals with the tools for identification of new products and the process undertaken for new product development.

2.4.1 Sources of Product Innovation

Design engineers and marketers always remain in hot pursuit for scoring an idea leading to development of a new product. There are a number of techniques for finding a new product and a brief discussion on these techniques is as follows. Largely, there are two categories of research that are used for finding new products :

• Basic Research

• Applied Research

Basic Research

It concerns with the advancement of scientific knowledge that has no commercial use. But this type of research can be instrumental in invention of products that are radically new to the markets. For this reason, companies keep on investing in the basic research and explore for potential opportunities for developing new products. For example, the current research in the field of superconductivity falls in this category. Once fundamental breakthroughs are obtained, this field has scope for solving energy problems and can also be instrumental in fast speed transportation.

Applied Research

This type of research concerns the advancement of scientific knowledge that has specific commercial use. Companies invest in this type of research, to come up with the products that can be of some value to the customers. These products are capable of providing benefits to the customers and hence can be easily commercialized. For example, Du Pont was able to deploy the advances in material sciences to provide valuable products to the customers. The company was able to translate advanced research on Polymerization to make insulating material, offering value to the customers of insulators and electric wires. Apart from investing in research, there are other techniques for developing new products such as :

• Market Research

• Competitor Analysis

• Brainstorming

Market Research

Market research involves reaching out to customers, suppliers and channel members to seek ideas for new products. Market surveys and studies are undertaken for understanding the needs and expectations of the customers, so as to come with valuable ideas of new products. This technique carries the advantage of resulting out the products with good prospects of commercialization. As the ideas are coming from the market itself, there is a greater likelihood of commercialization of the product in a smooth manner. The major steps in market research are as follow:

1. Define market research problem,

2. Develop research program,

3. Research design,

4. Select representative sample,

5. Collect data,

6. Refine analyse and interpret data, and

7. Discuss results and take action.

Competitor Analysis

Companies always keep a watch on the activities and product mix of the competitors. Industry leaders are able to neutralize challenges, posed by followers, which involve launching a new product in the market. Although a lot of skill is required on part of an industry leader to take a clue out of competition and come up with a better product in lesser time, yet there is always a possibility of emerging successful. Managers can conduct competitor analysis by identifying their competitors (direct, indirect, and substitutes), gathering information regarding price, features, reputation, and quality of products available in the market, and finally conducting comparative analysis.

Brainstorming

Brainstorming as a tool of developing new product has been successfully used by a number of Japanese companies. Brainstorming is an activity which involves generating new ideas by a group without any constraint on contributions from group members. Basic theme of brainstorming is to provide freedom to the participants to come up with ideas. This activity can lead to ideas for new products with potency of commercialization. Brainstorming aimed at identifying new products can involve employees as well as other participants such as customers, business partners etc. Gilda Bonanno has classified brainstorming in seven steps as: Brainstorming process explanation, followed by problem under discussion, idea gathering, capturing all ideas publically, sorting better ideas, cull the ideas, and finally prioritizing the remaining ideas.

2.4.2 New Product Development Process

The following are the major steps involved in the process of developing a new product as shown in Fig.2:

- Need Identification
- Concept Generation
- Prototype Design and Development
- Production Process Design and Development
- Product Evaluation
- Product Use and Support

These steps are discussed as follows :

Need Identification

New product development is always aimed at fulfilling the needs of the customers. In the first step, once idea of a new product emerges, it is justified that the new product will be able to fill the gap. It is also ascertained that the existing products are not good enough for filling the gap/meeting the customer need, because undertaking the new product development consumes valuable and scarce resources.

Concept Generation

After understanding the consumer needs, next step is generating a conceptual design of the product. Good innovation skills are required at this step so as to come up with a workable and excellent product concept. This step primarily involves translating the needs identified in the first step into product/service. There can be a number of ways in for fulfilling the identified need. Different solutions in sight are compared on the basis of feasibility and novelty. Alternate concepts can be compared on the basis of technical, feasibility i.e. possibility of production as per intended concept, market feasibility i.e ability to create market, cost feasibility, feasibility of acceptance by the customers etc. Conceptual design of the product presents the basic properties of the product such as shape, weight, strength and other characteristics.

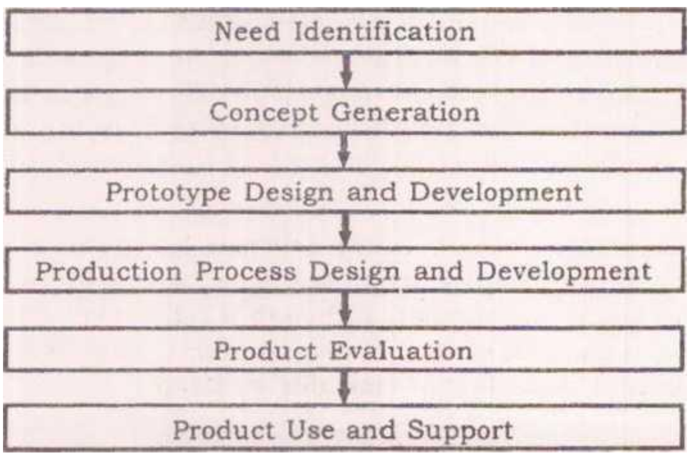


Fig. 2 : New Product Development Proces

Prototype Design and Development

At this stage of product development, attempts are made for converting the design on paper to a physical form. Detailed designing of the prototype is undertaken in order to ascertain the real working of the product. Tradeoffs are made among various design objective such as function, reliability, maintainability, safety and producibility. Design phase of the product is focused on the aspects such as cost, manufacturing process, specifications, tolerances etc. Major part of the product cost is decided at this stage., product specifications and process planning are the major determinants of cost of the product. There are a number of considerations that are taken into account at this stage, such as capability of existing resources to manufacture the product, availability of raw material and skilled labour for manufacturing operations. Due to large number of constraints, there are a number of iterations before reaching to final design of the product.

After finalizing the design, physical development of the product is undertaken. This involves building of prototype for extensive testing and honing of the design of the product. This step involves detailed manufacturing specifications, specific methods of manufacturing the product, assembly operations etc. End result of this stage is finalization of the product design with every minute detail in place.

Production Process Design and Development

Process design always follows product design. This stage involves designing the specific processes that may be required for manufacturing the product. Detailed plans for material acquisition, production, warehousing, logistics, distribution etc are prepared. Planning at this stage ensures that every dimension is set right and preparations are complete for undertaking the mass production of the product. By end of this stage, mass production of the product is started and different activities are undertaken for taking the product from manufacturing premises to the customers.

Product Evaluation

Companies are always interested in improving their products on regular basis, hence product evaluation is undertaken. Data pertaining to field performance and customer feedback is collected so as to identify the problem areas. Efforts are made to rectify the problems so as to provide superior services to the customers. Newer technologies and materials also contribute to product improvement.

Product Use and Support

While using the product, the customers may face a number of problems. Therefore, product support becomes an important activity. It has been seen that customers are not able to use the product to its full potential. To solve this problem field demonstrations and customer education are undertaken. This stage also deals with providing after sales services to customers in case of any problem in working of the product.

2.5 CONCURRENT ENGINEERING

Process of new product development is a critical activity because of large amount of resources at stake. Most important element of product development is time. Time directly affects the cost of product development. Therefore, it becomes important to filter out the faulty product design in the beginning itself and make the required changes in the development stage at the earliest possible. Delays in ironing out design defects and deficiency directly translate in wastage of resources as well as time. It is quite possible that a product is designed to know in the end that the required manufacturing facilities ate not available with the company or raw material availability is in question. Concurrent engineering can be answer to such problems. Concurrent engineering involves simultaneous efforts for designing the product as well as the process. This concept can be used for compressing the time required for product development. Concurrent engineering calls for close coordination among different departments such as design engineering, manufacturing, production planning and control, purchase, marketing and finance.

As the design process progresses, the concerned departments keep on pointing out the potential problems and these problems are set right at the earliest by effecting design changes and mutual understanding. This coordination is basically possible by the modern information sharing technologies whereby work done by one person/department is visible to others. As a result of this sharing , differences across the development process are eliminated without wastage of time. This results in compression of product development process in terms of time. The basic elements that are helpful in increasing the speed of product development are listed as follows :

• Concurrence of various activities of development process

• Performing various activities in parallel

• Integration and information sharing across different departments involved in development process

2.6 SUMMARY

Product planning deals with new products and changes in existing products as per the market requirements. Along PLC of product, variety goes on decreasing and volume goes on increasing. Product design broadly covers two aspects i.e. form and function. Form refers to shape, patterns, features and physical outlook of the product, while function refers to the working of the product as per intended objectives. Product reliability can be defined as the probability that the product will perform as intended for a prescribed lifetime under specified operating conditions. We can add value to design of a product by adopting modular designs and by incorporating standardization. Design for Manufacture ensures that it is easy to produce the product in lesser time and cost. There are a number of methods for getting ideas for a new product such as using basic and applied research, market research, competitor analysis and brainstorming. Concurrent engineering can be used for reducing design time and it ensures economy as well.

2.7 EXERCISE

1. Demand for all products varies over time and normally follows a standard life cycle. Explain.

2. Explain the factors that are necessary for the success of design of a product.

3. Illustrate the stages required in developing new products.

2.8 SUGGESTED READINGS

• Donald Waters, Operations Management, Pearson Education, 2nd Edition.

• Edward M. Knod, Operations Management : Meeting Customers' Demand, Tata McGraw-Hill Publishing Company Limited, New Delhi, 7th Edition, 2001.

MBA-CC (First Year)

OM 204-B OPERATIONS MANAGEMENT

Semester-II

Lesson No. 3

AUTHOR : DR. PARMOD KUMAR AGGARWAL

FORECASTING METHODS

STRUCTURE

3.0 CONCEPT OF FORECASTING

Forecasting is an important tool in any decision-making process. It refers to the analysis of the past and present conditions with a view to drawing conclusions about the future course of events. Forecasting refers to the using of knowledge we have at one moment of time to estimate what will happen at another moment of time. The forecasting problem is created by the interval of time between the moments. Neter and Wasserman have defined, 'Business forecasting refers to the statistical analysis of the.past and current movements in a given time series, so as to obtain clues about the future pattern of the movements". Prof. H.J. Wheldon states, Business forecasting is not so much the estimation of certain figures of sales, production, profits, etc. as the analysis of known data, internal and external, in a manner which will enable policy to be determined to meet probable future conditions to the best advantage." Thus forecasting is the process of making precise estimates about the future conditions on a systematic basis.

Implications of Forecasting

Success in business depends on successful forecasts of business events. Forecasting is essential for the governance of business policies and actions as given below:

1. Promotion of Organisation

Organized forecasting system is not required for all types of business concerns especially small concerns with simple operations. But as the business grows in size, complexity and the variety of products, forecasting becomes a separate management function with the promotion of the organisation.

2. Key to Planning

For effective planning of an enterprise a reasonably accurate forecast of trends in the economic activities of the economy and of the sales of an enterprise is necessary. The management may not act on the spur of the moment. Forecasting is the key to achieve planned objectives.

3. Coordination and Control

Competition is essential aspect of any business which poses a threat to the stability and

prosperity of the business and industrial activity. Knowledge of future forecasts help in coordination and control of business activities and thus successfully face the threat. A satisfactory method of control of raw materials, semi-finished and finished products, spare parts, work-in-process should depend on satisfactory forecasts of future requirements,

4. Success in Organisation

Success in an organisation depends on good forecasting. Forecasting requires teamwork among various departments such as general business 'research and market research, sales, production, planning, accounting and finance. Organised forecasting leads to the forecast for general business conditions on which the sales forecast are made. The sales forecast supports the complete structure of financial forecast, budget, and production forecast etc.

3.1 TYPES OF FORECASTING

Broadly there are three types of forecasting : short-term, medium-term and long-term :

1. Short-Term Forecasting

It is concerned with the immediate future that may range from a day up to one year. As the period is so short that production capacity can neither be expanded nor be reduced. Given the existing production capacity, short-term forecasting is concerned mainly with planning relating to production scheduling, material requirement, price policy and selling targets.

2. Medium-Term Forecasting

The effect of present policies cannot be foreseen for the long run. The impact cannot be predicted beyond a year ahead in case of internal (e.g. quality improvement) or external (e.g. government's tax policy) policies. Medium term forecasts depend on sound judgment and experience. These help in the decision about timing of an activity. The medium-term forecasts contribute to revision or control of the decisions based on long-term forecasts.

3. Long-Term Forecasting

It is concerned v/ith the estimation of the behaviour of events likely to occur over a period of 5 to 10 years. It is concerned with long-term planning of the business activity i.e. creation or reduction of production capacity. It is also concerned with long-term financial and manpower planning: For long term forecasts, reliance is placed on statistical techniques. Judgmental forecasting is also suited to long-term forecasting where regularities of the past are not significant.

3.2 FORECASTING METHODS

A businessman may suffer losses due to inaccurate forecasting. Inaccurate forecasting may be due to incorrect information. Forecasting done on a scientific basis proves very useful. In the last few decades, various forecasting techniques have been developed and improved upon. The most important methods of forecasting are given below :

1. Naive Method

It is the simplest method. It is based on the assumption that the future will exactly resemble the past. It is based on the principle that history repeats itself. In this method we forecast the value of variable for the time period t, to be equal to the actual value observed by variable in the previous period, the mercy of the subjectivity of the statistician.

2. **Business Barometer Method**

A Barometer is a device to measure the atmospheric pressure. A business barometer or indicator or index relates to business conditions in an economy. It measures changes in business activity during periods of crisis, depression, recovery and prosperity. A businessman takes into account the following conditions prevailing in the economy for purposes of fore casing :

(1) Employment (2) Gross National Project (3) Index of Industrial Production (4) Volume of Agricultural Production (5) Wholesale prices (6) Consumer prices (7) Stock prices (8) Bond yields (9) Volume of bank deposits and currency outstanding (10) Consumer credit (11) Disposable income (12) Departmental store sales (13) Export and Import Volumes.

3. **Diffusion Index Method**

This method is based on the proposition that various factors affecting business do not reach their peaks and troughs simultaneously. There is always a time-log between them. It shows the percentage of a given set of series as expanding or contracting from one suitable time interval chosen to another time interval (e.g. monthly quarterly etc.) The diffusion index is the index of general business activity. In calculating a diffusion index for a group of indicators, scores allotted are 1 to rising series, to constant series and zero to falling series. The diffusion index is calculated by the ratio of the number of indicators moving up or down to the total number of indicators. A graphic method is used to work out the diffusion index. This method suffers from three limitations :

(a) The lead time between changes in diffusion indices (chosen indicators) and the turning points in business cycle is small. If more indicators are included to extend the lead time, the interpretation becomes more difficult.

(b) This method helps in finding the direction and not the magnitude of measurement of the variable under forecast.

(c) It is a very time consuming technique as construction of a diffusion index is a very laborious job.

4. **Opinion Survey's Method**

It is a subjective method of forecasting based on reports or surveys of opinions. It assumes that future economic actions are carried out according to present plans. Present plans about future actions are obtained by asking businessmen in strategic positions. An opinion poll of the sales representations, wholesalers, marketing experts is useful in demand forecasting. The opinion poll of technical experts may be useful in estimating the life of a technology. In case of divergent views in opinion polls experts may be called for discussion and consensus may emerge which becomes the estimate of future business events.

5. **Trend Projections Method**

It is a classical method of business forecasting. It is based on the study of movements of variables through time. It requires a long and reliable time series data. This method is based on the assumption that the factors underlying for the past trends in the variable to be projected will also continue to influence the variable in future to the same extent in magnitude and direction, This method does not reveal the cause and effect relationship between the variables.

measurement. It includes the use of economic theory, mathematics and statistics. It is based on the assumption that changes in economic activity can be explained by a set of relationships among the critical economic variables, Economic activity can be described in terms of mathematical equations. This description is known as an econometric model which expresses the most probable interrelationships between a set of economic variables pertaining to the various aspects of the economy. The econometric models take the form of simultaneous equations. The constants in these equations are worked out by a study of time series. There are many variables affecting a business phenomenon and thus a large number of equations may be formed to construct a particular econometric model.

7. **Regression Analysis Method**

Managers make personal and professional decisions based on predictions of future events. To make these forecasts, they depend on the relationship between what is known and what is to be estimated. If the decision-makers can determine how the known is related to the future event, they can half the decision-making process to a large extent. Regression analysis tells us how to determine both the nature and strength of a relationship between two or more variables. We have to estimate the values of a, b, c, d... and put these values in the equation. The estimation of these values may rely c-n past data, some projections; some judgement etc, If the various factors affecting a business problem are interrelated, regression analysis may be used in business forecasting.

8. **Time Series Analysis Method**

As already discussed in the chapter on analysis of time series, it involves decomposition of historical series into its various components viz., Trend, seasonal variations, cyclical variations and random variations. This method takes into account the determination of two main components-secular trend and seasonal variations. After isolating the two components the adjusted series gives a very clear picture of the influence of various factors affecting the problem under study and thus they can be used for making estimates about the future behaviour of the series. As a method of forecasting, time series analysis is used

(a) When the data are available for a long period of time and
(b) When the trend and seasonal variations disclose the tendencies very clearly.

9. **Exponential Smoothing Method**

Smoothing method's try to cancel out the effect of random variations on the values of the series. The two smoothing methods are :

(a) moving average method, and
(b) Exponential Smoothing Method.

Exponential smoothing method is used for short-term forecasting. This method determines values by computing exponentially weighted system. The weights assigned to the values show the degree of importance attached to the values. The procedure of exponential smoothing combines last month's actual sales and last month's forecast by taking a weighted average of the two. The weight assigned to the actual sales is denoted by Greek letter a (alpha).

The procedure for exponential smoothing is

Next Forecast = Last Forecast for sales + a (last demand - last forecast)

i. e. $F(t+1) = F(t) + a (D(t) - F(t))$
where a must be between 0 and 1.

or mailed questionnaires asking individuals, business firms and government agencies about their future plans. Various types of surveys are conducted both in economic and sales *forecasting. Information may collect about the likely expenditures of consumers on various* items. Both qualitative and quantitative information can be collected which throws light on consumers preferences for various commodities. Demand for various goods can be forecasted through this method. This method can be used for forecasting demand for the existing products and new products. It is a costly and time-consuming method. Therefore a sample survey of only prospective consumers should be undertaken.

11. **Lead-Lag Analysis**

It is based on the assumption that most of the business data have the lead and lag relationship. This method has been quite popular in forecasting of the turning points of business cycle. The essence of forecasting lies in finding out a business indicator series whose turning points in the past have been consistently leading the cyclical movements in the overall business activity for various months. It is difficult to find such a leading series. Therefore, forecasting of the turning points of business activity should be based on the leading, lagging and coincident groups of time series. The Harvard Committee on Economic Research was the first to evolve the lead-lag relationship. This relationship was developed by graphic inspection and by correlation studies for a number of series. If the leading series curve shows a downward and the lagging series an upward movement, then the general business conditions will face down turn. If the leading series showed an upward movement and lagging series curve follows a downward movement then the upward movement in the business activity is sure to happen. The reliability of forecast on the basis of this method depends on the accuracy with which the time-lag between various activities is estimated.

12. **Input-Output or End-use Analysis**

The basis of this method is that various sectors of the economy are interrelated and such interrelationships are well-established. This method shows that industries in the economy are so interrelated that the output of one industry becomes the input of another industry. The increase or decrease in the demand for one industry's output is bound to influence the demand for the output of other industries. Forecasting is based on a set of tables that explain the interrelationship among the various sectors of the economy. The forecast of output based on input and forecast of input requirement based on fined output can be made by the input-output relationship. Because of this mechanism this method is called input- output analysis or end-use method. The interrelationships are known as coefficients. Input- output tables prepared by government and research organisations are widely used by business executives in 'forecasting business events.

13. **Factor-Listing Approach**

In this method forecast of business conditions is made by descriptive analysis. Various factors influencing business activity are located and each factor is analysed in order to ascertain its probable impact (favourable or unfavourable) on aggregate business activity. No mathematical tool is used. To forecast the business conditions in the near future, inferences are drawn regarding the effect of each factor. The main advantage of this method is that there is no restriction on the number and type of variables to be included in the analysis.

14. **Box and Jenkin's Method**

Box and Jenkin developed a method of forecasting using auto-regressive moving averages (ARIMA). It is also known as ARIMA method.’ This method may be used for shortterm forecasting. It combines smoothing method with auto regressive method. This method is applicable in situations where the inherent pattern in the series is complex and difficult to understand. The method passes through five stages of removal of trend, model identification (selection of combination), parameter estimation, verification and forecasting. It is a complex method based on search. Forecasting through this method is possible only with the help of computers. It is very expensive method. It requires highly qualified and experienced forecaster.

15. **Delphi Method**

It is an extension of the opinion poll method. The judgement of experts is the best and most feasible method of forecasting. The Rand Corporation developed this method as a means of forecasting by seeking expert opinions. In this method independent judgements of the experts are obtained by asking them to complete a detailed questionnaire independently and without knowledge of the responses of other experts. Experts opinions are consolidated to arrive at a compromise forecast, **to. Action and Reaction Theory**

This theory is based on Newton's third law of motion "for every action there is always an opposite and equal reaction." Thus if there is prosperity in a specific areas of business, there is found to be decline sooner or later. A business cycle passes through four phases: prosperity, decline, depression and recovery. According to this theory a certain level of business activity is normal. Whenever there is depression or prosperity in the business activity, It tends to become normal. Sub-normal or above-normal conditions cannot continue ior long. The magnitude and duration of prosperity must balance magnitude and duration of depression. But it is very difficult to decide what constitutes the normal business activity.

17. Cross-Section Analysis

It is based on the analysis of current economic forces rather than projection of past i rends. Business conditions are influenced by simultaneous inflationary and deflationary forces. Impact of inflationary forces results in booms and the influence of deflationary forces leads to depression in the business activity. The forecaster prepares three lists, one which includes inflationary forces, second including deflationary forces and the third listing stable forces. The determining forces change from time to time. The current factors which require careful attention are : government policies, technological changes, business expectations, demand-supply relationship, quantitative and qualitative changes in population. The impact of each factor influencing a particular phenomenon is studied separately and then attempt is made to estimate the combined impact of all the factors, giving due weight to each. It is a difficult process to isolate the effects of various factors affecting the selected series of business data.

3.3 QUALITATIVE FORECASTS

Surveys and opinion polls are often used to make short-term forecasts when quantitative data are not available. These qualitative techniques can also be very useful for supplementing quantitative forecasts which anticipate changes in consumer tastes or business expectations about future economic conditions. They can also be invaluable in forecasting the demand for a new product which the firm intends to introduce. In this section, **Me** briefly examine forecasting based on surveys and opinion polling.

Survey Techniques

The rationale for forecasting based on surveys of economic intentions is that many decisions are made well in advance of actual expenditures. For example, business usually plan to add to plant and equipment long before expenditures are actually incurred.

Consumer's decisions to purchase houses, automobiles, TV sets, washing machines, furniture, vacations, education and other major consumption items are made months or years in advance of actual purchases. Similarly, government agencies prepare budgets and anticipate expenditures a year or more in advance, Surveys of economic intentions, thus, can reveal and can be used to forecast future purchases of capital equipment, inventory changes and major consumer expenditures. Some big firms conduct regularly surveys of consumer choice about their products and products of their rivals. These surveys are becoming harder to conduct because consumers are not willing to spare time for the questionnaires or the sales peoples' inquiries.

Opinion Poll

A firm's sales are strongly dependent upon the general level of economic activity and sales the industry as a whole, but they also depend on the policies adopted by the firm. The firm can fore its sales by polling experts within and outside the firm. There are several such polling techniques.

1. **Executive Polling** : The firm can poll its top management from its sales, production, finance and personnel departments on their views on the sales outlook for the firm during the next quarter or a year. While these personal insights are to a large extent subjective, by averaging the opinions of the experts who are most knowledgeable about the firm and its products, the firm hopes to arrive at a better forecast than would be provided by these experts individually. Outside market experts could also be polled. To avoid a bandwagon effect (whereby the opinions of some experts might be over- shadowed by some dominant personality in their midst), the so-called Delphi method can be used.
2. **Sales Force Polling** : This is a forecast of the firm's sale in each region and for each- prod line that is based on the opinions of firm’s sales force in the field. The rationale is that these are people closest to the market and their opinion of future sales can provide very valuable information to the firm's top management.
3. **Consumer Intentions Polling** : Companies selling automobiles, furniture, household appliances and other durable goods sometimes poll a sample of potential buyers on their purchasing intentions. Based on the results of the poll, the firm can then forecast its national sales for different levels of consumer's disposable income.

3.4 DELPHI METHOD OF DEMAND FORECASTING

The value of the Delphi technique is that it aids individual panel members in assessing their forecasts. Implicitly, they are forced to consider why their judgement differs from that of other experts. Ideally, this evaluation process should generate more precise forecasts with each iteration. One problem with the Delphi method can be its expense. The usefulness of the expert opinion depends on the skill and insight of the experts, employed to make predictions. Frequently, the most knowledgeable people in an industry are in a position to command large fees for their work as consultants. Or they may be employed by the firm, but have other important responsibilities, which means that there can be a significant opportunity cost in involving them in the planning process. Another potential problem is that those who consider themselves experts may be unwilling to be influenced by the predictions of others on the panel. As a result, there may be few changes in the subsequent rounds of forecasts.

3.5 DEMAND FORECASTING THROUGH MOVING AVERAGE METHOD

This is a simple method of forecasting demand. By this method we want to ensure that the predicted figure for the demand in a given period (month, quarter, year etc.) is more or less equal to the average value of the time series in a number of previous periods. For example, with a three year moving average, the forecasted value of the time series for the next period is equal to the average value of a time series in the last three periods. In the same manner, the average value of a time series with a four year moving average is given by the average value of the previous four periods, and so on. The larger the number of years under consideration, he greater is likely to be the smoothing effect in as much as less and less weights are attached to the recent observations. The greater is the random component in these time series, the more useful is this method of fitting the trend to the time-series data. **Example :**

The following table presents hypothetical data on the market share percent of a company in the 12 year period 1987-88. Forecast the company's market share for 1999.

Year	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Market Share (percent)	20	22	23	24	18	23	19	17	22	23	18	23

We take the following steps in fitting the moving average trend.

1. We inspect the series to find that there is considerable random variation in the data but there hardly any secular or seasonal variation. We also find that the pattern of figures suggests a three-yearly moving average for the trend fitting.

Year	**The Company's** Actual **Market Share** JA)	**Three-year Moving Average Forecast (F)**	**A - F**
(1)	. 12) _________	**(3)**	**(4)**
1987	20	—	—
1988	22	—	—
1989	23	—	—
1990	24	21.67	2.33
1991	18	23.00	-5.00
1992	23	21.67	1.33
1993	19	21.67	-2.67
1994	17	20.00	-3.00
1995	22	19.67	2.33
1996	23	19.53	3.67
1997.	18	20.67	-2.67
1998	23	21.00	2.00
1999	—	21.33	—

2. Calculate three-year moving average as shown in column (3). That is, find the average of the figures of the first three years, (20 + 22 + 23)/ 3 = 21.67. Write this figure in column (3) in the row the year 1990.
3. Drop the first-year figure in column (2) and take up the fourth year (1991) figure to the three-years total formed in the 2nd step above. The new average for the three years is (22 + 23 + 24)/ 3 = 23. We write this figure in the row of 1991.
4. We repeat the process of dropping one figure in the three-yearly total and adding the next more therein to find the next average figure. The average to be written in

the row of 1992 is 21.67 and the same is the average for 1992 year.

5. Proceeding for each year in the same manner we go on writing the three-yearly moving average till we arrive at the year 1999. In this row we find the moving average to be 21.33.
6. By subtracting the figures in column (3) from those of column (2), we find the random fluctuations (A - F). The method of moving averages for fitting the trend to a time series is simple. But it is a naive method, not considered scientific because it involves a good deal of subjectivity.

3.6 DEMAND FORECASTING THROUGH EXPONENTIAL SMOOTHING METHOD

Trend projection can be considered to be just regression analysis where the only independent variable is time. A major assumption involved in this method is that each observation has the same weight. That is, the effect of the initial data item on the estimated coefficients is just as much as the last data item. If there were little or no change in the pattern over the entire time series, this is not a problem. However, in some cases, more recent observations will contain more accurate information about the future than those at the beginning of the series. For instance, the sales figures of the last three months may be more relevant in forecasting future sales than data for sales ten years in the past. Exponential smoothing is a technique of time series forecasting that gives greater weight to more recent observations. The first step in this technique is to choose a smoothing constant, a , where 0 < a < 1. If there are n observations in a time series, the forecast for the next period (i.e., n + 1) is calculated as a weighted average of the observed value of the series at period n and the forecasted value for that same period. That is,

Next Forecast = Last Forecast for sales + a (last demand - last forecast)

i. e. F(t+1) * F(t) + a (D(t) - F(t))

where F(t+1) is the forecast value for the next period, F(t) is the observed value for the last observation, and is a forecast of the value for the last period in the time series. The forecasted values for and all the earlier periods are calculated in the same manner. The exponential smoothing constant chosen by us determines the weight given to different observations in the time series. As a approaches 1.0, then (1-a) = 0 and it indicates that the forecast is determined only by the actual observation for the last period. In contrast lower values for a give greater weight to observations from previous periods.

Example :

The first five periods of demand data are shown in the following table. Using a smoothing coefficient, a=0.3, compute simple exponentially forecasts for periods through 2 through 5. Initialize the procedure with a forecast value for period 1 as 41.

Period	1	2	3	4	5
Demand	40	42	41	44	40

Solution:

The data, forecasts and absolute errors for the five period interval are given in following

table.

F(t+1) = F(t) + a(D(t) - F(t))

F(2) = 41 + 0.3(40 - 41) - 40.7 F(3) = 40.7 +
0.3(42 - 40.7) = 41.09 F(4) = 41.09 + 0.3(41 -

Period	Demand	Forecast	Error	Absolute Error
1.	40	41	-1.00	1.00
2.	42	40.7	1.30	1.30
3.	41	41.09	-0.09	0.09
4.	44	41.063	2.937	2.937
5.	40	41.944	-1.944	1.944
				Sum = 7.271

3.7 TIME SERIES ANALYSIS

One of the most important tasks before economics and business; these days is to make estimates for the future. For example, a business man is interested in finding out his likely sales in the coming years so that he could adjust his production accordingly and avoid the possibility of either unsold stocks or inadequate production to meet the demand. However, the first step in making estimates for the future consists of gathering information from the past. In this connection one usually deals with statistical data which are collected, observed or recorded at successive intervals of time. Such data are generally referred to as 'time - series'. Thus the time series is an arrangement of statistical data in accordance with the time of its occurrence. Hence, in the analysis of time series, time is the most important, it can be week, day, hour or even minutes or seconds. Mathematically

y ® f (t) where y = variable like production, population etc. and t = time like months, years census etc.

Definition

— "A series is a set of statistical observation arranged in chronological order" - Morris Hamburg.

— "A time series consists of statistical data which are collected, recorded or observed over successive increments." - Patterson.

It is clear from above definitions that time series consists of data arranged chronologically. Thus if we record, the data relating to population, per capita income, prices, output, etc. for the last 5, 10, 15, 20 years or some other period, the series so emerging would be called time series.

Uses of the Analysis of Time Series

1. It helps in understanding the past behaviour of a variable and ill determining the rate of growth and the extent and direction of periodic fluctuation.
2. It helps us to predict future tendencies.
3. It helps us to iron out intra-year variation. Thus seasonal ups and downs in sales may be reduced by making effective advertisements.
4. If facilitates comparison. Different time series are often compared and important conclusions drawn there from.

Components of Time Series

To classify the fluctuations of a time series, four basic types of variations are as follows:

1. Secular Trend
2. Seasonal Variation
3. Cyclical Variation
4. Irregular Variation

I. Secular Trend - T

The term 'trend' is very commonly used in day-to-day parlance. For example, we often talk of rising trend to population, prices, etc. The concept of trend does not include short- range oscillations but rather steady movements over a long time. Secular trend movements are attributable to factors such as population change, technological progress and large scale shifts in consumer tests. The underlying factor causing an upward trend in a time series may be application of natural science in the fields of agriculture and industry, the changes in the forms of business organisation facilitating accumulation of huge capital for specialisation and quality control etc. to raise the standard of living, productivity, etc.

No all time series show an upward trend. A declining rate is noticed in the data of epidemics, deaths and births, etc. owinfe to better and widely available medical facilities. This tendency secular movement meaning of trend:

1. The longer the period covered, the more significant the trend. To compute the trend the period must cover at least two or three complete cycles.
2. It is not necessary that the rise or fall must continue in the same direction throughout the period.

Secular trend is usually of two types :

(a) **Linear Trend :** When long term rise or fall in a time series takes place by a constant amount, then that is called a linear trend. This is also known as straight line trend. This is represented by the following equation :

$$Y = a + bX$$

(b) **Parabolic Trend :** The trend is said to be parabolic when long-term rise or fall in a time-series is not taking place at a definite rate. It has many forms but most prominent of them is the second Degree Parabolic or Quadratic trend. It equation is as follows :

$$Y = a + bX + cX^2$$

II. **Cyclical Variations - C**

The term 'Cycle' refers to the recurrent variations in time series that usually last longer than a year and are regular neither in amplitude nor in length. Cyclical fluctuations are long term movements that represent consistently recurring rises and declines in activity. These movements are known as cyclical variations as they pursue an oscillating movements which, in general, takes the form of a wave, though the distance from peak to through of the waves are uneven. There are four well defined periods or phases in the business cycle, namely : (i) prosperity, (ii) decline or recession, (ill) depression, and (iv) improvement or recovery.

The study of Cyclical variations is extremely useful in framing suitable policies, for stabilizing the level of business activity.

III. **Seasonal Variations - S**

Seasonal variations are those periodic movements in business which occur regularly every year and have their origin in the nature of the year itself. Climate and custom together play an important role in giving rise to seasonal movements to almost all the industries. Seasonal variation is evident when the data are recorded at weekly or monthly or quarterly intervals. Although the amplitude of Seasonal Variations may vary their period is fixed being one year. As a result, seasonal variations do not appear in series of annual figures.

IV. **Irregular Variations - I**

business activity which does not repeat in definite pattern. In fact the irregular variation is really intended to include all types of variations other than those accounting for the trend, seasonal and cyclical movements. Irregular variations are caused by such isolated special occurrences as floods, earthquakes strikes and wars. Sudden changes in demand or very rapid technological progress may also be included in this category. By their very nature these movements are very irregular and unpredictable.

3.8 METHODS OF MEASURING TREND

The main methods of measuring trend in a time-series are as follows :

1. Free Hand Curve Method
2. Semi-Average Method
3. Moving Average Method
4. Least Square Method

1. Free Hand Curve Method

This is the simplest of the trend-fitting. In this method first of all the original data of the time-series is plotted on a graph-paper. Thereafter, taking care of the fluctuations of data, a smooth curve is drawn which passes through the mid-points

of the fluctuations of time-series, In fact, this curve is called as freehand trend curve. This method is also called as trend fitting by inspection.

2. Semi-Average Method

In this method, first of all time-series is divided into two equal parts and thereafter, separate arithmetic mean is calculated for each part. The trends of arithmetic means is plotted in graph corresponding to the time-periods. Joining the two points, straight line thus obtained is called as trend line. The semi-average method can be applied in case of two situations :

(i) When the number of years in a series is even : When the given number of years in a series is even like 4, 6, 8 etc., then the series can be easily divided into two equal parts. In this situation trend-fitting process can be illustrated with the following example :

Example :

Fit a trend line by the method of semi-average to the data given below :

Year	1993	1994	1995	1996	1997	1998
Production ('000 Units)	22	26	24	30	28	32

Solution :

Fitting of Trend Line by Semi-Average Method

Year	Production (000 units)	Semi-Total	Semi-Average	Middle Year
1993	22			
1994	26	72	72/3 - 24	1984
1995	24			
1996	30			
1997	28	90	90/3 - 30	1987
1998	32			

(ii) When the number of years in a series is odd : When the number of years in a series is odd like 5, 7, 9, then there will be a problem in dividing the series into two equal parts. In such case, the mid-year figure is to be dropped. For example, if 1981 to 1989 figures are given, then we will delete 1985 i.e. 5th year and its corresponding figure and we will make 4-4 years' parts i.e. 1981 to 1984 and 1986 to 1989. The remaining process will be the same as before. Trend fitting in this case can be illustrated by the following example:

Example :

Fit a trend line by the method of semi-averages to the data given below :

Year	1991	1992	1993	1994	1995	1996	1997
Profit ('000 Units)	20	22	27	26	30	29	40

Also estimate the profit for the year 1998.

Merits and Demerits of Semi-Average Method

Merits :

(i) This is an easy method.
(ii) This method is free from bias.
(iii) Trend values thus obtained are definite.
(iv) Less time and effort is involved in drawing the trend line.

Demerits :

(i) This method is based on straight line trend assumption which does not always hold true.
(ii) This method is affected by extreme values.
(iii) This method ignores the effect of cyclical fluctuations.

3. Moving Average Method

Under this method, moving averages are calculated. In moving average computations, one has to decide what moving year average - 3 year, 4 year, 5 year, 7 year should be taken up. The period of moving average depends upon the periodicity of data and there is no specific rule for that. The period is determined by plotting the data on the graph paper and noticing the average time interval of successive peaks or troughs. However, it is essential to consider while selecting the period of moving average that after how many years most of the fluctuations occur in the data. Moving average method is studied in two different situations :

(i) Odd Period Moving Average
(ii) Even Period Moving Average.

(i) Odd Period of Moving Average : When period of the-moving average is odd, say 3 years, then following steps are to be taken for the computation of moving average :

1. First of all, add up the values corresponding to first 3 years in the time series and put the sum before the middle year (i.e. 2nd year).
2. Thereafter, leaving the first year value, add up second, third and fourth year values and put the sum in front of middle year (i.e. 3rd year). Carry this process further till we reach the last value of the series.
3. Moving totals thus obtained are to be divided by the period of the moving average and show the trend values of different years.

Similarly, five-yearly, seven-yearly moving averages can be obtained.

The computation procedure of 3-yearly moving averages can be illustrated with the following example :

Example:

From the following data, calculate trend values using 3-yearly moving average:

Year	1991	1992	1993	1994	1995	1996	1997
Production	20	22	27	26	30	29	40

Solution :

Since there are 7 years, the middle year 1994 will be left out and the arithmetic average of the two parts will be calculated as given below :

Year	**Production ('000 units)**	**Semi-Total**	**Semi-Average**	**Middle Year**
1991 1992 1993	20 22 27	69	69/3 - 23	1982
1994	26		Omitted	
1995 1996 1997	30 29 40	99	99/3 « 33	1986

(ii) Even Period Moving Averages : When moving average period is even, say 4 years, then moving averages have to be centered. It cam be computed by two methods :

(a) First Method

(b) Second Method

(a) First Method : The computation procedure of 4 yearly moving average is as follows:

(i) First of all, add up first 4 values corresponding to the first 4 years and put the sum in between second and third year. Thereafter the next total (i.e. from 2nd to 5th year total) is to be put in between 3rd and 4th year. Carry on this process till the last value of the series.

(ii) Now add up the 1st and 2nd 4-year totals and put them in front of 3rd year. Similarly, add up 2nd and 3rd 4-year total and put them in front of 4th year. Carry on this process till the last value.

(iii) 8 years totals thus obtained are to be divided by 8. These values are 4-yearly moving averages and show the trend values for different years.

The computation procedure is made clear by the following example :

Example :

Calculate the trend values using 4 yearly moving average from the following data :

Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Sales (in crores)	7	8	9	11	10	12	8	6	5	10

Solution :

Computation of 4 Yearly Moving Average (Trend)

Year	Sales (in crore)	4 yearly moving totals	2 period moving totals of 4 yearly moving totals	4 yearly moving average (centered) (Trend values)
1990	7			
1991	8	7 + 8 + 9+ 11 = 35		
1992	9	8 + 9 + 11 + 10 = 38	35 + 38 = 73	73/ 8 = 9.125
1993	11	9 + 11 + 10 + 12 = 42	38 + 42 = 80	80/ 8 = 10.00
1994	10	11 + 10 + 12 + 8 = 41	42 + 41 = 83	83/ 8 = 10.375
1995	12	10 + 12 + 8 + 6 = 36	41 + 36 = 77	77/ 8 = 9.625
1996	8	12 + 8 + 6 + 5 = 31	36 + 31 = 67	67/ 8 = 8.375
1997	6	8 + 6 + 5 + 10 = 29	31 + 29 = 60	60/ 8 = 7.5
1998	5			
1999	10			

(b) Second Method : There is an alternative method of constructing 4-yearly centered moving averages, the method of which is given below:

1. First of all add up the 4-values corresponding to the first 4 years and put the sum in between second and third year. Thereafter, the next total (i.e. from second to fifth year total) is to be put in between 3rd and 4th year. Carry on this process till the last value of the series.
2. 4-yearly moving totals thus obtained are divided by 4 to obtain 4-yearly uncentered moving averages.
3. Now add up 1st and 2nd 4-yearly moving averages and divide it by 2. Put this average in front of 3rd year. Similarly, add up 2nd and 3rd 4-yearly moving averages and divide it by 2 and put this average in front of 4th year. Carry on this process till the last value. These values so obtained are 4-yearly centered moving averages and show the trend values for different years.

Merit and Demerits of Moving Average Method

Merits :

(1) This method is easy to understand and simple to use.

(2) This method is flexible i.e. if number of years is added in a series, previous calculations are not affected.

(3) This method is most suitable for eliminating cyclical fluctuations.

(4) This method has great practical usefulness.

Demerits :

(1) It is difficult to ascertain the proper period of moving averages and if proper period is not ascertained, results will be misleading and inaccurate.

(2) The second defect of this method is that some beginning years' and some terminal

years' trend values remain beyond- the scope of calculations.

(3) The limitations of arithmetic mean affect this method adversely.
(4) If periodicity in the series is not clearly visible, this method should not be used.

4. Least Square Method

This is the best method of trend-fitting in a time series and is most used in practice. This is a mathematical method and a trend line in this method is fitted or obtained in such a way that following two conditions are fulfilled :

(1) $I(Y - Y_c) = 0$ i.e. the sum of the deviations of the actual values of Y and computed trend values is zero.
(2) $I(Y - Y_c)^2 = 0$ is least i.e. the sum of the squares of the deviations of the actual and computed trend values from this line is least.

Trend-line thus fitted under this method is called as the Line of Best Fit.

Least square method can be used to fit straight line trend or parabolic trend.

(1) Fitting of Straight Line Trend

A straight line trend can be expressed by the following equation :

$Y = a + bX$

Where Y =* Trend Values, X *= Unit of Time a is the Y-intercept and b is the slope of the line.

In the above equation, to determine two constants, a and b, the following two normal equations are solved:

$IY = Na + bX$ .... (i)

$IXY = a\ EX + bX^2$ .... (ii)

After determining the equation Y •= a + bX, we find the trend values related to different years and plot them on the graph paper which show a straight line trend.

There are two methods of computing straight line trend by using least square method:

(a) Direct Method
(b) Short Cut Method

(a) Direct Method

The procedure to compute straight line trend in this method is as follows :

(i) Any year other than the middle year is taken as the year of origin. Usually first year or before that is taken as zero, deviations of other years are marked on 1, 2, 3.... etc. Time deviations are denoted by X :
(ii) Then X, Y, XY and X2 are computed.
(iii) The values computed are put in the following normal equations:

Year	1989	1990	1991	1992	1993	1994
Production (Lakh Tons)	5	7	9	10	12	17

Also obtain the trend values.

Solution :

Fitting of Straight Line Trend

Year	**Production Y**	**Deviation from 1988 X**	**XY**	**X^2**
1989	5	1	5	1
1990	7	2	14	4
1991	9	3	27	9
1992	10	4	40	16
1993	12	5	60	25
1994	17	6	102	36
N=6	EY = 60	EX - 21	EXY = 248	EX^2 = 91

The straight line trend is defined by the equation:

Y- a + bX Two normal equations are

EY = Na + bX ....(i)

EXY = a EX + bX^2 ....(ii)

Substituting the values, we get

60 = 6a + 21b ....(i)

248 = 21a + 91b ....(ii)

Solving the two equations (i) and (ii).

Multiplying (i) by 7 and (ii) by 2 and then subtracting 420 = 42a + 147b 496 = 42a + 182b

-76 = -35b

b - -76/-3 5 = 2.17 By substituting the value of 'b' in equation (i), we get: 60 = 6a + 21b or 60 = 6a + 21(2.17) or 6a = 14.43

a = 2.40 Hence, the trend equation is

Y = 2.40 + 2.17X; origin = 1988, X unit = 1 Year. Computation of Trend Values

For 1989, X-1, Y = 2.40 + 2.17 (1) = 4.57

For 1990, X=2, Y - 2.40 + 2.17 (2) = 6.74

For 1991, X=3, Y = 2.40 + 2.17 (3) = 8.91

For 1992, X=4, Y = 2.40 + 2.17 (4) - 11.08

For 1993, X=5, Y = 2.40 + 2.17 (5) - 13.25

For 1994, X=6, Y = 2.40 + 2.17 (6) = 15.42

(b) Short Cut Method

The process of computation in this method to find straight-line trend is as follows :

1. First of all, middle-year is taken as the year of origin with value zero and deviations for other years are computed. Sum of the deviations will be zero i.e. X=0. Since deviations above middle-year will be -1, -2, -3 etc. and deviations after middle year will be 1, 2, 3... etc. and deviations above and below middle year will balance out. This is made clear by the following example :

Year	1992	1993	1994	1995	1996	1997	1998
X	-3	-2	-1	0	-1	+2	+3

2. Y, XY and X^2 are computed.
3. For computing the values of a, b, we need not have normal equations but they are found by the following formulae:
4. Finally, the calculated values of a, b are put in the equation Y = a + bX and with its help, trend values axe computed.

Short-cut method is studied in two cases

(i) When number of years is odd
(ii) When number of years is even

(i) When Number of Years is odd : When number of years is odd like 5, 7, 9... etc. then the computation of straight line trend can be illustrated with the following examples:

Example :

Fit a straight line trend by the method of least squares to the following data and also

show on graph paper :

Year	1993	1994	1995	1996	1997	1998	1999
Production ('000 units)	80	90	92	83'	94	99	92

Solution :

Year	Y	Deviations X	XY	X^2
1993	80	-3	-240	9
1994	90	-2	-180	4
1995	92	-1	-92	1
1996	83	0	0	0
1997	94	1	+94	1
1998	99	2	+ 198	4
1999	92	3	+276	9
N=7	**Y=630**	**X=0**	**XY = 56**	**X^2=28**

Let the equation of the straight line trend is: Y = a + bX

Since SX =0

a = SY/N, b = SXY/SX2 Substituting the values, we get a = 90 , b = 2 Thus, Y «= 90 + 2X

Origin = 1996, X unit - One Year

Computation of Trend Values

For 1993, X = -3, Y_c = 90 + 2 (-3) - 84 For 1994, X = -2, Y_c = 90 + 2 (-2) = 86 For 1995, X = -1, Y_c - 90 + 2 (-1) = 88 For 1996, X = 0, Y_c = 90 + 2 (0) = 90 For 1997. X = + 1, Y_c = 90 + 2 (1) = 92 For 1998, X = + 2, Y_c * 90 + 2 (2) = 94 For 1999, X = +3, Y_c = 90 + 2 (3) = 96

(ii) When Number of Years is Even : When given number of years is even (6, 10, 12 ... etc.), in such a case, what is to be the middle year becomes a problem. In such a case, mean of the two middle years is taken as year of origin i.e. zero value and correspondingly, deviations for other years are found out. Deviations will be -2.5, - 1.5, -0.5, 0.5, 1.5 and 2.5. To simplify the computation process, these deviations are multiplied by 2. The remaining steps are the same as before.

Example

Fit a straight line trend by the method of least square to the following data and find the trend values :

Year	1991	1992	1993	1994	1995	1996	1997	1998
Value	80	90	92	83	94	99	92	104

Solution:

Fitting of Straight Line Trend

Year	Value Y	Deviations from 1964.5	Deviations Multiplied by 2 X	XY	X²
1991	80	-3.5	-7	-560	49
1992	90	-2.5	-5	-450	25
1993	92	-1.5	-3	-276	9
1994	83	-0.5	-1	-83	1
1995	94	+0.5	1	94	1
1996	99	+ 1.5	3	297	9
1997	92	+2.5	5	460	25
1998	104	+3.5	7	728	49
2 H 00	Y = 734		X"0	XY-210	X² - 168

The equation of the straight trend line is:

Y = a + bX Since X = 0

a = ZY/N, b - SXY/LX²

Substituting the values, we get a » 91.75, b = 1.25 The straight line trend is:

Computation of Trend Values :

For 1991, X = -7, Y_c = 91.75 + 1.25 (-7) = 83

For 1992, X = -5, Y_c » 91.75 + 1.25 (-5) - 85.5

For 1994,	X - -1,	Y_c = 91.75 + 1.25 (-1)	= 90.5
For 1995,	X « +1,	Y_c = 91.75 + 1.25 (+1)	= 93.0
For 1996,	X = +3,	Y_c = 91.75 + 1.25 (+3)	- 95.5
For 1997,	X = +5,	Y_c = 91.75 + 1.25 (+5)	= 98.5
For 1998,	X - +7,	Y_c - 91.75 + 1.25 (+7)	= 100.5

Merits and Demerits of Least 8quare Method

Merits :

(1) This method is far better than moving average method because the trend values for all the years are obtained. Not even a single initial or terminal trend values is left over in this method.

(2) It results in a mathematical equation which may be used for forecasting.

(3) It is widely used method of fitting a curve to the given data. The results obtained are reliable and appropriate.

Demerits :

(1) The computation process in this method is complex which is not easily understandable.

(2) This method does not have the attribute of flexibility. If some figures are added to or subtracted from the original data, all computations have to be redone.

(3) It is difficult to select an appropriate type of equation in this method. Results based on inappropriate selection of equation are likely to be misleading.

3.9 EXERCISE

1. Discuss the methods of forecasting.
2. Write notes on :
   (a) Importance of forecasting.
   (b) Medium term forecasting.
   (c) Distinguish between short term and long term forecasting.
   (d) Regression Analysis Method.
3. How is the demand for a product estimated with the help of regression analysis?
4. What are the criteria for a good forecasting method? How do you rate Regression Analysis for this purpose?
5. How can a business economist make qualitative forecasts?
6. How can we use regression technique to fit a time trend to the demand for product or service for forecasting purposes?
7. What is meant by exponential smoothing of a demand function? How is it more useful than linear curve fitting?
8. Fit a trend line for the following data by semi-average method:

Year 1993	1994	1995	1996	1997	1998
Profit 80 ('000 Units)	82	85	70	89	95

9. Fit a trend line for the following data by semi-average method :

Year	1990	1991	1992	1993	1994	1995	1996
Production ('000 Units)	12	14	16	20	20	31	28

Also estimate the value for the year 1998.

10. Fit for straight line trend by method of least squares to the following data and show on graph paper :

Year	1981	1982	1983	1984	1985	1986	1987
Production (000 tons)	80	90	92	83	94	99	92

(Ans. Y = 89 + 2X, 84, 86, 88, 90, 92, 94, 96)

11. Fit for straight line trend by method of least squares to the following data and also tabulate the trend values :

Year	1971	1972	1973	1994	1975	1976	1977
Value	77	80	94	85	91	98	90

[Ans. Y = 89 + 2X; 85; 87; 89; 91; 93; 95) 12.

F'it a straight line trend by method of least squares and estimate the production for the year 1995 and 1997:

Year	3 989	1990	1991	1992	1993	1994
Production (in lakh tons)	25	40	47	59	68	80

(Ans. Y = 53.17 + 5.3X, 90.27, 111.47]

13. Fit a linear trend to the following time series by the method of least squares and also obtain the trend values :

Year	1954	1955	1956	1957	1958	1959
Production (in crores of Rs.)	7	10	12	14	17	24

[Ans. Y = 14 + 1.54X, 6.28, 9.37, 12.46, 15.55, 18.64, 21.73]

14. Fit a straight line trend by the method of least square (taking 1981 as year of origin) to the following data :

Year	1991	1992	1993	1994	1995
Value	15	21	25	33	40

[Ans: Y - 14.4+6.2X, 14.4, 20.6, 26.8, 33, 39.2]

Also obtain the trend values.

15. Fit a straight line trend by the method of least square to the following data :

Year	1989	1990	1991	1992	1993
Value	45	56	78	46	75

[Ans. : Y = 45 + 5X; 50, 55, 60 65, 70]

Also obtain the trend values.

16. Find trend values for the following data, by using 5 yearly moving averages. Also plot the

Year	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Production	672	679	690	702	712	802	807	809	816	821

[Ans. 691.0, 717.0, 742.6, 766.4, 789.2, 811.0]

17. Calculate trend values (using 3 yearly moving average) for the following data:

Year	1981	1982	1983	1984	1985	1986	1987	1988
Production ('000)	60	72	65	80	85	85	95	110

[Ans. 69, 70.67, 73.33, 76.67, 86.67, 96.67)

18. Find trend values using 4 yearly moving average form the following data:

Year	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Production ('000)	100	105	115	90	95	85	80	65	75 I	70	75	80

[Ans. 101.88, 98.75, 91.88, 84.38, 78.75, 74.38, 71.88, 73.13)

3.10 SUGGESTED READINGS

1. K. Aswathappa, **Production and Operations Management,** Himalaya Publishing House, Mumbai, Reprint, 2007.
2. R. Paneerselvam, **Production and Operations Management,** Prentice-Hall of India, New Delhi, 2nd Edition, 1999.
3. Elwood S. Buffa, **Modem Production Management,** Wiley Series, 8th Edition.

MBA-CC (First Year)

Semester-II

Lesson No. 4

OM 204-B OPERATIONS MANAGEMENT

AUTHOR : ER. SAHIL RAJ

PLANT LOCATION

STRUCTURE

4. OBJECTIVES

After reading this lesson, students would be able to answer :

- Importance of plant location
- Factors affecting location decisions
- Plant location Models

4.1 INTRODUCTION

Because the fundamental objective of an enterprise is to maximize its profits which can be done either by increasing sales or by reducing cost of production. If an enterprise is located near its potential market then the organization can have better and up to date understanding of the market and thus can formulate more effective production and marketing strategies to increase sales. The reduction in cost of production is possible when a firm is located at a place where all kinds of production economies are available. Thus location of a plant is important due to following factors :

1. Location of plant partially determines operating and capital costs. It determines the nature of investment costs to be incurred and also the level of many operating costs.
2. Each prospective location implies a new allocation of capacity to respective market area.
3. Location fixes some of the physical factors of the overall plant.

Localization Vs Delocalization

Concentration of similar type of industries at some particular place is known as localisation. The tendency of localisation can be observed in various industries e.g. localisation of jute industry in West Bengal, textile industry in Bombay and Ahmedabad. But localisation has many disadvantages :

1. Localisation leads to accumulation of too many workers at one place making the atmosphere crowdy and unhealthy.
2. It leads to unbalanced development and unequal distribution of wealth.

3. It is unsafe in the cases of war and due to other safety reasons.
4. Local population becomes economically dependent on the industries of that area and may face financial difficulty when the industries in the area fail in their performance.
5. The market of the product may be over exhausted.

Due to above factor's the trend in recent years is towards DELOCALISATION. Delocalisation is an indication tat there are many good locations for many industries. Delocalization is taking place on nationwide scale and within the industrial communities.

The main reasons responsible for Delocalisation are :

1. Development of large national markets.
2. Various incentives and concessions in tax, land etc. by various states to encourage industrialization.
3. Many times Delocalisation leads to better co-ordination, improved supply of lobour and raw material and better distribution of products.
4. Balanced regional development.

The degree of significance for the selection of location for any enterprise mainly depends on its size and nature. Sometimes, the nature of the product itself suggests some suitable location. A small scale industry mainly selects the site where in accordance with its capacity the local market for the product is available. But for large scale industries requiring huge amount of investment there are many considerations other than the local demand in the selection of proper plant location. These plants cannot be easily shifted to other place and the error of judgment in the selection of site can be very expensive to the organization.

Plant Location is one of the major decision for any organization. So it is very important to select ideal location. Selection of ideal location is governed by various factors. These factors can divided into three main categories.

4.2 FACTORS OF PLANT LOCATION

4.2.1 Selection of a Region

Selection of a region is a very broad decision. The managers take into account all the factors that determine general area where the plant is to be located. While selecting a particular region following important factors are considered.

Availability of Raw-Materials : Adequate and quality of raw-material over a long period is one of the important conditions for selecting a region. The raw-materials are divided into two categories as "ubiquities" and "localized". The UBIQUITICS are those raw- materials which are available everywhere such as soil, clay, water, pebbles, sand and the other type of raw-materials include minerals, timber, coal and agro based products. The localized materials are further divided into "pure" and "gross". Pure materials add to the weight of the end product and, therefore, those industrial units using pure materials are forced to be located near markets. E.g. cotton, raw wool, silk etc. Gross materials are those which lose their original weight in processing cycle, e.g. sugarcane, iron, coal etc. those industries which use these materials are located near to the source of the raw- materials.

power should be available.

Means of Transportation : Transportation is a factor that affects in two ways. First there is need for movement of raw-material and employees to the factory and second is the movement of end products. The factors to be considered in choosing a particular mode of transport will be- its cost, dependability, time for movement, availability, speed and flexibility. So a region should fulfill all these factors.

Market Place : A market place means people, their purchasing power and their preference to buy a particular product. The components of market are people, offer, product or service and the infrastructure for exchange. The location of plant nearer to or in the market place is determined by various factors. The most important one are- that location reduces the cost of transport of the end product and expenses, that it enables the firm to feel the pulse of market, that it makes possible for rendering prompt service, that it facilitates after sale service.

Topography : The meteorological factors such as heat, humidity, rainfall etc. in and around the location are veiy important. A scientific study should be conducted to study all these variables before selecting a region. For example a person working in a hot and humid condition gets tired very soon than a person working in a coo climate. Similarly hilly or rocky conditions also affect the transportation costs.

4.2.2 Selection of a Particular Community

Once the entrepreneurs have selected the region the next step is to select the community. The community here means the "locality". Selecting a particular community depends on various factors :

Labour : Like material cost, labour cost forms the substantial part of total cost of a product. Both production and product distribution activities are greatly and deeply influenced by it. So, priority is given to that locality which promises adequate supply of labour of right kind at least cost.

Banking Facilities : The finance is needed at every step of operation whether it is at the inception level or at the level of future expansion, diversification, rationalization all these activities need huge capital input. This situation of getting finance in this competitive world at least cost and with least string attached, exerts location pull. That is why, existence of banks and other financial institutions will have deeper and everlasting impact on the

- location pf plant.

Water Supply : Availability of water is another significant factor while selecting **a** locality. Water is used for industrial processing, sanitation, drinking, cooling, waste disposal etc. Depending on the nature of individual process involved and the size of it, the place must have adequate quantity of water which must be suitable.

Political Stability : Industrial peace and tranquility form the basis of sound working of any enterprise. The industrial peace and discipline is mainly determined by the politics of the locality. A locality might be suited to a particular business but the political situation prevailing in the locality might not encouraging. So political stability is very important factor in deciding a particular locality.

State Assistance : The extent and the nature of state assistance in monetary and non monetary terms to the industrial units or to be located decide the extent of attraction of new units to the locality. These can be in the form of subsidy, exemptions and concessions including incentive so to boost the industrialization.

4.2.3 Selection of an Exact Plant Site

The third and final round of selection of plant location is its exact site in different localities. The crucial factors that govern such selection are :

Price : One can not think of establishing his factor in the thin air. Land is a must. So price of land is one of the important factor in selecting the site.

Type of Soil : When one talks about the soil, it not only includes the surface soil but also the subsoil conditions. It is load bearing capacity of the hidden layers of soil. Soft and sandy soil demands expensive foundations. That is why, soil tests are conducted to assure solid building that last for decades.

Ease in Waste Disposal : Manufacturing is the process of using the inputs into outputs but it also involves some amount of waste. The waste warrants necessary arrangements for its disposal to reduce the dangers to flora and fauna. The site selected should have adequate arrangement of disposing the waste.

Potentiality for Future Expansion : While deciding the area of site, one should go by the not myopic considerations. While deciding the exact area one should take into account the future potential for expansion and growth.

Existence of Commercial Services and Amenities : A manufacturing unit can not work in isolation; it is to make use of commercial services, amenities and allied facilities. E.g. warehousing, workshop for repairs, security services, means of communication etc. The amenities include schools, colleges, clubs, hospitals etc. So all these factors are very much important for selecting a site.

4.3 PLANT LOCATION MODELS

Generally plant location decisions could be one of the two :

4.3.1 One Facility Out of Multiple Candidates

In this case, decision is to select one location out of many locations e.g. a firm may want to choose one location out of alternatives to build its factory and in the second case; the decision is to select k locations out of n alternatives. E.g. a firm wants to locate four regional warehouses to serve demand throughout the country. Therefore, it may have to choose four locations out of the say 10 alternatives available to it.

For the first case there are three different MODELS that can be used

(1) Location Factor Rating

It is one of the simplest methods to compare the alternatives sites using the factors identified to be relevant are to use a factor rating method. Factor rating is simple methodology to assess the attractiveness of each potential location. This method involves four different steps, in which relevant factors are identified, their relative importance is established, the performance of each location in each

- The easiest method to establish the relative importance of each factor is to rate each factor on the scale of 0 to 100.
- Rate the performance of each location using a rating mechanism.
- Compute a total score for each location, based on its performance against each factor and rank them in the decreasing order of the score.

(2) Centre Of Gravity Method

In the above method, we have used weighted scheme to assess the attractiveness of each location. However, it is possible to utilize more direct measures for evaluating each location. Often location planners tend to use a distance measure to evaluate the impact of the proposed location. Such an approach is more appropriate in case of locating the operations close to the market for the aw-products or for the raw-materials. By locating far away, an organization may end up spending considerably on transportation and distribution. Therefore, assessing the distance of the site vis-a-vis the reference market could be a better method for selecting appropriate location. In the centre of gravity method, all demand points or the supply points, if the raw-material is supplied from several locations are represented in a Cartesian coordinate system. Each demand (or supply point) will have also weights, which indicates the quantum of the demand (or supply). Per unit time. In this context, it is possible to identify the centre of gravity of the various demand or supply points. Locating the new facility at this point will be most appropriate.

(3) Load- Distance Method

The load-distance method enables a location planner to evaluate two or more potential candidates for locating a proposed facility vis-a-vis the demand or supply points. The load-distance method provides an objective measure of the total load-distance for each of the potential candidates. Choosing the location with the best load-distance among these will satisfy the objective if identifying an appropriate location for the proposed facility. Distance is measured using a Cartesian measure.

The Load-distance for a candidate j for the proposed facility LDj is nothing but the product of the distance between the candidates and all existing demand or supply points.

$$LD_j = \sum_{i=l}^{n} D_{ij} * W_i$$

4.3.2 Multiple Facility out of Multiple Candidates

Transportation Model : So far we have discussed the issue of choosing one location for the proposed new facility. However, a situation may arise when we have to choose multiple locations. The location planner must also decide which of the demand points will be served by each of these locations and to what extent. Locating distribution centers for nationwide distribution of the product is a typical example belonging to this category of decision-making. Choice of multiple locations requires combined set of locations will ensure minimum cost of transportation pertaining to the flow of products in the distribution chain. Therefore, the problem is one of managing network flows to satisfy set of demand satisfy the demand points. There is a unit transportation cost of shipping the material from every point to every demand point, and an optimal choice of supply points, total cost of transportation is minimized. In the process of doing this, it is ensured that none of the capacity constraints in the supply point is violated. Similarly, it is also ensured that at every demand point the requirement is fully satisfied.

4.4 EXERCISE

1. Why Plant location is Important for the success of any organization?
2. What are various factors important for choosing an ideal location?
3. Explain the different location models for choosing single facility out of many candidates?
4. Explain the location model for choosing multiple facility out of multiple candidates?

4.5 SUGGESTED READINGS

1. Jacobs, Aquilano, Agarwal and Chase — Operations Management
2. Mahadevan B : Operations Management
3. Charry S. N. : Operations Management
4. Buffa : Production and Operations Management
5. Taha, H. A. : Operations Research: An Introduction

MBA-CC (First Year)

Semester-II

Lesson No. 5

OM 204-B OPERATIONS MANAGEMENT

AUTHOR : ER. SAHIL RAJ

PLANT LAYOUT

STRUCTURE

5. OBJECTIVES

After reading this lesson, students would be able to answer :

- Importance of plant layout
- Types of layout
- Models and techniques for designing layout

5.1 INTRODUCTION

Once the decision about the plant has been taken, next important problem before the management is to plan suitable layout for the plant. Efficiency and performance of good machines and sturdy building depend upon layout of a plant. Plant layout is the method of allocating machines and equipment, various production processes and other necessary services involved in transformation process of a product with the available space of the factory so a to perform various operations in the most efficient and convenient manner providing output of high quantity and minimum cost. Thus plant Layout is identically involves the allocation of space and arrangement of equipment in such a manner that overall operating costs are minimized. Planning the layout is a continuous process as there are always chances of making improvements over the existing arrangement specially with shifts in the policies of management of techniques of production.

5.2 OBJECTIVES OF LAYOUT

1. Economies in materials facilitate manufacturing process and handling of semifinished and finished goods.
2. Proper and efficient utilization of available floor space.
3. To ensure that work proceeds from one point to another point inside the plant without any delay.
4. Provision of better supervision and control of operations.
5. Careful planning to avoid frequent changes in layout which may result in undue increase in cost of production.
6. To provide adequate safety to the workers from accidents.
7. Provision of medical facilities and cafeteria at suitable and convenient places.
8. To meet quality and capacity requirement in the most economic manner.

9. To provide efficient material handling system.
10. To suggest improvements in production process and work methods **Why layout problem exists**

The various problems for the layout can be-

— Enlargement or contraction of existing departments
— Movements of a department due to change in the design of product.
— Addition of some new department.
— Replacement or addition of some new facility/machinery.

5.3 ADVANTAGES OF PLANT LAYOUT

To the Worker

— Lesser number of operations and material handling.
— Reduction in length of hauls and motions between operations.
— More labour productivity
— More safety and security to workers from accidents.
— Better working conditions resulting improved efficiency.

To Manufacturing Costs

— Maintenance and replacement costs are reduced.
— Loss due to waste and spoilage is minimized.
— Improved quality of product with reduction in handling.
— Better cost control.

To Production Control and Supervision

— Provides more space for production operations.
— Control and supervision operations are provided at appropriate rates.
— Better and convenient storage facilities.
— Efficient arrangement for receipt, transportation and delivery of raw material and finished goods.
— Results in less inspection activity.
— Cost and efforts in the supervision of production are minimized.

5.4. TYPES OF LAYOUT

5.4.1 Product Layout

Here the position of a particular machine is determined at some definite stage or place where the machine is required to perform some operation from a sequence of operations designed to manufacture the product. The position and order of a machine or equipment is fixed. Once the machine is in line, it cannot perform any operation, which is not designated in the sequence of operations. Manufacturing of large quantity of standardized products is the primary condition to this type of layout. Examples: Sugar refineries, cement plants, rolling mills and paper mills.

Advantages of Product Layout

1. Ensures smooth and regular flow of materials and finished goods.
2. Provides economies in materials and labour by minimizing wastages.
3. Since travel, storage and inspection occur less frequently, time and opportunity for delay in operations are minimized.
4. In this system, there are direct channels of flow of materials flow, short distance between operations, and lesser back-tracking. This reduces proportion of material

handling requirements.

5. One can use special purpose automatic or semi automatic machines greater specialization of jobs results in highly proficient operations.
6. This type of layout helps in lesser inspection.
7. There is more floor area available for production. Because of less storage is needed and less inspection stations.
8. Due to standardized operations, routing and scheduling is to be done in beginning only. This facilitates production planning and control problem.

Disadvantages of Product Layout

1. Product layout is inflexible in nature- The facilities are designed to perform special operations. The machines cannot be interchanged either in capacity or regard to other operations.
2. Vulnerability to production line shut down- If any machine or equipment in production line breaks down the whole production line is immobilized.
3. Supervision is difficult- The system requires more specialized and skilled supervision because the activities are diversified and requires special knowledge.
4. Requires heavy capital investment - In this system there is unavoidable duplication of facilities, which increases capital investment.

5.4.2 Process Layout

In this layout more emphasis is given to specialization or functional homogeneity on various components of the system. All operations of similar nature are grouped together in the same department or part if the factory. Here machines performing same type of operations are installed at one place e.g. all drilling machines are located at one place known as DRILLING SECTION. Similarly operations are classified in different sections such as moulding, packaging etc.

Advantages of Process Layout

1. In the case of smaller quantities and with varying specifications the type of layout is most appropriate.
2. In each specialized section, workers expert in the specific operations can be used.
3. Each production unit of the system works independently and is not affected by the happenings in another section.
4. Provides cohesiveness and enable individual bonus schemes.
5. Wide flexibility in production facilities.
6. Supervision and inspection work can be independently and efficiently carried out in department.
7. Machine breakdowns does not disrupt production schedule as during breakdown the work can be easily transferred to another machine in the same section.
8. The production facilities can be utilized to greater capacity with lesser duplication of machines. This leads to lesser investment.

Disadvantages of Process Layout

1. Here there is no definite channel through which all work can flow. There is too much movement of semi finished goods from one place to another inside plant this leads to higher material handling.
2. The speed of the various operations in the system is likely to be low as more time is required for material handling, transportation and inspection.

3. *With increase in the size of the plant and the variety of operations it can perform the function of co-ordination of various processes and operations becomes difficult.*
4. *A larger proportion of the floor area is required for the service.*
5. *The inspection is more frequent and costlier.*
6. *It requires highly skilled labour to operate a number of machines.*

5.4.3 Stationary Layout

This type of layout is used in those situations where the semi-finished goods are of such a size and weight that their movement from one place to the other is not possible. Here men, equipment and the raw materials are moved to a place where all the manufacturing activities are carried out.

E.g. ship building, manufacturing activities of locomotives, construction of dams.

Advantages of Stationary Layout

1. *Layout is simple and capable of frequent adjustments.*
2. *Laborers and workers can be employed and remain busy throughout the process in one work or another.*

Disadvantages of Stationary Layout

1. *Since machines and equipment are transferred to some particular place, heavy and sophisticated equipment cannot be used.*
2. *Due to low efficiency of men and machines this layout is suitable for some special type and for the production of smaller amount of items.*

5.5 MODELS FOR DESIGNING

5.5.1 Design of Process Layout

The first step is identifying the number of departments required and the space required for each department. Since process layouts are made on the basis of functional similarity of the resources this is not a difficult decision. The second step in the design process is to estimate the flow of material between departments and the cost of moving one unit across departments. Once the basic data is available then appropriate method from following two can be used in the third step.

Qualitative Approach to Layout: In this approach, some qualitative measures are used to decide which department is to be located next to smother department. One method can be "the use the interdepartmental flow as the basis on which closeness between one department and another department could be established. Using closeness ratings between the departments, layouts can be constructed.

Quantitative Approach to Layout Design : The quantitative method in designing uses measures for assessing the impact of the layout and seeks to arrive at the best method for locating the departments. It uses the information regarding the flow rate; distance between the departments and the cost, then by using quantitative method a design is finalized. This quantitative method can be based on mathematical programming or it can be computerized procedure. In the mathematical programming the concepts of Assignment are used to select the best layout. In the computerized procedure uses Computerised Relative Allocation of Facilities (CRAFT). CRAFT uses the improvement method for obtaining the best layout. In the CRAFT, an initial feasible layout is formed and a series of improvement opportunities are explored through a pair-wise exchange of departments. After all these evaluations, the best possible pair-wise exchange is identified.

5.5.2 Designing of Product Layout

Assembly Line Balancing : This technique is being used to design the process layout. E.g. Bajaj produces 10,000 two wheelers every day. So it is very important that all the sub- assemblies need to co-ordinate to match production rate. The assemblies also need to have resources at each work station. So a proper layout is very necessary. Line balancing is a method by which the tasks are optimally combined without violating precedence constraints and a certain number of workstations are designed to complete the task.

In line balancing, all the important parameters are can be calculated which are very helpful in designing the process layout.

Important Parameters that are calculated

- *Daily Production Rate*
- *Maximum cycle time*
- *Minimum number of workstations*
- *Average Utilization*

There is a trade-off between numbers of workstations. If we go for less number of workstations, then the cost will decrease as the requirement of resources will also be less but the cycle time will increase and production rate will decrease. Similarly when we assign task to more workstations then more resources are required.

Example : A factory working in 2 shifts each of 8 hours produces 24,000 electric bulbs using a set of workstations. Using this information, compute the actual cycle time of the plant operation. There are 8 tasks required to manufacture the bulb. The sum of all tasks is equal to 12 seconds. How many workstations are required to maintain this level of production assuming that combining of tasks in those workstations is a possible alternative?

*Sol. : Available time - 2*8*60*60*

- 57,600 sec

*Actual production * 24000 electric bulbs*

Max. Cycle time = 57,600/24000 = 2.4

Number of Workstations - 12/2.4 » 5 Workstations

5.6 TECHNIQUES OF PLANT LAYOUT

Template A template which is the drawing of a machine or equipment cut on a thick paper. A template is the pattern consisting of a thin plate of a wood or a metal street which serves as a gauge or a guide in mechanical work. A plaint layout template is a scaled replica of a physical set of object in a layout. These objects may be machines and equipments, a worker or even the material. Templates are little or miniature cutouts cut to definite scale which is generally used to represent machines and equipments. These are models of machines, equipments, conveyors, men, materials, pallets and other space filling items. These Templates can be:

Block Templates A block template is a cut out which shows the outer boundary of the maximum projected area of the equipment or machine. Though very in expense, these give only single dimension space occupied in the overall plan. A two dimension template gives much more than mere area; it gives machine or equipment outline and other details. Two dimensional templates have three

The disadvantages are

1. **Non-technical personnel cannot grasp to get clear picture**
2. *Overhead facilities cannot be visualized*
3. *They do not real situation real situation like three-dimensional models.*

Model Equipment Model or three dimensions represents a machinery or equipment installed in a factory. It is a replica or a miniature proto type of machines and equipments. These models are made to acceptable scales of wood or die cast plastic. They show minor details and can be mounted on a thick plastic sheet acting as the floor of the plan. These models are three dimensional and are not only restricted to factory machines and equipments, but are extended to material handling machines and other facilities. Normal scale is 0.25 inch to 1 foot. Models are much more effective than drawings and templates. The major advantages are 1 Model layout is easier to understand. 2. Easier to explain the layout to management. 3 Models can be shifted easily and quickly.4 Overhead structure can be easily checked. Models convey much more real life situation which are life-like. The disadvantages are 1 Models are quite expensive 2 Models are bound to consume storage space

3 *Models are difficult to take to shop-floor for reference purpose as is the case with blue prints.*

Layout Drawings These layout drawings or blue prints indicate the total square feet or meter floor area and its allocation among various work stations and plant facilities on the basis of some standard scale.

Plant Plan A plot plan is a miniature of the entire factory building shown as a part site giving details of production and service departments and other production facilities that are essential and desirably provided.

5.7 LAYOUT PROCEDURE

Data Accumulation It refers to collection of data pertaining to layout. A detailed operation list indicating the operations involved, the places of their performance, sequence and the tools required to be prepared, volume and rate of production, standard time to complete the operations etc.

Data Analysis And Co-Ordination :• Analysis and co-ordination of the basic data undertaken to find out the work size and its type, number of work stations needed, the equipment required, storage and other requirement.

Machine And Equipment Decision What type machine and equipments are needed for the company's product manufacturing is to be decided by taking into account the factors such as volume, capacity and time taken to produce the product.

Material Handling Plan :• Material handling equipments are essential to move raw material, semi finished products and finished products from one end to another. The type equipment to be selected will depend on factors like material to be handled, product to be moved, length and distance of movement etc.

Building Layout the building layout involves the location of internal transportation passages, external passages, service departments etc. the building plan should be sketched in such a way that it should maximize material gifts such as ventilation and lighting.

General Flow Pattern The heart of the plant is the flow of materials throughout the plant. Every effort should be made to keep the flow direct and short.

Design Individual Work Stations A workstation is place occupied by the worker and the

Storage Space Needed Storage space is needed to stock incoming raw materials work in progress at different work stations and at central point and even to stock finished goods till they are shipped out. It is scientific activity of housing and caring for inventories in various forms of locations, pickup and staking back and to protect them from human and natural forces.

Make work stations flow diagrams A flow diagram indicates the procedure of operations and guides in deciding up the most economical sequence of the plant operations.

Locate Service Departments Service departments are very important as they support and strengthen the working of production department. There can be good number service departments such as time office, rest rooms, cafeteria, water supply; fire fighting etc. the location of theses departments should be at convenient places to reduce operating costs.

Design the Master Layout Plan Master plan gives a bird's eye view of the actual layout that is going to be applied in future. It is designed with the help of drawings, replicas or templates. It is very important to design the master plan for the effective layout.

Check and Recheck It is very important to check and recheck the fined layout and make corrections if necessary.

Install the Layout Plan After getting the official approval the layout is implemented step by step which involves actual installation of plant and machinery?

5.8 EXERCISE

1. *What do you understand by Plant Layout?*
2. *What are the different types of layout?*
3. *How Process Layout designs are designed?*
4. *What is Assembly Line Balancing?*
5. *What are different techniques used in Plant Layout?*
6. *Explain the layout procedure?*

5.9 RECOMMENDED READINGS

Agarwal and Chase

2. *Mahadevan*	*Operations*	*Management*
3. *Charry*	*Operations*	*Management*
4. *Buffa*	*Production and Operations Management*	

MBA-CC (First Year) OM 204-B

Semester-II OPERATIONS MANAGEMENT

Lesson No. 6 AUTHOR : AUTHOR : ER. SAHIL RAJ

CAPACITY PLANNING

STRUCTURE

6.0 OBJECTIVES

The purpose of this lesson is to :

- *Introduction of Capacity Planning*
- *Discuss the modes, framework and models of Capacity Planning*
- *To introduce the concept of Material Resource Planning*
- *Discuss the operation of MRP*

6.1 INTRODUCTION

Capacity planning is the systematic approach for the

- *Estimating the amount of the capacity required.*
- *Evaluating alternative methods to increase capacity.*
- *Devising a method to use capacity efficiently and effectively.*

Every operating firm uses labour, machine, tools and fixtures. All these resources are fixed in quantity. Capacity is fixed investment for the repetitive use of these fixtures until it requires replacement because of depreciation or wear and tear. Capacity is measured in the terms of utilization

Capacity utilization » capacity put to use/total capacity available

6.2 MODES OF CAPACITY PLANNING

There are two modes for capacity planning

- *Reactive mode*
- *Proactive mode*

In the Reactive mode a firm wait until a demand increases then it increases its capacity but in the Proactive mode a firm increases capacity in advance i.e. without actual increase of *demand. So the basic objective is to maximize capacity, but many processes have multiple operations and their capacities are not identical. A Bottleneck is an operation that has the lowest capacity of any operation in the process and thus in limits the overall output. E.g. in a process there are three operations having different capacities 200/hr, 50/hr, 200/hr. so in this process to increase overall output of the system the limiting capacity is 50/hr, so to increase overall capacity the bottleneck capacity 50/hr has to be increased. Theory of constraints is the approach which deals with this aspect of capacity. It states that management should focus more on the bottlenecks to increase the overall capacity of the system.*

6.3 CAPACITY PLANNING FRAMEWORK

- *Estimate future capacity requirements*
- *Identify gaps by comparing requirements with the available capacity*
- *Develop alternative plans for filling the gaps.*
- *Evaluate each alternative, both quantitatively and qualitatively, and make a final choice*

Step 1 : Estimate Capacity Requirements

A process's capacity requirement is what its capacity should be for some future time period to meet the demand of its customers, allowing for the desired capacity cushion. It can be expressed in one of two ways; with an output measure or with an input measure. Either way, the foundation for the estimate is the forecast of demand, productivity, competition and technological change. These forecasts normally need to be made for several time periods in a planning horizon, which is the set of consecutive time periods considered for the planning purposes. Long term planning is more reliable. Depending upon the situation each time period within the time horizon could be a year, month or even it can hour.

Step 2 : Identify Gaps

A capacity gap is any difference between projected demand and current capacity. Identifying gaps require use of the correct capacity measure.

Step 3 : Develop Alternatives

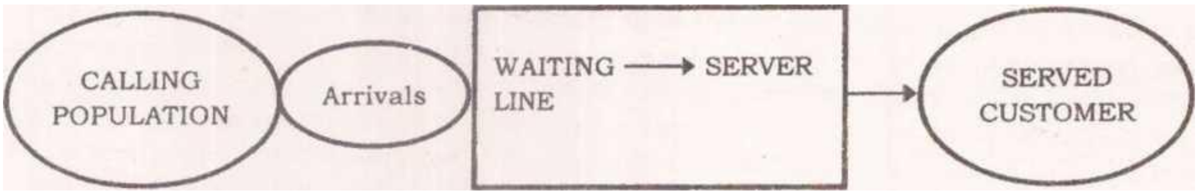
The next step is to develop alternative plans with projected gaps. One alternative, called base case, is to do nothing and simply lose orders from any demand that exceeds current capacity. Other alternatives are various timing and sizing options for adding new capacity. Step 4 : Evaluating the Alternatives

In this step the manager evaluates each alternatives, both quantitatively and qualitatively The evaluation can be done using DECISION TREE ANALYSIS. Decision tree is a 'systematic model in which the different sequences and steps involved in a problem and the consequences of the decision are systematically portrayed. Decision trees comprise nodes and branches. Each node represents the decision point and the branches represent the potential outcomes of the decision. The consequence of each outcome is measured as the cost of the impact, and the uncertainty associated with each outcome could b associated with the requisite branch. Using this basic information, the tree is constructed. After the tree is constructed, each branch in the tree is evaluated with respect to the costs, benefits and uncertainty. The tree is evaluated from right to left. As we move right to left, unattractive portions of the tree are eliminated to arrive at the final decision.

6.4 WAITING LINE MODELS

Waiting line models are specially used in case of service industry. Capacity decisions in the service industry are often made on the basis of the impact on the customers. In service *system, waiting time is an important operational measure that determines service quality. Waiting line models make use of queuing theory fundamentals such as queue length, waiting time and the utilization of the resources, to analyze the impact of the alternative capacity choices on important operational measures in operating systems. Therefore, capacity planning problems could be analyzed using queuing theory fundamentals.*

Basic Structure of a Waiting Models



Above figure depicts the basic structure of the waiting model. The demand for the products/services offered by the operating system originates from calling population. In case of restaurant, the calling population of the demand could be the citizens in the locality. The demand manifests in the form of arrivals at the system. In case of service system it could be actual customers arriving to get the service. The third element in the model is waiting line, which characterizes the provision made for the arrivals to wait for their turn. There are servers in the system for service delivery and finally the served customers exit the system. So taking into account these factors proper capacity planning can be done even in case of service industry.

6.5 MATERIAL RESOURCE PLANNING

For any manufacturing company to produce end items and meet the demands, the availability of sufficient production capacity must be co-coordinated with the availability of all raw materials and purchased items from which the end items are produced. So it is important to plan the procurement or production of specific components that will be required to produce the products according to the master production schedules. Thus the plan for procurement or manufacturing of the specific components that will be required the required quantities of end products as per the production schedule .the technique is known as material requirement planning (MRP) technique. MRP is a computer based system in which the given production schedule is exploded into the required amounts of raw materials, parts and sub-assemblies, needed to produce the end items in each period of the planning horizon. The gross requirement of these materials is reduced to net requirements by taking into account the materials that are in inventory.

6.6 OBJECTIVES OF MRP

- *To improve customer service by meeting delivery schedules promised and shortening delivery lead times.*
- *To reduce inventory costs by reducing inventory levels.*
- *To improve plant operating efficiency by better use of productive resources.*

6.7 THREE FACETS OF MRP TECHNIQUE ARE

- *The MRP technique as a requirement calculator*

- *MRP- A manufacturing, planning, and control system*
- *MRP - A manufacturing resource planning system*

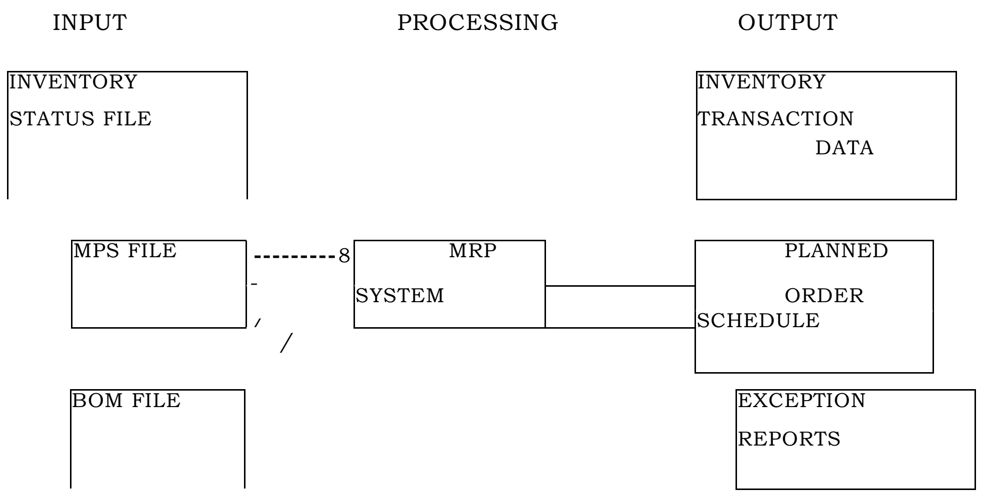
The MRP technique as a requirement calculator was originally used as an inventory control tool, providing reports that specify how many components should be ordered, when they should be ordered and when they should be procured or produced in-house. Since MRP is a computer based system it can be expanded to manufacturing, planning and control system by providing information for planning and controlling both the material and capacity required to manufacture the products. Hence MRP serves as a key component in an information system for planning and controlling production operations and procurement of materials. When both the material requirement planning and capacity requirement planning are integrated within one system the system is known as MRP-I and when MRP is extended to include feedback from and control of vendor orders and production operations, it is called 'CLOSED LOOP MRP' which helps managers achieve effective manufacturing control.

6.8 MATERIAL RESOURCE PLANNING -II (MRP-II)

When the capabilities of closed loop MRP are extended to integrate financial, accounting, personnel, engineering and marketing information along with the production planning and control activities of basic MRP system, the resulting system is known as MRP-

2. *MRP-2 is the heart of the corporate management resource system for many companies, as it provides information about inventory levels, plant expansion needs and work force requirements and also coordinating the activities of marketing, finance, engineering and manufacturing to achieve the company's overall plans.*

6.9 OPERATIONS OF MRP SYSTEM



6.10 MRP SYSTEM INPUTS

Master Production Schedule (MPS) :- The MPS specifies what end product are to be produced and when. The planning horizon should be long enough to cover the cumulative lead times of all the components that must be purchased or manufactured to meet the end product requirement.

Bill of Material File (BOM) :- This file provides the information regarding al the *materials , parts and sub-assemblies that go into the end product. The bill of material can be viewed as having a series of levels, each of which represents a stage in the final assembly or end product. The BOM file identifies each component by a unique part number and facilitates processing by exploding the end product requirements into components requirements.*

Inventory Status File - The inventory status file gives complete and up-to-date information on the on-hand quantities, gross requirements, scheduled receipts and planned order releases for the item. It also includes other information such as lot sizes, lead times, safety stocks and scrap allowances.

6.11 MRP SYSTEM OUTPUTS

Two primary outputs

- *Planned order schedule which is a plan of the quantity of each material to be ordered in each time period. The order may be a purchase order on the suppliers or production orders for parts and sub-assemblies on the production department.*
- *Changes in the planned orders.*

The Secondary Outputs are

- *Exception reports which list items required management attention to control.*
- **Performance reports regarding how well the system is operating.**
- *Planning reports such as inventory forecasts, purchase commitment reports etc.*

6.12 BENEFITS OF MRP

Inventory : The information provided by the MRP system is useful to better coordinate orders for components with production plans for parent items. This results in the reduced levels of average inventory for dependent demand items.

Production : Information from MRP facilitates better utilization of human and capital resources. Because of more accurate priority information from MRP, it is possible to improve delivery performance.

Sales : MRP helps to check in advance whether the desired delivery dates are achievable. It also improves the company's ability to react to changes in customers orders, improves customers service by helping production, meet assembly dates and helps cut delivery lead times.

Engineering : MRP helps in planning the design releases and design changes.

Planning : MRP can simulate changes in the MPS for the purpose of evaluation of alternative MPS. It facilitates the projection of equipment and facility requirements, workforce planning and procurement expanses for a proposed MPS.

Purchasing : MRP helps the purchase department by making known the real priorities and recommending changes in due dates for orders so that the purchase staff may expedite or delay the orders placed on vendors. Because of this, the vendor relations can be improved.

Scheduling : Better scheduling can result from MRP through better knowledge of priorities.

Financc : MRP can help planning of cash flow requirements. It can identify time capacity constraints or bottlenecks work centre, there by helping operations manager to make better capital investment decisions.

6.13 PROBLEMS IN USING MRP

Preparation of MPS : Under uncertainties in market environment and non-availability of adequate lead times from customers for delivery of end products.

Maintaining accurate BOM files : Changes incorporated in BOM by the design department should be communicated to all the users of BOM.

Incorrect stock status : A major problem is to know the correct status of all materials at all stages. Incorrect stock status results in an erroneous net requirement of materials.

Unrealistic lead times : Most crucial step in the MRP system which minimizes inventory is the time-phasing of requirements and release of orders; advancing by the lead time required, so that materials arrive just when required.

6.14 EXERCISE

1. *What do you understand by Capacity Planning?*
2. *What are different modes for Capacity Planning?*
3. *What is Capacity Planning framework?*
4. *Explain the use of Waiting Line Models in Capacity Planning?*
5. *What do you understand by Material Resource Planning?*
6. *What are the different benefits and limitations of MRP?*

6.15 SUGGESTED READINGS

1. *Jacobs, Aquilano, : Operations Management*
   Agarwal and Chase
2. *Mahadevan B.* *Operations* *Management*
3. *Charry S. N.* *Operations* *Management*
4. *Buffa* *Production and Operations Management*

MBA-CC (First Year) OM 204-B

Semester-II OPERATIONS MANAGEMENT

Lesson No. 7 AUTHOR : VIKAS SINGLA

SCHEDULING

STRUCTURE

7. INTRODUCTION

Scheduling is the process of allocating resources over time to accomplish specific tasks. Two basic types of scheduling that are useful in both service and manufacturing industries are: workforce scheduling, which determines when employees work and operations scheduling, which assigns jobs to machines or workers to jobs. In manufacturing, operations scheduling is crucial because many performance measures such as on-time delivery, inventory levels, manufacturing cycle time, cost and quality relate directly to the scheduling of each production lot. Operations schedules are shortterm plans designed to implement the master production schedule. Operations scheduling focuses on how best to use existing capacity, taking into account technical production constraints. Often, several jobs must be processed at one or more workstations. Typically, a variety of tasks can be performed at each workstation. If schedules are not carefully planned to avoid bottlenecks waiting lines may develop. At each workstation someone must determine which job to process next because the rate at which jobs arrive at a workstation often differs from the rate at which the workstation can process them, thereby creating a waiting line. In addition, new jobs can enter the manufacturing process at any time, thereby creating a dynamic environment. Such complexity puts pressure on managers to develop scheduling procedures that will handle efficiently the production stream.

A clear understanding of the nature of scheduling problems at the most detailed level and of the procedures of the scheduling will provide inputs to the higher level decisions. Therefore, job shop scheduling problems have been focused. To illustrate the differences among alternative scheduling procedures and the impact of a choice of a scheduling procedure on a desired performance measure, single processor scheduling is examined in some detail.

7.1 SINGLE MACHINE SCHEDULING

Consider an automated chemical plant that produces several different products, but only one product can be produced at a time. Suppose that the production manager of the plant has to decide on the scheduling of four products, the production times and due dates for which sire shown in Table 7.1. The table shows, for example, that product 4 will require

8 days in manufacturing and that it is due to be delivered in 17 days. The production manager has several alternatives for scheduling the production of these products. In fact there are 24 distinct ways of scheduling the production of these four products. The decision facing the production manager is which one of these possible 24 schedules should be chosen?

Table 7.1

Product	*Production Time (Days)*	*Due Date (Days)*
1	4	6
2	7	9
3	2	19
4	8	17

The choice of a schedule will depend on the criterion or objective that the production manager wishes to consider in his or her evaluation. Some notations and definitions and discussion of some criteria that are often employed are being provided below.

Each job in the single machine scheduling model is described by two parameters:

Pi = processing time for the job i dj
- due date for the job i

Several variables determine the solution of a scheduling decision. Some of the more important of these are:

Wj = waiting time for job i Cj = completion time of job i F; = flow time of job i Lj = lateness of job i Tj ■» tardiness of job i E; = earliness of job i

W; is the amount of time job I has to wait before its processing begins. The first job on the schedule will have zero waiting time, and the second job on the schedule will have to wait by the amount of the processing time of the first job. Cj is the time at which processing of job I is completed. Fj is the amount of time a job spends in the system. Lateness is the amount of time by which the completion time of job I exceeds its due date. Thus - Cj - d_f. Note that, $L_;$ can be either positive or negative. A positive lateness represents a violation of the due date and is called tardiness. Similarly, a negative lateness represents the completion of a job before its due date and is called earliness.

7.2 SCHEDULING PROCEDURES

Following scheduling procedures will be illustrated using the example in Table 7.1.

7.2.1 Shortest Processing Time (SPT) Procedure

A schedule obtained by sequencing jobs in nondecreasing order of processing times is called

Table 7.2

Job	*Processing Time (p_t)*	*Due Date (d,)*	*Completion Time (Ci)*	*Flow Time (Fi)*	*Tardiness (T.)*
1.	*4*	*6*	*6*	*6*	*0*
2.	*7*	*9*	*13*	*13*	*4*
3.	*2*	*19*	*2*	*2*	*0*
4.	*8*	*17*	*21*	*21*	*4*

This shows that job 3 is processed first, followed by jobs 1,2 and 4, in that order. In Table 7.2, job 3 is first in the sequence hence its completion time is 2 days. Job 1 is started after job 3 is finished and takes 4 days. Thus, the completion time for job 1 is 6 days. The completion times for the remaining jobs are similarly computed. The mean flow time is computed as :

(FI + F2 + F3 + F4) / 4 = (6 + 13 + 2 + 21)/4 = 10.5 The SPT procedure is simple to implement and provides good results even in the more complex scheduling situations.

7.2.2 Due Date (DD) Procedure

In due date procedure jobs are sequenced in the order of non decreasing due dates. The sequence obtained by this rule is

< 1, 2, 4, 3 >

This procedure minimizes the maximum tardiness. In Table 7.3, the computations for individual job tardiness Ti, for the due date sequence is shown. The maximum tardiness is 2 days and no other schedule can produce a tardiness of less than 2 days.

Table 7.2

Job	*Processing Time (p_f)*	*Due Date (d,)*	*Completion Time (Ci)*	*Tardiness (T.)*
1.	*4*	*6*	*4*	*0*
2.	*7*	*9*	*11*	*2*
3.	*2*	*19*	*21*	*2*
4.	*8*	*17*	*19*	*2*

7.2.3 Moore Procedure

The Moore procedure is used to minimize the total number of tardy jobs. The procedure is described as follows :

Step 1 : Arrange the jobs in nondecreasing order of their due dates. If this sequence yields one or zero tardy jobs then the DD schedule is optimal and the procedure stops. But as shown in the example, 3 jobs are tardy in the DD schedule (Table 7.3) so proceed to next step.

Step 2 : Identify the first tardy job in the DD schedule. The first tardy job in the example is job

DD schedule	*< 1*	*2**	*4*	*3 >*
Completion time	*4*	*11*	*19*	*21*
Due date	*6*	*9*	*17*	*19*

Step 3 : Identify the longest job from among the jobs including and to the left of the job marked with (*) in the schedule in step 2. In the example, jobs 1 and 2 are candidates and since job 2 has the longer processing time of the two, it is selected.

The identified job is removed and the completion times for the remaining jobs are revised as shown below :

DD schedule	*< 1*	*4*	*3 >*
Completion time	*4*	*12*	*14*
Due date	*6*	*17*	*19*

Now repeat the step 2. In this example, all the jobs are now on time, so we terminate the procedure. The Moore schedule is

< 1, 4, 3, 2 >

7.3 FLOW SHOP SCHEDULING

In many situations, there is more than one processor and a job consists of several operations that are to be performed in a specific order. Moving from a single processor job to a multiple processor job shop poses a challenge. In single machine scheduling the makespan

i. *e. total time to complete a group of jobs is same regardless of the priority rule chosen, in the scheduling of two or more operations in a flow shop the makespan varies according to the sequence chosen. Determining a production sequence for a group of jobs so as to minimize the makespan has two advantages.*

1. *The group of jobs is completed in minimum time.*
2. *Utilization of two station flow shop is maximized.*

Johnson's rule is a procedure that minimizes makespan in scheduling a group of jobs on two workstations. In the procedure the sequence of jobs at the two stations should be identical and that therefore the priority assigned to a job should be the same as both. The procedure is based on the assumption of a known set of jobs, each with a known processing time and available to begin processing on the first workstation. The procedure is as follows:

Step 1 : Scan the processing times at each workstation and find the shortest processing time among the jobs not yet scheduled. If there is a tie, choose one job arbitrarily.

Step 2 : If the shortest processing time is on workstation 1, schedule the corresponding job as early as possible. If the shortest processing time is on workstation 2, schedule the corresponding job as late as possible.

Step 3 : Eliminate the last scheduled job from further consideration. Repeat steps 1 and 2 until all jobs have been scheduled.

Example : A machine company received an order to repair five motors for materials handling equipment. The motors will be repaired at two workstations in the following manner:

Motor	*Workstation 1*	*Workstation 2*
Ml	*12*	*22*
M2	*4*	*5*
M3	*5*	*3*
M4	*15*	*16*
M5	*10*	*8*

Solution :

The logical sequence is given below:

Table 7.4

Iteration	*Job Sequence*					*Comments*
1.					*M3*	*Shortest processing time (SPT) is 3 hours for M3 at workstation 2. Therefore, M3 is scheduled as late as possible.*
2.	*M2*				*M3*	*Eliminate M3's time from the table of estimated times. The next SPT is 4 hours for M2 at workstation 1. Therefore, M2 is scheduled first.*
3.	*M2*			*M5*	*M3*	*Eliminate M2 from the table. The next SPT is 8 hours for M5 at workstation 2. Therefore, M5 is scheduled as late as possible.*
4.	*M2*	*Ml*		*M5*	*M3*	*Eliminate M5 from the table. The next SPT is 12 hours for Ml at workstation 1. Ml is scheduled as early as possible.*
5.	*M2*	*Ml*	*M4*	*M5*	*M3*	*The last motor to be scheduled is M4. It is placed in the last remaining position.*

So, the optimal schedule is < M2, Ml, M4, M5, M3 >

No other sequence of jobs will produce a lower makespan. The makespan and idle time for both the workstations is calculated as in the following table :

	Workstation 1		*Workstation 2*		*Idle Time*	
	Start time	*End time*	*Start time*	*End time*	*Workstation 1*	*Workstation 2*
M2	*0*	*4*	*4*	*9*	*0*	*4*
Ml	*4*	*16*	*16*	*38*	*0*	*7*
M4	*16*	*31*	*38*	*54*	*0*	*0*
M5	*31*	*41*	*54*	*62*	*0*	*0*
M3	*41*	*46*	*62*	*65*	*19*	*0*

As the schedule in Table 7.4 has shown that job M2 would be processed first, thus it spends 4 hours at workstation 1 and for that time workstation 2 remains idle. After being processed at workstation 1 job M2 goes at workstation 2 and takes 5 hours for processing. When job M2 was being processed at workstation 2, the processing of next job in the schedule i.e. Ml begins as it was idle during that duration. It should also be noted that till Ml is completely processed at workstation 1 workstation 2 remains idle because according to the schedule Ml has to be processed after M2. This is repeated till all the jobs are processed and makespan is calculated which is 65 hours in this example. This schedule minimizes the idle time of workstation 2 and gives the fastest repair time for all five motors.

7.4 SCHEDULING IN SERVICES

One important distinction between manufacturing and services that affects scheduling is that service operations cannot create inventories to buffer demand uncertainties. Another difference is that in service operations demand often is less predictable. Thus, capacity in the form of employees is crucial for service providers.

Scheduling Customer Demand

1. *Appointments : An appointment system assigns specific times for service to customers. The advantages of this method are timely customer service and high utilization of servers. Doctors, dentists, lawyers are examples of service providers that use appointment systems. If timely service is to be provided care must be taken to tailor the length of appointments to individual customer needs rather than merely scheduling customers at equal intervals.*
2. *Reservations : Reservation systems are used when the customer actually occupies or uses facilities associated with the service. The major advantage of reservation systems is the lead time they give service managers to plan the efficient use of facilities.*
3. *Backlogs : A less precise way to schedule customers is to allow backlogs to develop; that is, customers never know exactly when service will commence. They present their service request to an order taker, who adds it to the waiting line of orders already in the system. Various priority rules can be used to determine which order to process next. The usual rule is first come first served, but if the order involves rework on a previous order, it may get a higher priority.*

Scheduling the Workforce

Another way to manage capacity with a scheduling system is to specify the on-duty and off-duty periods for each employee over a certain period. This approach is used when customers demand quick response and total demand can be forecasted with reasonable accuracy. In these instances, capacity is adjusted to meet the expected loads on the service system.

Suppose that a company is interested in developing an employee schedule that operates seven days a week and provides each employee two consecutive days off. The objective is to identify the two consecutive days off for each employee that will minimize the amount of total slack capacity. The procedure involves the following steps.

Step 1 : From the schedule of net employee requirements for the week, find all the pairs of consecutive days that exclude the maximum daily requirements. Select the unique pair that has the lowest total requirements for the two days. Suppose that the number of employees required are : Monday: 8, Tuesday: 9, Wednesday: 2, Thursday: 12, Friday: 7, Saturday: 4, Sunday: 2.

The maximum capacity requirement is 12 employees on Thursday. The pair having total requirements is Saturday-Sunday with 4 + 2 = 6 employees.

Step 2 : If a tie occurs choose one of the tied pairs.

Step 3 : Assign the employee the selected pair of days off. Subtract the requirements satisfied by the employee from the net requirements for each day the employee is to work. In this case, the employee is assigned Saturday and Sunday off. After requirements are subtracted, Monday's requirement is 7, Tuesday's is 8, Wednesday's is 1, Thursday s is 11 and Friday's is 6, Saturday's and Sunday's requirements do not change because no *employee is yet scheduled to work those days.*

Step 4 : Repeat steps 1-3 until all requirements have been satisfied or a certain number of employees have been scheduled.

This method reduces the amount of slack capacity assigned to days having low requirements and forces the days having high requirements to be scheduled first.

Example : The requirement schedule at the time days off is assigned to worker 1 is:
M T W Th F S Su
R 3 3 4 3 3 1 2
Step 1 : Identify a unique pair of days that has the lowest level of requirements. In this case, it is S-Su. That pair is assigned as days off to worker 1.

Step 2 : The requirements for each work day are reduced by 1, reflecting the days worked by worker 1, to produce a requirements schedule to be used to assign days off for worker 2. In this case the original and reduced schedules are as follows :

M T W Th F S Su
R1 3 3 4 3 3 (1 2)

Repeat step 1. ... chosen as assignment for ... is subtracted from worker 2's wor...

	M	T	W	Th	F	S
R1	3	3	4	3	3	1
R2	2	2	3	2	(2	1)
R3	1	1	2	1	2	1

-T is chosen a the days off for worker i 3 as it

Su
2

	M	T	W	Th	F	S	S
R1	3	3	4	3	3	1	2
R2	2	2	3	2	(2	1)	2
R3	(1	1)	2	1	2	1	1
R4	1	1	1	0	1	0	0

For R4, the unique pair of days off at minimum requirement is S-Su. Reduction of R4 results in 0 requirements for all days, completing the schedule. The work days off can be summarized as follows:

	M	T	W	Th	F	S	Su
Worker 1	W	W	W	W	W	**O**	**O**
Worker 2	W	W	W	W	0	0	W
Worker **3**	0	0	W	W	W	W	**w**
Worker **4**	**w**	W	**w**	W	W	0	**o**
Workers	**3**	**3**	**4**	**4**	**3**	**1**	**2**
Slack	0	0	0	1	0	0	0

= Number of workers working on a particular day - number of workers required.

ution is optimal because the requirements have been met with four workers.

7.5 EXERCISE

1. The following data are given for a single processor, static job shop:

Job	*1*	*2*	*3*	*4*	*5*	*6*
Processing time	*3*	*2*	*9*	*4*	*2*	*4*
Due date	*17*	*21*	*5*	*12*	*15*	*24*

a. *Give a schedule that minimizes the average flow time. What is the average flow time for the schedule?*

b. *Give a schedule that minimizes maximum tardiness. What is the maximum tardiness for the schedule?*

c. *Give a schedule that minimizes the number of tardy jobs. How many jobs are tardy in the schedule?*

2. *Consider a flow shop that has only two processors. A job is completed first on processor 1 and then on processor 2. The data for 10 jobs are as follows:*

Processing Time

Job	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Processor 1	*2*	*7*	*9*	*0*	*3*	*10*	*1*	*5*	*6*	*8*
Processor 2	*6*	*8*	*4*	*10*	*9*	*7*	*5*	*1*	*2*	*3*
Due Date	*25*	*19*	*30*	*25*	*16*	*55*	*60*	*32*	*45*	*39*

a. *Determine the schedule that minimizes the maximum flow time.*

b. *What is the maximum flow time for the schedule?*

7.6 SUGGESTED READINGS

- *Elwood S. Buffa, Modem Production Management, Wiiey Series, 8th Edition.*
- *Lee J. Krajewski, Operations Management, Prentice-Hall of India, New Delhi, 8th Edition.*
- *R. B. Khanna, Production and Operations Management, Prentice-Hall of India, New Delhi, 2007.*

MBA-CC (First Year)
Semester-II

Lesson No. 8

OM 204-B
OPERATIONS MANAGEMENT

AUTHOR : ER. VIKAS SINGLA

STATISTICAL QUALITY CONTROL

STRUCTURE

8. INTRODUCTION

Statistical process control (SPC) involves using statistical techniques to measure and analyze the variation in processes. Most often used for manufacturing processes, the intent of SPC is to monitor product quality and maintain processes to fixed targets. Statistical quality control refers to using statistical techniques for measuring and improving the quality of processes and includes SPC in addition to other techniques, such as sampling plans, experimental design, variation reduction, process capability analysis, and process improvement plans. SPC is used to monitor the consistency of processes used to manufacture a product as designed. It aims to get and keep processes under control. No matter how good or bad the design, SPC can ensure that the product is being manufactured as designed and intended. Thus, SPC will not improve a poorly designed product's reliability, but can be used to maintain the consistency of how the product is made and, therefore, of the manufactured product itself and its as-designed reliability. A process is said to be in a "state of statistical control" if the variations among the observed sampling results from it can be attributed to a constant system of chance causes.

8.1 CONCEPT OF VARIABILITY

The manufacturing manager needs to make decisions very day about the manufacturing process in the presence of variability. In a manufacturing process, variability can be divided into two different sources: chance and assignable causes of variability. These two types of variability are also labeled common (chance) and special (assignable) causes. These are defined as follows:

Chance (common) Causes : Factors, generally numerous and individually of relatively small importance, which contribute to variation, but which are not feasible to detect or identify.

Assignable (special) Causes : A factor which contributes to variation and which is feasible to detect and identify.

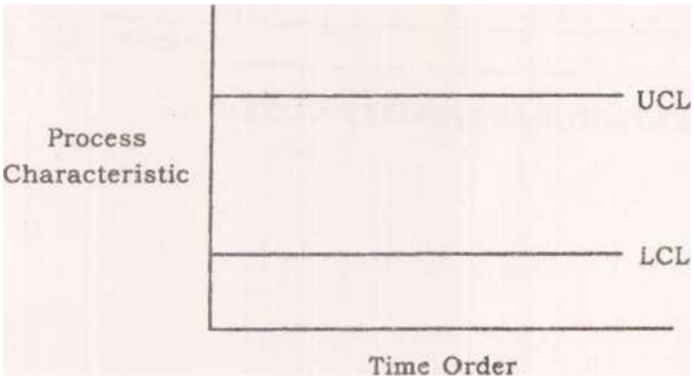


Figure 8.1

The distinction should clarify the meaning of statistical control as defined. The Figure

8.1 *shows graphically the relationship between two sources of variability. The lines denoted UCL and LCL are defined to be upper control limit and lower control limit, respectively. The manufacturing manager can say that when all points fall within the calculated control limits, the manufacturing process exhibits a state of process control.*

8.2 CONTROL CHARTS

A primary tool used for SPC is the control chart, a graphical representation of certain descriptive statistics for specific quantitative measurements of the manufacturing process. These descriptive statistics are displayed in the control chart in comparison to their "in- control" sampling distributions. The comparison detects any unusual variation in the manufacturing process, which could indicate a problem with the process. Several different descriptive statistics cam be used in control charts and there are several different types of control charts that can test for different causes, such as how quickly major vs. minor shifts in process means are detected.

8.2.1 Types of Control Charts

There are two basic categories of control charts: attributes and variables.

Category	*Type of Charts*	*Purpose*
Variable	*x-bar*	*Control Process average*
	R	*Control spread of process*
	S	*Control spread of process*
Attribute	*P*	*Fraction nonconforming*
	np	*Number nonconforming*
	c	*Number of nonconformities*

8.3 CONTROL CHARTS FOR VARIABLES

Control charts for variables concern productions whose quality characteristic is able to be measured on a numeric scale. Their most important goal is to maintain control over both the process mean and its variability. Plotted values on charts represent the following :

- *The Mean value of the quality characteristic over several samples to plot the X bar- chart.*
- *The Variability with the range or the standard deviation of a sample of n units to*

plot the R- or the S-chart.

By studying the mean value and the variability, we can detect assignable causes.

X bar control charts

♦

An x-bar chart is used to measure the mean. When the assignable causes of process variability have been identified and the process variability is in statistical control, an x-bar chart can be constructed to control the process average. The control limits for the x-bar chart are given in the table 1 where

X (double-bar) = centred line of the chart and is the average of past sample means A_2 = constant to provide three sigma limits R control charts*

A range chart or R chart is used to monitor process variability. To calculate the range of a set of sample data, the smallest measurement is subtracted from the largest in each sample. If any of the data fall outside the control limits, the process variability is not in control. The control limits for the chart are given in Table 8.1 where

R-bar = average of several past R values and central line of the control chart

For an X-bar chart	*Averages of the quality characteristic over a sample of n units*	*. r*.* *x = ^—*
For an R-chart	*Ranges of measures in a sample of n units*	

Table 8.1

	Central Line		*Control Limits*	
	Definition	*Formula*	*Upper limit*	*Lower limit*
X-bar chart	*Average on m samples of the quality characteristic averages over n units tested per sample*	*m* _ . I*, *X =*	*UCL. = X+ A_l R* *X*	*LCL = X-A_1R* *X*
R-chart	*Average on m samples of the ranges calculated for each sample of n units*	*m* . I	*UCL $_R$ = D,R*	*LCL h = D, R*

To know if the process available for a specified process characteristic exhibits a state of statistical control following steps should be followed :

Step 1 : After having decided which quality characteristic of the product is going to be studied, m samples of n units are selected for controls.

samples.

Step 3 : Determine the upper and lower control limits of the R-chart.

Step 4 : Plot the sample ranges. If all are in control, proceed to step 5. Otherwise, find the assignable causes, correct them and return to step 1.

Step 5 : Calculate x-bar for each sample and the central line of the chart, x-double bar. Step 6 : Determine the parameters for UCL and LCL and construct the x-bar chart. Step 7 : Plot the sample means. If all are in control, the process is in statistical control in terms of the process average and process variability. Continue to take samples and monitor the process. If any are out of control, find the assignable causes, correct them and return to step 1.

Example

The management of a company is concerned about the production of a special metal screw used by several of the company' largest customers. The diameter of the screw is critical. Data from five samples are shown in the accompanying table. The sample size is 4. Is the process in control?

Step 1 **: The data is shown in the following table :**

	Observation					
Sample number	*1*	*2*	*3*	*4*	*R*	*X-bar*
1	*0.5014*	*0.5022*	*0.5009*	*0.5027*	*0.0018*	*0,5018*
2	*0.5021*	*0.5041*	*0.5024*	*0.5020*	*0.0021*	*0.5027*
3	*0.5018*	*0.5026*	*0.5035*	*0.5023*	*0.0017*	*0.5026*
4	*0.5008*	*0.5034*	*0.5024*	*0.5015*	*0.0026*	*0.5020*
5	*0.5041*	*0.5056*	*0.5034*	*0.5047*	*0.0022*	*0.5045*
				Average	*0.0021*	*0.5027*

Step 2 : Compute the range for each sample by subtracting the lowest value from the highest value. For example in sample 1 the range is 0.5027 - 0.5009 ■ 0.0018. Similarly other ranges are calculated and then average range is calculated.

Step 3 : To construct the R-chart calculate control limits as:

*UCL = D_4 * Raverage =■ 2.282 * 0.0021 - 0.00479*

*LCL ** D_3* Raverage = 0 * 0.0021 - 0*

Step 4 *: Plot the ranges on R chart as shown in the Figure 8.1. None of the sample ranges falls outside t* *statistical*

control.

0.005
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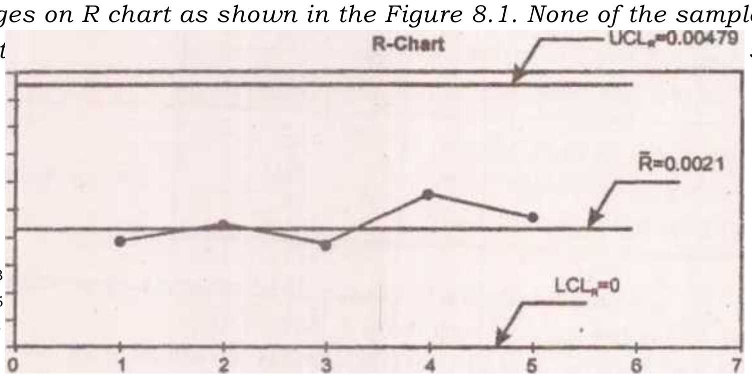
0.004
0.0035
&
£
K
0.0015
0.003
0.0025
0.002



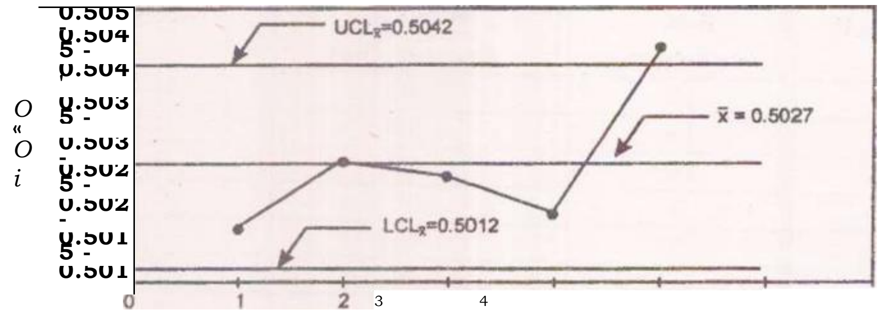
8»mpl» Numbti

Figure 8.1

Step 5 : Compute the mean for each sample and then X (double bar).

Step 6 : Now construct the X-bar chart for the process average by computing the control limits as follows :

*UCL = X (double bar) + A^2 * Raverage - 0.5027 + 0.729 * 0.0021 = 0.5042 LCL = X (double bar) - * Raverage ■ 0.5027 - 0.729 * 0.0021 = 0.5012 Step 7 : Plot*



Samp la Number

Figure 8.2

The mean of the sample 5 falls above the upper control limit, indicating that the process average is out of control.

8.4 CONTROL CHARTS FOR ATTRIBUTES

p-chart and c-chart are the two charts commonly used for quality measures based on product or service attributes. The p-chart is used for controlling the proportion of defective products or services generated by the process. The c-chart is used for controlling the number of defects when more them one defect can be present in a product or service, p-charts

In this type of chart the quality characteristics is counted rather than measured and the entire item can be declared good or defective.

- *An element or item under inspection may have one or more definable attributes.*
- *If any one of the inspected attributes is nonconforming, the entire item is counted as nonconforming.*
- *The number of items in the sample that are determined to be nonconforming are summed and a proportion of the total is evaluated.*
- *The p-Chart is a graph of the proportion of nonconforming items in each sample or population.*
- *The graph is then used to determine whether or not a process is stable.*

The standard deviation of the distribution of proportion defectives is :

-I *(pXi-p)*

where n = sample size

p-bar = average population proportion defective and central line on the chart. The standard deviation chart

UCL = p + 3s *LCL = p - 3a*

Periodically a random sample of size n is taken, and the number of defective products is counted. The number of defectives is divided by the sample size to get a sample proportion defective p, which is plotted on the chart. When a sample proportion defective falls outside the control limits it indicates the process is statistically not in control and analyst starts search for some assignable cause.

Example:

Sample	*Non-conforming*	*Subgroup Sample Size*	*Proportion*
1	10	50	0.200
2	11	50	0.220
3	10	50	0.200
4	9	50	0.180
5	8	50	0.160
6	11	50	0.220
7	10	50	0.200
8	9	50	0.180
9	10	50	0.200
10	9	50	0.180
11	11	50	0.220
12	13	50	0.260
13	9	50	0.180
14	8	50	0.160
15	9	50	0.180

Step 1 *: With equal sample sizes, the first step requires calculating the mean subgroup proportion. This is accomplished by averaging all of the proportions calculated from each*

t

sample set **-t*

F k

Mean Subgroup Proportion (Equal Sample Sizes) where :

P, = Sample proportion for subgroup i k = Number of*

samples of size n _ **0.200** + **0.220** + **0.200** + **0.180** + ...

P~ 50

Step 2 : Once the Mean Subgroup Proportion has been determined, it is used to determine the standard error for the subgroup proportions

P

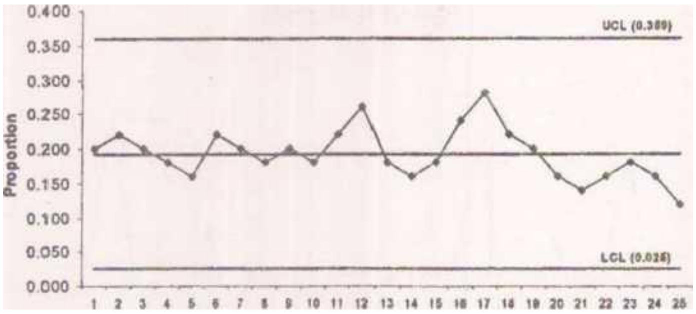
192X1-0.192) =a0J6

50

Step 3 *: Use the sample error of the subgroup proportions to calculate the upper and lower control limits for the chart*

*Upper Control Limit : UCL = p + 3*s_p *UCL = 0.192+ 3(0.056) = 0.359*

*Lower Control Limit : LCL = p-3*s_p *LCL = 0.192-3(0.056) = 0.025*



Ob»»rv»tiorn (Sample Numbtr)

[Proportion ---------------------- UCL (0.359) —p-tw* (0.192) —LCL (o'ffisTj

Figure 8.3

c-charts

Sometimes products have more than one defect per unit. For example, a roll of carpeting may have several defects. When management is interested in reducing the number of defects per unit c-chart type control chart is used. This chart is based on the assumption that the occurrence of nonconformity in a manufacturing process is from a Poisson distribution. It is based on the assumption that defects occur over a continuous region and that the probability of two or more defects at any one location is negligible.

The control limits are : UCL_c *- c-bar + 3 * (c-bar)*$^{1/2}$ *and LCLc = c-bar - 3 * (c-bar)*$^{1/2}$ *where c-bar = average of number of defects per unit.*

Example :

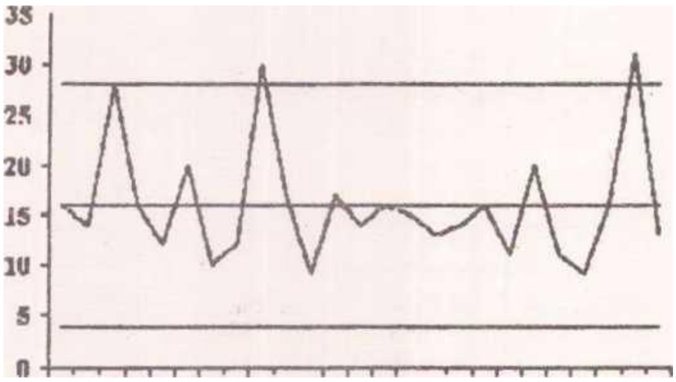
An example may help to illustrate the construction of control limits for counts data. We are inspecting 25 successive wafers, each containing 100 chips. Here the wafer is the inspection unit.

Wafer Number	*Number of Defects*	*Wafer Number*	*Number of Defects*
1	16	14	16
2	14	15	15
3	28	16	13
4	16	17	14
5	12	18	16
6	20	19	11
7	10	20	20
8	12	21	11
9	10	22	19
10	17	23	16
11	19	24	31
12	17	25	13
13	14		

From this table we have

_ Total number of defects 400 ,,
c -- -- -- ---------- 16
Total number of samples 25

UCL - c + 3>/c = 16+2V16 = 28 LCL - c-
kVc



1 3 5 7 9 11 13 IS 17 19 21 23 25 Figure 8.4

The number of defects in sample 24 are more than upper control limit indicating that the process is out of control.

Np-chart

In industrial statistics, the np-chart is a type of control chart that is very similar to the p-chart except that the statistic being plotted ia a number count rather than a sample proportion of items. For example, an np-chart often shows the number of nonconforming items in each sample. Since we are counting failures or successes, clearly the appropriate data for np-charts need to be attribute data. The subgroup size must be constant, as comparisons of counts would otherwise be meaningless.

1. The "np" stands for the number of nonconforming items, which can be expressed as n (sample size) times p (proportion of nonconforming items)
2. Need a good definition of nonconforming items - usually a categorical definition
3. Subgroup size must be constant
4. Normally need large subgroups - can even be up to total for the period

Control limits for the np-chart are calculated on the basis of the binomial distribution and an approximation based on the central limit theorem.

The control limits for this chart type can be determined by the formula :

np±3^np(l-p)

8.5 ACCEPTANCE SAMPLING

Acceptance Sampling is an inspection procedure used to determine whether to accept or reject a specific quantity of material. As more firms initiate total quality management (TQM) programs and work closely with suppliers to ensure high levels of quality, the need for acceptance sampling will decrease. The TQM concept is that no defects should be passed from a producer to a customer, whether the customer is an external or internal customer. However, *in reality, many firms must still rely on checking their materials inputs. The basic procedure is straightforward.*

1. *A random sample is taken from a large quantity of items and tested or measured relative to the quality characteristic of interest.*
2. *If the sample passes the test, the entire quantity of items is accepted.*
3. *If the sample fails the test, either (a) the entire quantity of items is subjected to 100 percent inspection and all defective items repaired or replaced or (b) the entire quantity is returned to the supplier.*

Acceptance sampling may be applied where large quantities of similar items or large batches of material are being bought or are being transferred from one part of an organization to another. Unlike statistical process control where the purpose is to check production as it proceeds, acceptance sampling is applied to larger batches of goods which have already been produced. Other reasons for applying acceptance sampling are that when buying large batches of components it may be too expensive or too time consuming to test them all. In other cases when dealing with a well established supplier the customer may be quite confident that the batch will be satisfactory but will still wish to test a small sample to make sure. For example, a large supermarket sells prepacked sandwiches. The sandwiches are bought in large batches from a catering firm. The manager wants to test them to make sure they are fresh and of good quality. She can test them only by unwrapping them and tasting them. After the test it will no longer be possible to sell them. She must therefore make a decision as to whether or not the batch is acceptable based on testing a relatively small sample of sandwiches. This is known as acceptance sampling.

8.5.1 Acceptance Sampling Attributes

In acceptance sampling by attributes each item tested is classified as conforming or non-conforming. A sample is taken and if it contains too many non-conforming items the batch is rejected, otherwise it is accepted. For this method to be effective, batches containing some non-conforming items must be acceptable. If the only acceptable percentage of non- conforming items is zero this can only be achieved by examining every item and removing any which are non-conforming. This is known as 100% inspection and is not acceptance sampling. However the definition of non-conforming may be chosen as required. For example, if the contents of jars of jam are required to be between 450g and 460g, it would be possible to define a jar with contents outside the range as non-conforming. Batches containing up to say 5% non-conforming items, could then be r.ccepted in the knowledge that, unless there was something very unusual about the distribution, this would ensure that virtually all jars in the batch contained between 450g and 460g.

Quality and Risk Decisions

Two levels of quality are considered in the design of an acceptance sampling plan. The first is the acceptable quality level (AQL), or the quality level desired by the consumer. The producer of the item strives to achieve the AQL, which typically is written into a contract or purchase order. For example, a contract might call for a quality level not to exceed 1 defective unit in 10,000, or an AQL of 0.0001. The producer's risk (a) is the risk that the sampling plan will fail to verify an acceptable lot's quality and thus reject it-a type I error. Most often the producer's risk is set at 0.05, or 5 percent. Fortunately, the consumer also is interested in a low producer's risk because sending good materials back to the producer (1) disrupts the consumer's production process and increases the likelihood of shortages in materials, (2) *adds unnecessarily to the lead time for finished products or services, and (3) creates poor relations with the producer.*

The second level of quality is the lot tolerance proportion defective (LTPD), or the worst level of quality that the consumer can tolerate. The LTPD is a definition of bad quality that the consumer would like to reject. Recognizing the high cost of defects, operations managers have become more cautious about accepting materials of poor quality from suppliers. Thus, sampling plans have lower LTPD values than in the past. The probability of accepting a lot with LTPD quality is the consumer's risk (P), or the type II error of the plan. A common value for the consumer's risk is 0.10, or 10 percent.

8.5.2 Sampling Plans

All sampling plans are devised to provide a specified producer's and consumer's risk. However, it is in the consumer's best interest to keep the average number of items inspected (ANI) to a minimum because that keeps the cost of inspection low. Sampling plans differ with respect to ANI. Three often-used attribute sampling plans are the single-sampling plan, the double-sampling plan, and the sequential sampling plan. Analogous plans also have been devised for variable measures of quality.

Single Sampling Plan

The single-sampling plan is a decision rule to accept or reject a lot based on the results of one random sample from the lot. The procedure is to take a random sample of size (n) and inspect each item. If the number of defects does not exceed a specified acceptance number

(c) *, the consumer accepts the entire lot. Any defects found in the sample are either repaired or returned to the producer. If the number of defects in the sample is greater than c, the consumer subjects the entire lot to 100 percent inspection or rejects the entire lot and returns it to the producer. The single-sampling plan is easy to use but usually results in a larger ANI than the other Double Sampling Plan*

In a double-sampling plan, management specifies two sample sizes (nl and n2) and two acceptance numbers (cl and c2). If the quality of the lot is very good or very bad, the consumer can make a decision to accept or reject the lot on the basis of the first sample, which is smaller than in the single-sample plan. To use the plan, the consumer takes a random sample of size nl. If the number of defects is less than or equal to cl, the consumer accepts the lot. If the number of defects is greater than c2, the consumer rejects the lot. If the number of defects is between cl and c2, the consumer takes a second sample of size n2. If the combined number of defects in the two samples is less than or equal to c2, the consumer accepts the lot. Otherwise, it is rejected. A double-sampling plan can significantly reduce the costs of inspection relative to a single-sampling plan for lots with a very low or very high proportion defective because a decision can be made after taking the first sample. However, if the decision requires two samples, the sampling costs can be greater than those for the singlesampling plan.

Sequential Sampling Plan

A further refinement of the double-sampling plan is the sequential-sampling plan, in which the consumer randomly selects items from the lot and inspects them one by one. Each time an item is inspected, a decision is made to (1) reject the lot, (2) accept the lot, or (3) continue sampling, based on the cumulative results so far. The analyst plots the total number of defectives against the cumulative sample size, and if the number of defectives is less than *a certain acceptance number (cl), the consumer accepts the lot. If the number is greater than another acceptance number (c2), the consumer rejects the lot. If the number is somewhere between the two, another item is inspected.*

8.S.3 Operating Characteristics

For any particular plan the operating characteristic curve is a graph of accepting a batch against the proportion non-conforming in the batch. Provided the sample is small compared to the size of the batch and the sampling is random, the probability of each member of the sample being non-conforming may be taken to be constant. One possible acceptance sampling plan is to take a sample of size 50 and to reject the batch if 3 or more non- conforming items are found. If two or less non-conforming items are found the batch will be accepted. This plan is often denoted by n=50, r=3. For a batch containing a given proportion of non-conforming items the probability of the sample containing two or less non-conforming items may be read directly from tables of the binomial distribution as shown below :

Proportion non-conforming in batch	*Probability of accepting*
0.00	*1.000*
0.01	*0.986*
0.02	*0.922*
0.04	*0.677*
0.06	*0.416*
0.08	*0.226*
0.10	*0.112*
0.15	*0.014*
0.20	*0.001*

For example, if the batch contained 4% non-conforming items, the probability of any particular item in the sample being classified no-conforming is 0.04 and the probability of the batch containing two or less non-conforming items and therefore being accepted is

0.6767

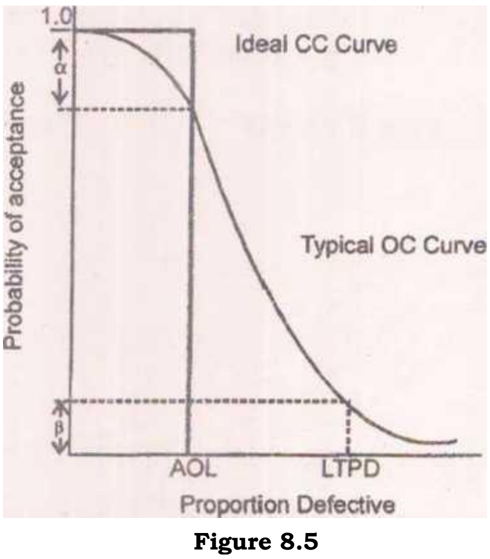


Figure 8.5

The larger the sample size the steeper the graph. That is, the larger the sample size, the better the plan discriminates between good batches (i.e. batches with a small proportion of non-conforming items) and bad batches (i.e. batches with a large proportion of non- conforming items). Following is the graph of an ideal situation.

Example : (Single Sampling Plan)

A manufacturer receives large batches of components daily and decides to institute an acceptance sampling scheme. Three possible plans are considered, each of which requires a sample of 30 components to be tested:

Plan A : Accept the batch if no non-conforming components are found, otherwise reject.

Plan B : Accept the batch if not more than one non-conforming components is found, otherwise reject.

Plan C : Accept the batch if two or fewer non-conforming components are found, otherwise reject.

For each plan calculate the probability of accepting a batch containing

(a) **2% non-conforming**

(b) **8% non-conforming**

Solution:

(a) **For a batch containing 2% non-conforming, the probability of any member of the sample being a non-conforming component is 0.02 (denoted by p). The probability of any member of the sample not being a non-conforming component is**

$q = 1 - 0.02 - 0.98$

The probability of no non-conforming components i.e. for r - 0, in the sample is P(r =

$0) - {}^{n}C_r\, p^r q^{n-r} - 0.98^{30} - 0.545$

And this is the probability of batch being accepted if Plan A is used.

If Plan B is used the batch will be accepted if the sample contains r » 0 or r = 1 non-conforming items and the probability of this is :

$0. \quad 98^{30} + 30 * 0.02 * 0.98^{39} - 0.879$

If Plan C is used the batch will be accepted if the sample contains r = 0, 1 or 2 non-conforming components. The probability of this is

$0. \quad 98^{30} + 30 * 0.02 * 0.98^{29} + 435 * 0.02^{2} * 0.98^{28} - 0.978$

(b) **Similar calculations may be carried out when the batch contains 8% non- conforming components with n = 30, p - 0.08. this gives the following results for the probability of acceptance:**

Plan A : 0.082 Plan B : 0.296 Plan C : 0.565

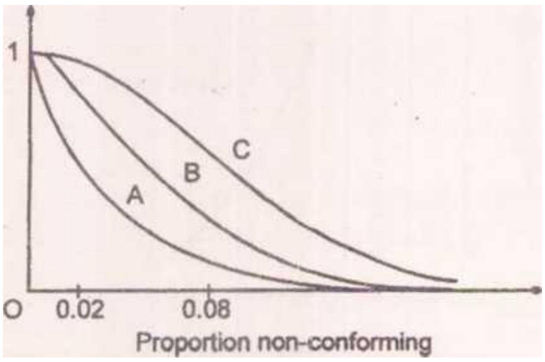


Figure 8.6

Example : (Double Sampling Plan)

A firm is to introduce an acceptance sampling scheme. The following plan is being considered:

Take a sample of 40 and accept the batch if no non-conforming items are found. Reject the batch if 2 or more are found. If one is found, then take a further sample of size 40. If a total of 2 or fewer is found, accept the batch otherwise reject.

Find the probability of acceptance for the plan if batches are submitted containing 1% non-conforming and 10% non-conforming items.

Solution :

Sample size = 40

Number of non-conforming items = 1% of 40 = 0.4 Probability of occurrence of non-conforming items, p = 0.4/40 ■ 0.01 Probability of non-occurrence of non-conforming items, q=l-p=l - 0.01 = 0.99 According to the plan, when first sample is drawn accept it if there are zero non- conforming items. If 2 or more are found in first sample the batch is immediately rejected. But, sample is accepted if 1 in first sample and 0 in second sample or 1 in first sample and 1 in second sample.

Thus, probability of acceptance may be expressed as:

*P(0) + P(l) * P(0) + P(l) * P(l)*

*P(0) = (1 - p)™ = 0.669 and P(l) - 40 * p * (1 - p)^{39} P(accept) - 0.669 + 0.270 * 0.669 + 0.2702 = 0.923 Similarly, probability for 10% non-conforming items can be calculated.*

8.6 EXERCISE

1. *An electric company produces incandescent light bulbs. The following data on the number*

	Observation			
Sample	1	2	3	4
1	604	612	588	600
2	597	601	607	603
3	581	570	585	592
4	620	605	595	588
5	590	614	608	604

Calculate control limits for an R-chart and an x-bar chart.

2. *The data processing department of a bank has five data entry clerks. Each day their supervisor verifies the accuracy of a random sample of 250 records. A record containing one or more errors is considered defective. The results of the last 30 samples are shown in the table.*

Sample	*No. of defective records*	*Sample*	*No. of defective records*	*Sample*	*No. of defective records*	*Sample*	*No. of defective records*
1	*7*	*9*	*6*	*17*	*12*	*25*	*13*
2	*5*	*10*	*13*	*18*	*4*	*26*	*10*
3	*19*	*11*	*18*	*19*	*6*	*27*	*14*
4	*10*	*12*	*5*	*20*	*11*	*28*	*6*
5	*11*	*13*	*16*	*21*	*17*	*29*	*11*
6	*8*	*14*	*4*	*22*	*12*	*30*	*9*
7	*12*	*15*	*11*	*23*	*6*		
8	*9*	*16*	*8*	*24*	*7*		

Based on these historical data set up a p-chart

3. *The safety department monitors accidents at an intersection. Accidents at the intersection have averaged three per month. Which type of control chart should be used? Construct a control chart.*

8.7 SUGGESTED READINGS

- *Lee J. Krajewski, Operations Management, Prentice Hall of India, New Delhi, 8th Edition.*
- *Elwood S. Buffa, Modem Production Management, Wiley Series, 8th Edition.*

Lesson No. 9__________________________________ AUTHOR : DR. FARMOD KUMAR AGGARWAL

NETWORK ANALYSIS BY PERT/CPM

STRUCTURE

9. OBJECTIVE OF THE LESSON

Objective of the lesson is to tell how logical sequence of various activities to be performed to achieve various project objectives.

9.1 INTRODUCTION

The Operations Research techniques used for planning, scheduling and controlling large and complex projects are often referred to as network analysis. A network is a graphical diagram consisting of certain configuration of arrows and nodes for showing the logical sequence of various activities to be performed to achieve the project objectives. Two most popular techniques used in many scheduling situations are the critical path method or simply CPM and the Programme Evaluation and Review Technique or popularly known as PERT.

9.2 BASIC STEPS IN PERT/CPM TECHNIQUES

The procedure involved in applying PERT/CPM consists of the four main steps.

Step 1. Planning : The planning phase is started by splitting the total project into small projects. These small projects are divided into activities and are analyzed by the department. The relationship of each activity with respect to other activities are defined.

Step 2. Scheduling : The ultimate object of the scheduling phase is to prepare the time chart showing the start and finish times for each activity as well as its relationship to other activities of the project.

Step 3. Allocation of Resources : The allocation of resources is performed to achieve the desired objective. A resource is a physical variable such as labour, finance, equipment and space.

Step 4. Controlling : The final phase in project management is controlling. CPM facilitates the application of the principle of management in identifying the areas that are critical to the completion of the project. By having progress report from time to time and updating the network continuously, a better financial as well as technical control over the project is exercised.

9.3 BASIC CONCEPTS OF NETWORK ANALYSIS

In project scheduling, the first step is to sketch an arrow diagram which shows the interdependence and precedence relationship between activities of the project. In a network representation, certain basic definitions are used.

(i) *Activity : Any individual operation which utilizes resources and has an end and a beginning is called an activity. An arrow is commonly used to represent an activity with its head indicating the direction of progress of the project.*

(ii) *Dummy Activity : Any activity which does not consume any kind of resource but merely depicts the technological dependence is called a dummy activity.*

(iii) *Event : An event represents a point in time signifying the completion of some activities and the beginning of new ones. This is usually represented by a circle in a network which is also called a node or connector.*

(iv) *The first prerequisite in the development of a network is to maintain the precedence relations. In order to make a network, following points should be kept into consideration.*

(a) *What job or jobs precede it?*

(b) *What job or jobs could run concurrently?*

(c) *What job or jobs succeed it?*

(d) *What controls the start and finish of a job?*

(v) *Labeling : For the network, it is necessary that various nodes axe properly labeled. A standard procedure called the I-J rule developed by Fulkerson is most commonly used for this purpose. Main steps of this procedure are*

(a) *A start event is one which has arrows emerging from it but none entering it. Find the start event and number it as unity. 1*

(b) *Number all the remaining events as 2, 3 and so on from top to bottom and left to right that may facilitate other users in reading the network diagram.*

(c) *Go on repeating the step (b) Until the end is reached.*

9.4 TIME ESTIMATES IN NETWORKS

For each activity an estimate must be made of time that will be spent in the actual accomplishment of that activity. The next step after making the time estimates is the calculation of earliest times and latest times for each node. These calculations are done in the following way.

(a) *Let zero be the starting time for the project. Then for each activity there is an earliest starting time (ES) relative to the project starting time, which is the earliest possible time when an activity can begin, assuming that all of the predecessors also are started at their ES. Then for that activity, its earliest finish time (EF) is simply the ES + activity time.*

Thus, if ESi denotes the earliest start time of all the activities emanating from event i and tij is the estimated time of activity (i, j), then EFi or ESj = Max (Esi + tij)

for all (i, j) activities, with ESi = 0 being the earliest start time of the beginning event of the project.

(b) *Let us suppose that we have a target time for completing the project. Then this time is called the latest finish time (LF) for the final activity. The latest start time (LS) is the latest time at which an activity can start if the target is to be maintained.*
Thus, if LFi is the latest finish time of all the activities emanating from event i and

tij is the estimated time of the activity (i, j), then LFi = Min (LFi - tij), for all defined (i, j) activities.

9.5 CRITICAL PATH CALCULATIONS

An activity is said to be critical if a delay in its start will cause a further delay in the completion of the entire project. On the other hand a non critical activity is such that the time between its ES and LF is longer than its actual duration. In this case, the non critical activity is said to have a slack or float time.

There are in general three types of floats, namely total float, free float and independent float.

(a) *Total float : This is calculated for any activity by using the following rules.*

(i) *Determine the difference between earliest start time of tail event and the latest finish time of head event for the activity.*

(ii) *Subtract the duration time of the activity from the value obtained in step (i) to get the required total float for the activity.*

Thus the total float TFij for the activity (i, j) is obtained as TFij = LFj - ESi - tij

(b) *Free float ; It is defined by assuming that all the activities start as early as possible. The free float for the activity (i, j) is the excess available time over its duration. Thus*

FFij = ESj - ESi - tij

(c) *Independent float : The time by which an activity can be rescheduled without affecting the preceding or the succeeding activities is known as independent float. It is calculated as follows :*

Independent float = Free float - tail event slack

9.6 CRITICAL PATH METHOD (CPM)

The iterative procedure of determining the critical path is as follows:

Step 1. List all the jobs and then draw a network diagram. Each job is indicated by an arrow with the direction of the arrow showing the sequence of jobs.

Step 2. Consider the jobs times to be deterministic.

Step 3. Calculate the earliest start time (EST) and earliest finish time (EFT) for each event.

Also calculate the latest start time (LST) and latest finish time (LFT).

Step 4. Tabulate various times i.e. activity normal times, earliest times and latest times and mark EST and LFT on the arrow diagram.

Step 5. Determine the total float (slack) for each activity by taking the differences between EST and LFT.

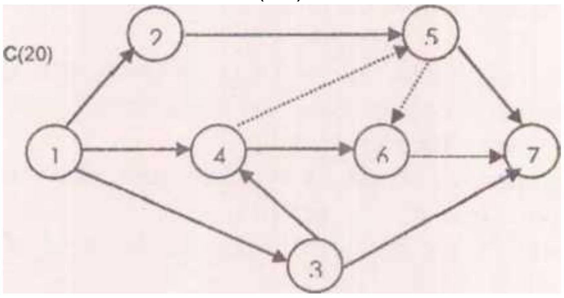
Step 6. Identify the critical activities and connect them with the beginning node and ending node in the network diagram by double line arrows. This gives the critical path.

Step 7. Calculate the total project duration.

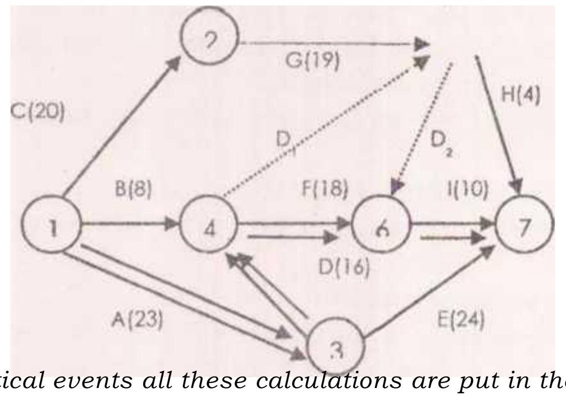
Find also the minimum time of completion of the project, when the time (in days) of completion of each task is as follows :

Task : ABCDEFGHI Time : 23 8 20 16 24 18 19 4 10 Solution : Using the given constraints, the resulting network is shown below. The dummy activities are introduced to establish the correct precedence relationships. The events of the projects are numbered in such a way that their ascending order indicates the direction of progress in the project :

G(19)



Task	*Normal time*	*Earliest time*		*Latest time*		*Total*
		Start	*Finish*	*Start*	*Finish*	
d.2)	*20*	*0*	*20*	*18*	*38*	*18*
(1,3)	*23*	*0*	*23*	*0*	*23*	*0*
(1,4)	*08*	*0*	*08*	*31*	*39*	*31*
(2,5)	*19*	*20*	*39*	*38*	*57*	*18*
(3,4)	*16*	*23*	*39*	*23*	*39*	*0*
(3,7)	*24*	*23*	*47*	*43*	*67*	*20*
(4,5)	*0*	*39*	*39*	*57*	*57*	*18*
(4,6)	*18*	*39*	*57*	*39*	*57*	*0*
(5,6)	*0*	*39*	*39*	*57*	*57*	*18*
(5,7)	*04*	*39*	*43*	*63*	*67*	*24*
(6,7)	*10*	*57*	*67*	*57*	*67*	*0*



To evaluate the critical events all these calculations are put in the following table. The above table shows that the critical events are. for the tasks (1, 3), (3,4), (4,6) and (6,7). It is observed from the figure that the critical path comprises the tasks A, D, F and I.

This path represents the least possible time to complete the entire project.

9.7 PROGRAMME EVALUATION AND REVIEW TECHNIQUE (PERT)

The network method discussed so for may be termed as deterministic, since estimated activity times are assumed to be the expected values. Deterministic network methods assume that the expected time is the actual time taken. Probabilistic methods, on the other hand, assume the reverse, more realistic situation, where activity times are represented by a probability distribution. This probability distribution of activity time is based upon three different time estimates made for each activity. These are as follows:

t_o = *the optimistic time is the shortest possible time to complete the activity if all goes well. That is, there is very little chance that activity can be done in time less than tp.*

t_p = *the pessimistic time is the longest time that an activity could take place if everything goes wrong. That is, there is very little chance that activity can be done in time less than tp.* t_m * *the most likely time is the estimate of the normal time an activity would take. If only one were available, this would be it. Otherwise it is the mode of the probability distribution. From these values it is necessary to derive the expected time. This is accomplished by an approximation developed by the experts of PERT and is given by* T_e *(expected time)* = $(t_o + 4t_m + t_p) / 6$ *ct (standard deviation)* = $(t_p - t_o) / 6$

9.8 PROBABILITY OF MEETING THE SCHEDULE TIME

With PERT, it is possible to determine the probability of completing a contract on schedule. The scheduled dates are expressed as a number of time units from the present time. Initially they may be the latest time, TL, for each event, but after a project is started we shall know that how far it has progressed at a given date and the scheduled times will be the latest times if the project is to be completed on its original schedule. The variance or standard deviation is used to find the probability of completing the whole project by a give date. The underlying procedure is as follows:

Compute the variance of all the activity durations of the critical path. Add them up and take the square root to find the standard deviation of the total project duration. The project expected time follows approximately a normal distribution curve. The standard normal distribution curve has an area equal to unity and a standard deviation of one and is symmetrical about the mean value. 3 s give the limits of the total possible duration with 99 percent confidence. In other words to find the probability of completing the project in time T, the standard normal variate is calculated as:

Z = (Due date - Expected date of completion) / Standard deviation Z = (T - Te) / a

The probability is then read from the standard normal probability distribution table for the value of Z calculated above.

Example : A small project is composed of seven activities whose time estimates are listed in the table as follows :

Estimated duration			
Activity	*Pessimistic*	*Optimistic*	*Most likely*
1-2	7	1	1
1-3	7	1	4
1-4	8	1	2
2-5	1	2	1
3-5	14	1	5
4-6	8	2	5
5-6	15	3	6

(a) *Draw the project network.*

(b) *Find the expected duration and variance of each activity.*

(c) *Calculate early and late occurrence times for each event. What is the expected project length.*

(d) *Calculate the variance and standard deviation of project length. What is the probability that the project will be completed :*

(i) *at least 4 weeks earlier than expected.*

(ii) *no more than 4 weeks than expected.*

(e) *If the project due date is 19 weeks, what is the probability of meeting the due date?*

Solution : The expected time and variance of each activity is computed in table below.

	to	tm	tp	te	Variance
1-2	1	1	7	2	1
1-3	1	4	7	- 4	1
1-4	2	2	8	3	1
2-5	1	1	1	1	0
3-5	2	5	14	6	4
4-6	2	5	8	5	1
5-6	3	6	15	7	4

By constructing the network diagram, we observe the following:

Critical path: 1-3-5-6

The expected duration of the project is 17 weeks.

Variance of the project is given by=l+4+4 = 9 The standard normal deviate is:

Z = (Due date - Expected date of completion) / Standard deviation

(i) *At least 4 weeks earlier than expected Z - (13-17) /3 = -1.33*
From Z tables probability = 0.4028 Required
probability = 0.5 - .4082

= 0.0918 = 9.18%

The interpretation of the above is that if the project is performed 100 times under the same conditions, there will be 9 occasions when this job will be completed 4 weeks earlier than expected.

From Z tables probability = 0.4028 Required probability - 0.5 + .4082

= 0.9028 = 90.28%

(e) *When the due date is 19 weeks Z = (19-17)/3 - 0.67*
The probability of meeting the due date is = 0.7486

= 74.86%

Thus the probability of not meeting the due date is = 1-0.7486

- 0.2514
- 25.14%

9.9 EXERCISE

1. *Discuss the advantages and disadvantages of Network Techniques.*
2. *Write notes on :*
   (a) *Event and Activity*
   (b) *Phases of Project Management*
3. *A project schedule has the following characteristics*
   Activity 1-2 1-4 1-7 2-3 3-6 4-5 4-8 5-6 6-9 7-8 8-9 Time 22141584335

   Construct the PERT Network and find the critical path and time duration of the project.

4. *Three time estimates (in months) of all activities of a project are as given below :*

1-2	3	4	5
2-3	6	8	10
2-4	2	3	4
3-4	4	5	12
4-5	5	7	9
5-6	9	16	17

   (a) *Find the expected duration and standard deviation of each activity.*
   (b) *Construct the project network.*
   (c) *Determine the critical path, expected project length and variance of the project.*

9.10 SUGGESTED READINGS

1. *V.K. Kapoor : Operations Research Techniques for Management.*
2. *Kanti Swarup, : Operations Research P.K. Gupta & Man Mohan*

Lesson No. 10 ________________________________ **AUTHOR : DR. PARMOD KUMAR AGGARWAL**

ASSIGNMENT PROBLEMS

STRUCTURE

10. OBJECTIVE OF THE LESSON

The Objective of the Lesson is to explanin how maximum profit/minimum cost to be obtained from various origin to destinations.

10.1 INTRODUCTION

The assignment problem is a particular case of transportation problem in which the number of jobs or origins or sources are equal to the number of facilities or destinations or machines or persons and so on. The objective is to maximise total profit of allocation or to minimise the total cost. An assignment problem is a completely degenerate form of transportation problem. The units available at each origin and the units demanded at each destination are all equal to one.

10.2 MATHEMATICAL FORMULATION OF AN ASSIGNMENT PROBLEM

Given n jobs or activities and n persons and effectiveness (in terms of cost profit, time and others) of each person for each job, the problem lies in assigning each person to one and only one job so that the given measure of effectiveness is optimised. The data matrix for this problem is shown as :

Jobs (Activities)

Persons (Resources)

			• • •	J	Supply
w,	c„	C,a	. . .	c_{10}	1
W_2	Cm		• •	c_{2n}	1
:	;	:	*	*	*
w_n	C,	c*	. .		1
Demand	1	1	. • •	1	n

In the above table, C_u be the cost of assigning ith person to the Jth job.

Let Xjj denote the assignment of person i to job j such that X_u = 1 if person i is assigned to job j 0 otherwise The assignment problem can be stated as :

Minimise Z = X

n n

i=l j=i

subject to the constraints

n

~ 1, for i = 1,2 ....n

j-i

n

*and £xu = *, for j = 1,2 .... n*

i-i

and X_y = 0 or 1 for all i and j

Cjj = Cost of assignment of person i to job j.

10.3 HUNGARIAN METHOD

This method was developed by D. Konig, Hungarian mathematician. This method provides us with an efficient method of finding the optimal solution without having to make a direct comparison of every solution. Various steps of calculation of optimal solution can be summarised as :

Step 1 : If the number of rows are not equal to number of columns and vice-versa, then a dummy row or column must be introduced with zero cost elements.

Step 2 : Find the smallest cost element in each row of the cost matrix. Subtract this smallest cost element from each element in that row. Therefore, there will be atleast one zero in each row of this matrix which is called the 1st reduced cost matrix.

Step 3 : In the reduced cost matrix, find the smallest element in each column, subtract the smallest cost element from each element in that column. As a result, there would be at least one zero in each row and column of the second reduced matrix.

Step 4 : Determine an optimum assignment :

(i) *Examine the row successively until a row with exactly one unmarked zero is obtained. Make an assignment to this single zero by making a square (□) around it.*

(ii) *For each zero value that becomes assigned, eliminate all other zeros in the same row or column.*

(iii) *Repeat steps 4 (i) and 4 (ii) for each column with exactly single zero value cell that has not been assigned or eliminated.*

(iv) *If a row or column has two or more unmarked zeros and one cannot select by inspection, then select the assigned zero cell arbitrarily.*

(v) *Continue this process until all zero in rows/columns are either enclosed (assigned) or struck off (X).*

Step 5 : An optimal assignment is found if the number of assigned cells equals the number of rows and columns. If a zero cell is arbitrarily selected, there may be an alternate optimum. If no *assignment) then go to next step.*

Step 6 : Draw the minimum number of horizontal and vertical lines through all the zeros as follows :

(i) *Mark (V) to those rows where no assignment has been made.*

(ii) *Mark (V) to those columns which have zeros in the marked rows.*

(iii) *Mark (V) rows (not already marked) which have assignments in marked columns.*

(iv) *The process may be repeated until no more rows or columns can be checked.*

(v) *Draw straight lines through all unmarked rows and marked columns.*

Step 7 : If the minimum number of lines passing through all the zeros is equal to the number of rows or columns, the optimum solution is attained by an arbitrary allocation in the positions of the zeros not crossed in step 3. Otherwise go to the next step.

Step 8 : Revise the cost matrix as follows :

(i) *Find the elements that are covered by a line, select the smallest of these elements and subtract this element from all the uncrossed elements and add the same at the point of intersection of the two lines.*

(ii) *Other elements crossed by the lines removed unchanged.*

Step 9 : Go to step 4 and repeat the method till an optimum solution is obtained.

Example 1

The assignment cost of assigning any one operator to any one machine is given in the

	I	II	III	IV
A	10	5	13	15
Machine B	3	9	18	3
C	10	7	3	2
D	5	11	9	7

Find the optimal assignment.

Solution :

Step 1 : Subtracting the smallest element of each ro ''
corresponding row, we get the reduced matrix as :

~~ 5	0	8	10
0	6	15	0
8	5	1	0
0	6	4	2

Step 2: Subtracting the smallest element of each column of the reduced matrix from every element of the corresponding column, we get the following reduced matrix :

5	0	7	10
0	6	14	0
8	5	0	0
0	6	3	2

Example 2

A department has five employees with five jobs to be performed. The time (in hours) each man will take to perform each job is given in the cost matrix.

Employees

	' I	II	III	IV	V
A	“10	5	13	15	16
B	3	9	18	13	6
Jobs C	10	7	2	2	2
D	7	11	9	7	12
E	7	9	10	4	12

How should the jobs be the allocated, one per employee so as to minimise the total man-hours?

Solution :

Applying step 1 and 2 of the algorithm, the reduced time matrix is shown below:

5	0	8	10	11
0	6	15	10	3
8	5	0	0	0
0	4	2	0	5
_ 3	5	6	0	8 _

Step 3 : Starting with row 1, box a single zero , if any, and cross all other zeros in its column.

Thus, we get

“ 5	0	8	10	i r
CD	6	15	10	3
8	5	□a	8	0
H	4	2	H	5
_ 3	5	6		8 _

The solution is not optimal since only four assignments are made.

Step 4 : Since row D does not have any assignment we tick this row (V)

	1	II	III	IV	V
A	" 5	GD	8	10	ll“
B	m	6	15	10	3
C	8	5	0	0	H
D		4	2	K	5
E	_ 3	5	6	0	8 _

(i) *Now, there is a zero in the 1st and IVth column of the ticked row. So, we tick I and IVth column.*

(ii) *Mark (V) in the rows B and E since columns I and IV have an assignment in rows B and E, respectively.*

(iii) *Draw straight lines through all unmarked rows A and C and marked columns, I and IV as shown below :*

	I	II	III	IV	V
A	*~ 5*	*m*	*8*	*10*	*1f*
B		*6*	*15*	*10*	*3*
C	*8*	*5*	*m*	*ft*	*ft*
D	*ft*	*4*	*2*	*ft*	*5*
E	*3*	*5*	*6*	*m*	*8*
	" V			*V*	

Step 5 : In step 4, the minimum number of lines drawn is 4, which is less than the order of the cost matrix (order is 5), indicating that the current assignment is not optimum. To increase the minimum number of lines, we generate new zeros in the modified matrix.

Step 6: Develop the new Table by selecting the smallest element among all uncovered elements by the lines. Here, the element is 2. Subtract this element from all the uncovered elements and add the same to ail the elements lying at the intersection of the lines. We obtain the following new reduced cost matrix.

~7	**0**	**8**	**12**	**1 f**
0	4	13	10	1
10	5	0	2	0
0	2	0	0	3
_ 3	3	4	0	6_

Step 7 : Repeat 3 to 6 to find a new solution. The new assignment is :

~7	fo] , 8		12	11"
|~0~|	4	13	10	1
10	5	SC	2	f0~]
H	2 [-0~|		6(	3
_ 3	3	4	**fQ]**	**6 _**

Since the number of assignments (5) equals the number of rows (5), the solution is optimal. The optimum assignment is :

A -> II, B -> I, C-» V,D -> III, E -> IV The minimum total time for this assignment schedule is5 + 3 + 2 + 9 + 4 = 23 hours.

10.4 VARIATIONS OF THE ASSIGNMENT PROBLEM

1. Non-square matrix (unbalanced assignment problem)

The Hungarian method of assignment requires that the number of columns and rows in the assignment matrix must be equal. When the given cost matrix is not a square matrix, then the problem is called an unbalanced problem. In this case dummy row(s) or column(s) with zero cost is/are added to make it a square matrix. These cells are treated in the same way as the real cells during the process. Then, adopt the Hungarian method to find the solution.

2. Maximisation problem

There may be problems of maximising the profit, revenue, and so on. Such problems may be solved by converting the given maximisation problem into a minimisation problem *before the Hungarian method is applied. The transformation may be done in the following two ways:*

(i) *by subtracting all the elements from the highest element of the matrix.*
(ii) *by multiplying the matrix elements by - I.*

3. Multiple optimal solutions

While making an assignment in the reduced assignment matrix, it is possible to have two or more ways to strike off certain number of zeros. Such situation leads to multiple solutions with the same optimal value of objective function. In such cases the most suitable solution may be considered by the decision-maker.

4. Restrictions on assignments (or) impossible assignment

Cells in which assignments are not allowed are assigned a very heavy cost (written as M or oo). Such cells are prohibited to enter into the final solution.

10.5 UNBALANCED PROBLEM

Example 3

In the modification of a plant layout of a factory four new machines M,, M_2, M_3, M_4 are to be installed in a machine shop. There are five vacant places A, B, C, D and E that are available. Because of limited space, machine M_2 cannot be placed at C and M_3 cannot be placed at A. The cost of placing of machine i and place j (in rupees) shown below :

9	11	15	10	11
12	9	-	10	9
-	11	14	11	7
14	8	12	7	8

M.

Machine M_2

m_3

	A	B	C	D	E
Mi	9	11	15	10	11
M_2	12	9	M	10	9
m_3	M	11	14	11	7
m_4	14	8	12	7	8
M_s	0	0	0	0	0

	A	**B**	**C**	**D**		**E**
M		2	6	1	2	
, M	3	0	M	1	£	
2	M	4	7	4		D
	7	1	5	El		1
	8		El	K		0

The optimal solution is obtained. The schedule are :

M_1 -> A, M_2 -> B, M_3-> C, M_4 -> D, M_5-> C and the total minimum cost is Rs. :9+9+7+7+0= Rs. 32.

10.6 MAXIMISATION PROBLEM

Example 4

A company has four territories open, and four salesman available for the assignment. The territories are not equally rich in their sales potential; it is estimated that a typical salesman operating in each territory would bring in the following annual sales :

Territory :	*I*	*II*	*III*	*IV*
Annual Sales (Rs) :	*60,000*	*50,000*	*40,000*	*30,000*

Four salesman are also considered to differ in their ability. It is estimated that working under the same conditions, their yearly sales would be proportional as follows:

Salesman	*A*	*B*	*C*	*D*
Proportion	*7*	*5*	*5*	*4*

If the criterion is maximise expected total sales, then the intuitive answer is to assign the best salesman to the richest territory, the next best salesman to the second richest and so on. Verify this answer by the assignment technique.

Solution :

Step 1 : Construct the effectiveness matrix.

To avoid the fractional values of annual sales of each salesman in each territory, for convenience consider the yearly sales as 21 (the sum of the sale proportion = 7 + 5 + 5 + 4 = 21), taking Rs. 10,000 as one unit. Now, divide the individual sales in each territory by 21 to obtain the required annual sales by each salesman.

6

		6	*5*	*4*	*3*
Sales proportion		*~ I*	*II*	*III*	*IV*
7	*A*	*42*	*35*	*28*	*21*
5	*B*	*30*	*25*	*20*	*15*
5	*C*	*30*	*25*	*20*	*15*
4	*D*	*24*	*20*	*16*	*12*

Step 2 : Convert maximisation into minisation problem.

	I	*II*	*III*	*IV*
A	*"o*	*7*	*14*	*21*
B	*12*	*17*	*22*	*27*
C	*12*	*17*	*22*	*27*
D	*18*	*22*	*26*	*30*

Step 3 : *Apply Hungarian method to get the optimal solution.*

(i) *Subtract the smallest element in each row from every element in that row.*

(i) *Subtract the smallest element in each column. The reduced matrix is obtained*

as follows :

	I	II	III	IV
A	0	3	6	9
B	0	1	2	3
C	0	1	2	3
D	0	0	0	0

Step 4 : Assignment is made in row A. All zeros in the assigned column I are crossed out. Column II has only one zero in cell (D, II). Assignment is made in this column and other zeros are crossed in row D. The reduced matrix is shown below :

	I	II	III	IV
A	0	3	6	9
B	8	1	2	3
C	H	1	2	3
D	8	0	H	8

Step 5 : Since row B and C does not have any assignments, we tick this row. Since there is a zero in the I column of the ticked row, we tick I column. Further, there is an assignment in the first row of the ticked column, so we tick first row. Draw lines through all unmarked rows and marked columns.

	1	II	in	IV
A	El	3	6	9
B	8	1	2	3
C	H	1	2	3
D	H	m	8	8

The number of lines drawn is 2, which is less than order of cost matrix, therefore the current assignment is not optimal.

Step 6 : Revised matrix is developed by selecting the minimum element (= 1) among all uncovered elements by the lines. Subract 1 from each uncovered element and add it to the element at the intersection of two lines. The revised Table is :

	I	II	III	IV
A	DD	2	5	8
3	8	m	1	2
C	BC	K	1	2
D	1	8		m

Again, the solution is not optimal. Repeat Step 1 to 5. Two alternative optimal assignments we get are :

		II	III	IV
A	*E*	*2*	*4*	*7*
B	*BC*	*&*	*s*	*1*
C	*K*	*0*	*BC*	*1*
D	*2*	*1*	*SC*	*0*

		II	III	IV
A		*2*	*4*	*7*
B	*BC*	*fit*	*m*	*1*
C	*BC*	*0*	*BC*	*1*
D	*2*	*1*	*BC*	

The two possible solution are :

(i) *A -> I, B -* III, C-+II, D-+IV*

(ii) *A -> I, B -> II, C -► III, D -> IV*

with maximum sales of Rs. (42 + 20 + 25 + 12) = Rs. 99 [or Rs. (42 + 25 + 20 + 12) = Rs. 99.]

Both solution show the best salesman A is assigned to the richest territory I, the worst salesman D to the poorest territory IV. Salesman B and C are equally good and they may be assigned VI or III.

10.7 MULTIPLE SOLUTION

Example 5

	1	2	3	4
i	*2*	*3*	*4*	*5*
ii	*4*	*5*	*6*	*7*
iii	*7*	*8*	*9*	*8*
IV	*3*	*5*	*8*	*4*

Solution :

(i) *Subtract the smallest element in the row from each*

(ii) *Subtract the smallest element in the column from The*

	1	2	3	4
I	*0*	*0*	*0*	*2*
11	*0*	*0*	*0*	*2*
III	*0*	*0*	*0*	*0*
IV	*0*	*1*	*3*	*0*

Since single zeros do not exist either in the column

following alternative solutions :

	1	2	3	4
I	**SC**	**m**	**SC**	**2**
II	**BC**	**(X**	**m**	**2**
III	**BC**	*k*	**BC**	**m**
IV	**0**	**1**	**3**	*K*

	1	2	3	4
I	**0**	**m**	**0**	**2**
II	**BC**	*<x*	**m**	**2**
III	**BC**		**K**	**m**
IV		**1**	**3**	**H**

	12		3	4
I	*K*	*K*	m	**2**
	K		*h*	**2**
II		*fit*	**8**	*m*
II		*i*	*3*	**0**

The possible optimal solutions with each of cost Rs. 20 are :

*I-> **2**, II -* 3, III -► 4, IV 1*
I-> 1, II -> 2, III -> 3, IV -> 4
I - 3, II -> 2, III -> 1, IV 4*
I -> 3, II -> 2, III -> 4, IV -> 1
*I -•» **2**, II -> 3, III -* 1, IV 4*

10.8 RESTRICTIONS ON ASSIGNMENTS Example 6

Four new machines M_p $M_{2>}$ M_3, M_4 are to be installed in a machine shop. There are five vacant places A, B, C, D, E that are available. Because of limited space, machine M_2 cannot be placed at C and M_a cannot be placed at A. The cost matrix is shown below :

	A	B	C	D	E
M_1	4	6	10	5	4
m_2	7	4	–	5	4
	–	6	9	6	2
m_4	9	3	7	2	3

Find the optimal assignment schedule.

Solution :

As machine M_2 cannot be placed at C, M_3 cannot be placed at A, assign a large cost M in cells (M_2, C) and (M_3, A). The assignment problem is unbalanced. So, balance it by adding a dummy row with cost **0** *as shown below :*

	4	**6**	**10**	*5*	*4*
	7	*4*	*M*	*5*	*4*
M[	*M*	**6**	*9*	**6**	**2**
m2	*9*	*3*	*7*	**2**	*3*
m3	**0**	**0**	**0**	**0**	**0**
m4					

	A	B	C	D	E
M		**2**	**6**	**1**	**2**
, **M**	*3*	**0**	*M*	**1**	*H*
2	*M*	*4*	*7*	*4*	*m*
	7	**1**	*5*		*l*
m 4	*J**	*K*	**0**	*H*	*K*

The optimal assignment is :

M, - A, M2 -> B, M3 -> C, M4 -» D, Ms -> C (C will remain vacant)*

Total assignment cost = Rs. (4 + 4 + 2 + 2) = Rs. 12.

10.9 CREW BASED ASSIGNMENT PROBLEM

The method of solution discussed in this section can be used to plan the assignment of crew members in different locations by a transport company.

Example 7

A trip from Chandigarh to Delhi takes six hours by bus. A typical time table of the bus service in both directions is given below :

Departure from	Route Number	Arrival at Delhi	Arrival at	Route Number	Departure from
06.00	a	12.00	11.30	1	05.30
07.30	b	13.30	15.00	2	09.00
11.30	c	17.30	21.00	3	15.00
19.00	d	01.00	00.30	4	18.30
00.30	e	06.30	06.00	5	00.00

The cost of providing this service by the transport company depends upon the time spent by the bus crew (driver and conductor) away from their places in addition to service time. There are five crews. There is a constraint that every crew should be provided with more than 4 hours of rest before the return trip again and should not wait for more than 24 hours for the return trip. The company has residential facilities for the crew at Chandigarh as well as at Delhi. Find the optimal service line connections.

Solution :

As the service time is constant for each line it does not appear directly in the computation. If the entire crew resides at Chandigarh then the waiting times in hours at Delhi for different route connections are given in the following Table :

	1	2	3	4	5
a	17.5	21	M	6.5	12
b	16	19.5	M	5	6.5
c	12	15.5	21.5	M	6.5
d	4.5	8	14	17.5	23
e	23	M	8.5	12	17.5

If route a is combined with route 1, the crew after arriving at Delhi at 12 noon start at 5.30 next morning. Thus, the waiting time is 17.5 hrs.

Some of the assignments are infeasible. Route 3 leaves Delhi at 15:00 hrs. Thus, the crew of route a reaching Delhi at 12 noon are unable to take rest of 4 hours if they are asked to leave by route 3. Hence, (a, 3) is an infeasible assignment. Its cost is thus, M, a large positive number.

Similarly, if the crew are assumed to reside at Delhi (so that they start from and came back to Delhi with halt for minimum time at Chandigarh), then waiting time at Chandigarh *for different service line connections are given by the following Table.*

	1	2	3	4	5
a	*18.5*	*15*	*9*	*5.5*	*M*
b	**20**	*16.5*	*10.5*	*7*	*M*
c	*M*	*20.5*	*14.5*	**11**	*5.5*
d	*7.5*	*M*	**22**	*18.5*	*13*
e	*13*	*7.5*	*M*	*M*	*18.5*

As the crew can be asked to reside at Chandigarh or Delhi, minimum waiting time from the above operation can be computed for different route combination by choosing the minimum of the two waiting time. These values of the waiting time are shown below:

	1	2	3	4	5
a	*17.5*	*15*	*9*	*5.5*	**12**
b	*16*	*16.5*	*10.5*	*5*	*10.5*
c	**12**	*15.5*	*14.5*	**11**	*5.5*
d	*4.5*	**8**	*14*	*17.5*	*13*
e	*13*	*9.5*	*8.5*	**12**	*17.5*

Hungarian method can now be applied for finding the optimal route connections which gives minimum over all waiting time and hence the minimum cost of bus service operations. It consists of the following steps.

Step 1 : Find the first and second reduced cost matrix

	1	2	3	4	5
a	**12**	*9.5*	*3.5*	**0**	*6.5*
b	**11**	*11.5*	*3.5*	**0**	*5.5*
c	*6.5*	**10**	*9*	*5.5*	**0**
d	**0**	*3.5*	*9.5*	*13*	*8.5*
e	*4.5*	**1**	**0**	*3.5*	*9*

	1	2	3	4	5
a	**12**	*8.5*	*3.5*	**0**	*6.5*
b	**11**	*10.5*	*5.5*	**0**	*5.5*
c	*6.5*	*9*	*9*	*5.5*	**0**
d	**0**	*2.5*	*9.5*	*13*	*8.5*
e	*4.5*	**0**	**0**	*3.5*	*9*

Step 2 **: Check for optimality.**

	1	2	3	4	5
a	**12**	*8.5*	*3.5*	*0*	*6.5*
b	**11**	*10.5*	*5.5*	*H*	*5.5*
c	*6.5*	*9*	*9*	*5.5*	*e*
d	*E*	*2.5*	*9.5*	*13*	*8.5*
e	*4.5*	*e*	*SC*	*3.5*	*9*

The solution is not optimal, as the number of assignments is less than the number of rows or columns.

Step 3 : Mark V in row b since no assignment was made in this row. Note that row b has zero in column 4, therefore mark V in column 4. We then mark V in row a, since column 4 has an assigned zero in row a. Draw straight lines through all unmarked rows and marked columns. The resulting matrix is :

	1 2 3 4 5	
a	*12 8.5 3.5 [J) 6.5*	
b	**11** *10.5 5.5 % 5.5*	*V*
c	*—6t5 --------- 9----------"S'---------- 5 | "5--------- 0 ' -*	
d	*— -0- -------- 2 .-5" ---- 9t5 ---------- 1(3 -------■&: 5—*	
e	*—4-r5 ------ 1—0~ | -- -------------- 3 j-5--------- 9 —*	

Step 4 : Develop a new revised matrix. Examine those elements that are not covered by the lines and among those elements take the smallest element. Here, 3.5 is the element. Subtract 3.5 from the uncovered elements and add 3.5 with the elements at the intersection of two lines, we get the new Table as :

8.5	*5*	**0**	**0**	*3*
7.5	*7*	**2**	**0**	**2**
6.5	*9*	*9*	*9*	**0**
0	*2.5*	*9.5*	*16.5*	*8.5*
4.5	**0**	**0**	*7*	*9*

Step 5 **: Check if optimal assignment can be made in the current feasible solution.**

8.5	5	[0]	~~0~~	3
7.5	7	2	[0]	2
6.5	9	9	9	[0]
[0]	2.5	9.5	16.5	8.5
4.5	[0]	~~0~~	7	9

As the number of assignment is equal to the number of rows or columns, the current solution is optimal.

Therefore, the routes to be paired to achieve the minimum waiting time are ad 3, bd 3, cd 5, dd 1 and e d 2. We can obtain the waiting times of these assignments as well as the residence of the crew as

Crew	*Resident at*	*Service number*	*Waiting time hours*
1	*Chandigarh*	*(d—1)*	*4.5*
2	*Delhi*	*(2—e)*	*9.5*
3	*Delhi*	*(3-a)*	*9.0*
4	*Chandigarh*	*(b-4)*	*5.0*
5	*Delhi*	*(5—c)*	*5.5*
			Total = 33.5

Total minimum waiting time is thus 33.5 hours.

10.10 TRAVELLING SALESMAN PROBLEM

Suppose a salesman wants to visit a certain number of cities starting from his headquarters. The distances (or cost or time) of journey between every pair of cities, denoted *by e, that is, distance from city i to city j is assumed to be known. The problem is:*

Salesman starting from his home city visited each city only one and returns to his home city in the shortest possible distance (or at the least cost or in the least time).

Given n cities and distance c_{j7} the salesman starts from city 1, then any permutation of

2,..........*3* *n represents the number of possible ways for his tour. So, there are (n-1)! possible*

ways for his tour. The problem is to select an optimal route that could achieve his objective. The problem may be classified as :

(i) *Symmetrical: If the distance between every pair of cities is independent of the direction of his journey.*

(ii) *Asymmetrical: For one or more pair of cities the distance changes with the direction.*

	To item				
From item	*A*	*B*	*C*	*D*	*E*
A	*oo*	*4*	*7*	*3*	*4*
B	*4*	**00**	**6**	*3*	*4*
C	*7*	**6**	*oo*	*7*	*5*
D	*3*	*3*	*7*	**00**	*7*
E	*4*	*4*	*5*	*7*	**00**

If he processes each type of item once and only once each week, how should he sequence the items on his machine in order to minimise the total set-up cost?

Solution:

Step 1: Reduce the cost matrix using Step 1 and 2 of the Hungarian algorithm and then make assignments in rows and columns having single zeros as usual.

∞	1	3	[0]	1
1	∞	2	~~0~~	1
2	1	∞	2	[0]
~~0~~	[0]	3	∞	4
[0]	~~0~~	~~0~~	3	∞

Step 2 : Note that row 2 is not assigned. So, mark V to row 2. Since there is a zero in the 4th column of the marked row, we tick 4th column. Further, there is an assignment in the first row of 4th column. So, tick first row. Draw lines through all unmarked rows and marked columns. We can find the number of lines is 4 which is less than the order of the matrix. So, go to next step (see table).

∞	1	3	[0]	1
1	∞	2	~~0~~	1
2	1	∞	2	[0]
~~0~~	[0]	3	∞	4
[0]	~~0~~	~~0~~	3	∞

V

Step 3 : Subtract the lowest element from all the elements not covered by these lines and add the same with the elements at the intersection of two lines. Then we get the table

	1	**2**	**3**	**4**	**5**
1	**00**	**BC**	**2**		**BC**
2	**ca**	**CO**	**1**	**BC**	**BC**
3	**2**	**1**	**00**	**3**	**El**
4	**K**	**ra**	**3**	**00**	**4**
5	**K**	**H**		**4**	**go**

The optimum assignment is l-> 4, 2 -> 1, 3 -> 5, 4 -> 2, 5 -> 3 with minimum cost as Rs.

20.

This assignment schedule does not provide us the solution of the travelling salesman problem as it gives l-> 4, 4 ->■ 2, 2 - 1, without passing through 3 and 5.*

Next, we try to find the next best solution which satisfies this restriction. The next minimum (non-zero) element in the cost matrix is 1. So, we bring 1 into the solution. But the element '1' occurs at two places. We consider all cases separately until we get an optimal solution.

We start with making an assignment at (2, 3) instead of zero assignment at (2, 1). The resulting assignment schedule is

1_> **4** *2, 2 -► 3, 3 5, 5 -> 1 When an assignment is made at (3, 2) instead of zero assignment at (3, 5), the resulting assignment schedule is*

l-> 5, 5 -> 3, 3 -> 2, 2 -► 4, 4 -> 1

The total set-up cost in both the cases is 21.

Example 9

Solve the travelling salesman problem given by the following data : c_{12} » *20,* c_{13} *- 4,* c_{M} *= 10,* c_{23} *- 5,* $c_{3«}$ = **6**

∞	20	4	10	∞
20	∞	5	∞	10
4	5	∞	6	6
10	∞	6	∞	20
∞	10	6	20	∞

Repeating the steps as before using the Hungarian algorithm, the optimum table obtained is :

∞	12	[0]	~~0~~	∞
11	∞	~~0~~	∞	[0]
~~0~~	1	∞	[0]	1
[0]	∞	~~0~~	∞	9
∞	[0]	~~0~~	8	∞

The solution is

1 -> 3, 3 -> 4, 4 - 1, 5 -» 2, 2 -> 5*

which is not the solution of the travelling salesman problem as the sequence obtained is not in the cyclic order.

The next lowest number (other than 0) is 1- Therefore, make an assignment in the cell (3, 2) having the element 1. Consequently, make an assignment in the cell (5, 4) having element **8**, *instead of zero element in the cell (5, 2). The resultant Table is*

∞	12	[0]	~~0~~	∞
11	∞	~~0~~	∞	[0]
~~0~~	[1]	∞	~~0~~	1
[0]	∞	~~0~~	∞	9
∞	~~0~~	~~0~~	[8]	∞

The shortest for the travelling salesman is

1 —► *3* —► *2* —► *5* —► *4* —> *1*

10.11 EXERCISES

1. *What is an assignment problem? Give two areas of its applications.*
2. *Explain the conceptual justification that an assignment problem can be viewed, as a linear programming problem.*
3. *Explain the difference between a transportation problem and an assignment problem.*
4. Find the optimal solution for the assignment problem with the following cost matrix.

	I	II	III	IV	V
A	**11**	17	**8**	16	**20**
B	9	7	**12**	**6**	15
C	13	16	15	**12**	16
D	**21**	24	17	28	26
E	14	**10**	**12**	**11**	15

(Answer. A - 1, B -> IV, C -> V, D -* III, E -* II, minimum cost = 60.)*

5. *Five men are available to do five different jobs. From the past records, the time (in 2 hour) that each man takes to do each job is known and given in the following*

Table

A

B

C

D

I	II	III	IV	V
2	9	2	7	1
6	8	7	6	1
4	6	5	3	1
4	2	7	3	1
5	3	9	5	1

Find the assignment of men to jobs that will minimise the total time taken.

(Answer. A -+ III, B -> V, C -» I, D -> IV, E -> II, optimal value = 13 hours.)

6. *Solve the following assignment problem.*

A	8	4	2	6	1
B	0	9	5	5	4
C	3	8	9	2	6
D	4	3	1	0	3
E	9	5	8	9	5

(Answer. A -» 5, B -> 1, C -> 4, D -> 3, E -> 2, minimum cost = 9.)

7. *For the following problem of assigning four slaes persons to four different sales regions,*

Sales Region

		II	III	III
A	10	22	12	14
B	16	18	22	10
C	24	20	12	18
D	16	14	24	20

10.12 SUGGESTED READINGS

1. *Loomba, N.P. : Management - A Quantitative Perspective (New York, Macmillan, 1978).*

2. *Sharma, K.K. : Quantitative Techniques and Operation Research (New Delhi, Kalyani, 1992).*

3. *Taha, Hamdy A. : Operations Research - An Introduction (New York, Macmillan, 1987).*

4. *Swarup Kanti, : Operations Research (New Delhi, Sultan Chand & Sons, Gupta, P.K. and 2005)*

TRANSPORTATION PROBLEM

STRUCTURE

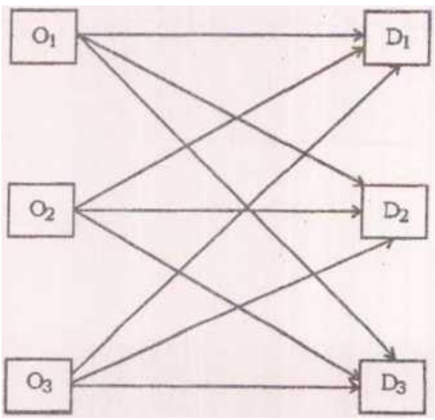
11.1 INTRODUCTION

The transportation model deeds with a special class of linear programming problems in which the objective is to transport a homogenous commodity from various origins to different destinations at a minimum total cost. Given the information regarding the total capacities of the origins, the total requirements of the destinations, and the shipping cost per unit of goods for available shipping routes, the transportation model is used to determine the optimal shipping program that results in minimum total shipping cost. The transportation model can be extended to solve problems related to topics such as production planning, machine assignment, and plant location.

Transportation models can also be used when a firm is trying to decide where to locate a new facility. Before opening a new warehouse, factory, or sales office, it is good practice to consider a number of alternative sites. Good financial decisions concerning facility location also attempt to minimize total transportation and production costs. The eminent scholars like Weber, Polander Losch, Hotelling, etc. emphasised to attain the point of minimum transportation costs so as to achieve to maximum profits for the location of new industrial units.

11.2 MATHEMATICAL FORMULATION OF THE PROBLEM

Origin



Destination

Formula : Let there are m origins 0,, 0₂ .... 0_m having respective capacity of production a,, a^................ a_n and Let there are n destinations D,, D₂.............. D_n having respective demand b,f b₂...........b_n. The cost of transportation of one unit of commodity from O. be c^., which is known as cost coefficient (i - 1, 2, ...m; J - 1, 2, 3,............... n). Again if Xij be the number of units to be transported from Oi to Dj, then the problem is to find XiJ so that

Z = £ (m n; i-1 j=1) **C„ Xy is minimum - 1**

Under the Constraints :

n

m

X X„ » b^; j « 1, 2 .... n (requirement constraints) - 3

X;j £ 0 for all i, j.

for, a feasible solution to exist it is necessary that total capacity equal total requirement

m n

Za' = (i=1 j=1) **(R i m Condition) - 4**

Transportation Table

Destination I Origin ->	*D,*			*Dn*	*Available Supply*
Ol	*c„*	*cia*		*C,n*	*a.*
02	*ca,*			*C2n*	
Om	*Cm,*	*Cm₂*		*Cmn*	*am*
Requirement or Demand	*b,*			*bn*	**m n** *I-=Zbj* **i=1 j=1**

Solution : Set

X =

xn	**x12**	xln
x21	x22	**x2n**
xml	xm2	*xnm*

Observations :

(i) *Total supply from ith origin to all destinations is equal to total quantity produced at the ith origin i.e.*

$X_{,.} + X_{2j}$ + ... Xin = ai, j-1, 2 .... m

(ii) **Total quantity transported at jth destination from various origins is equal to the quantity required at the jth destination; ie.,**

X,j + Xj + ...+ Xmj = bj, j - 1, 2,............ n

(iii) **A set of non-negative values**

Xij, i - 1, 2, - m, j - 1, 2 .... n

that satisfies (i) and (ii)

and Z = $\overset{m}{S}\,\overset{n}{S}$ Cij Xij is called a feasible solution to the transportation problem. i=l j=i

(iv) *An initial feasible solution with (m + n - 1) number of variables Xij, i = 1, 2............ m; j =* **1, 2** *n is called a basic feasible solution.*

(v) *A feasible solution (may not be basic) is said to be optimum if it minimises total transportation cost.*

(vi) *If Lai - Lbj. T. P. is balanced otherwise, unbalanced.*

(vii) *Transportation table is diorded into mn, number of boxes arranged in m rows and n column. Each box is known as a cell. The cell situated at ith row and jth column is known as {i, j) Cell.*

11.3 BASIC ASSUMPTIONS OF THE MODEL

The transportation model depends upon the following conditions to be satisfied :

(i) *The supply of the items must be equal to the demand/requirements of the consumption centres, that is, there must be a balance between the demand and supply of the items. Otherwise, if unbalance is there, it must be transformed into the balance, by adding a dummy row or column, as it needs, which is significant for solving the problem, and it will not enter into the solution mix.*

(ii) *Items can easily be transported from every production centre to consumption centres.*

(iii) *There must be the complete knowledge of the transport costs of every centre to and from.*

(iv) *The basic objective of the transport model is to minimize the total transport costs not the transport cost of an individual route.*

11.4 APPROACH OF THE TRANSPORTATION METHOD

The transportation method consists of the following three steps :

First Step : In involves making the initial shipping assignment in such a manner that a basic feasible solution is obtained. This means that m + n - 1 cells (routes) of the transportation matrix are used for shipping purposes.

Second Step : This step is to test the optimality of the solution.

Third Step : It involves determining a new and better basic feasible solution.

All the steps outlined above are applied in the systematic manner in the transportation method.

11.5 INITIAL BASIC FEASIBLE SOLUTION

There are five important methods of developing an initial feasible solution, these axe :

(i) *North-West Comer Method*
(ii) *Least-Cost Entry Method*
(iii) *Vogel's Approximation Method*
(iv) *Row Minima Method*
(v) *Column Minima Method*

The detailed description of first three methods is presented as under :

11.5.1 North-West Corner Method (Rule)

According to this rule, first allocation is made to the cell occupying the upper left hand (north-west) corner of the matrix. Further, this allocation is of such a magnitude that either the capacity exhausted, or the requirements are satisfied, then we move to the right in the same row, so on so forth, till the capacities and requirements of the problem are not satisfied. In this process, we have no accountability of the transport costs of the different routes. In brief :

(i) *Exhaust the supply at each row before moving down to the next row.*
(ii) *Exhaust the requirements of each column before moving to the right to the next column, and*
(iii) *Check that all supply and demands are met.*

Table 11.1

Origin	Destination				Capacity
	D,	d2	d3	D<	
o,	5	3	6	7	35
02	2	8	1	9	60
03	1	4	8	3	25
Destination Requirements	30	45	25	20	120

The solution of the above problem by north-west comer rule is as follows :

Table 11.2

Origin	Destination				Capacity
	Di	d2	d3		
o,	5 ®	3 ©	6	7	35
02	2	8 ©	1 ©	\ 9	60
03	10	4	© 8	(g) 3	25
Destination Requirements	30	45	25	20	120

Detailed Analysis of Allocations to Different Cells

We move from the north-west corner (0,D,) allocated 30 units to OjD, which satisfied the requirements of the first destination (D,), but the capacity of 5 units is in surplus, which is allocated to the next column of D_2 which has a requirement of 45 units and the balance of 40 units is provided from the next capacity origin (0_2), now the requirements of the D_2 destination is satisfied, and similarly we allocate the other capacity to the requirements and move to next until the capacity is exhausted or the requirements satisfied. By this way, we get the complete solution by the North-West Comer Rule. Diagrammatically, the rule can be presented by the following way :

i ______

I i

I

Thus, if x_y is the transportation quantity from origin O. to destination D^, then the feasible solution is x_n = 30, x_{12} = 5, x^ - 40, x^ - 20, x_{33} = 5, x_{36} = 20. This is the first basic feasible solution.

Basic Feasible Solution

A basic feasible solution indicates the number of positive allocations (number of occupied cells) which equal to m + n - **1** *where m * no. of rows and n is the no. of columns. The present example satisfiess the criteria, i.e.*

Number of Occupied Cells =

m + n - 1 = Number of Columns plus Number of Rows minus l = 4 + 3- l = **6** *Number of Occupied Cells "m+n-1-6*

Hence the initial feasible solution is the basic feasible solution.

Total Transportation Cost

As per the above route of North-West Comer Method, the Total Transportation Cost is as under :

Total Transport Cost for the route = OlDl + 01D2 + 02D2 + 02D3 + 03D3 + 03D4 is (TTC) = 30 x 5 + 5 x 4 + 40 x **8** *+ 20 x 1 + 5 x* **8** *+ 20 » x3 = 150 + 15 + 320 + 20 + 40 + 60*

- 605

Hence the total transportation cost by North West Corner rule is Rs. 605/-.

11.5.2 Least/Lowest Cost Entry Method

The basic approach of this method is to select that cell in the cost matrix which gives the lowest cost entry and allocate the capacity as per requirements of the cell. This process will go on, till the total capacity is not exhausted and all the requirements are not satisfied. That will be the

provides the lower cost than the north-west corner method. This method is clarified by the example of 3.1. The solution is as under :

Table 11*3

Origins	*Destination*				*Capacity*
	D,		$^{D}3$		
Oi	*5*	© 3	**6**	*7*	*35*
02	©	© 00	© 1	*9*	*60*
03	**10**	*4* ©	**8**	©	*25*
Destination Requirements	*30*	*45*	*25*	**20**	**120**

In the above table, the Cell 0_2D_3 has the least cost of one, its requirements are of 25 units, which are fully allocated out of the capacity of 60 units. The next Cell 0_2D has the least cost, its requirements of 30 units are fully allocated out of the remaining 35 units. Both the cells have been allocated the capacity as per constraints. The next least cost cells are O^., and 0_3D_4 with cost Rs. 3. We allocate here according to requirements and avail abality i.e. quantity 35 in $0,D_2$ and 20 in 0_3D_4. The next Cell O_aD_2 has the least cost of Rs. 4, the remaining five units is allocated.

And the last surplus of the capacity of 0_2 of five units is allocated to Cell 0_2D_r Hence this is the way of least cost method to be applied.

Basic Feasible Solution

The initial feasible solution is the basic feasible solution, because the number of the occupied cells is equal to the number of columns plus no. of rows minus one, which is equal to six.

Total Transportation Cost (TTC) for this solution :

TTC ^{m} ($0,D_2$ + 0_2D, + 0_2D_2 + 0_3D_2 + 0_3D_4) route :

= 35x3 + 30x2 + 5x8 + 25x1 + 5x4 + 20x3 =
105 + 160 + 40 + 25 + 20 + 60 = 310

11.5.3 Vogel's Approximation Method (VAM)

Vogel's approximation method is another way of finding the initial feasible solution to the transportation problems. Indeed, this is the best technique and has an edge of superiority over the earlier technique of North-West Corner Rule and the Least Cost Entry Method, because it takes into account the costs associated with each route alternative. To apply VAM, we first compute for each row and column the penalty costs, if we should skip over the second best route instead of the least cost route. The following are six steps to be followed for applying the VAM :

Step 1 : For each column and row of the Transportation table, find the difference between the two lowest unit shipping costs.

Step 2 : Identify the row or column with the greatest opportunity cost or difference.

Step 3 : Assign as many units as possible to the lowest cost square in the row or column selected on the basis of Step 2.

Step 4 : Eliminate any row or column that has just been completely satisfied by the assignment just made as per the requirements or the capacity constraint. This can be done by placing X's in each appropriate square.

Step 5 : Recompute the cost difference of the remaining rows and columns and revise the Steps from Step 2 to Step 4.

Table 11.4

Origin	*Destination*				*Capacity*	*Cost Difference*
	D.	*d_2*	*D,*	*d_4*		
	5	3	**6**	7	35	**2**
o_2	**2**	**8**	**1**	9	60	**1**
o,	**10**	4	**8**	3	25	**1**
Destination Requirements	30	45	25	**20**		
Cost Diference	3	**1**	5	4		

The greatest cost difference is of column D_3, at least cost cell in this column is 0_2D_3 now assign 25 units of requirements out of the capacity of 60 units of cell 0_2. As the requirements of this column are satisfied, cross the other cells in this column and recompute the cost difference of the remaining rows and columns :

Table 11.5

Origin	*Destination*				*Capacity*	*Cost Difference*
		··· ····	*p* **D2**			
o,	5 X	3	**6** X	7	35	
02	©	**8**	©	9	60	©
03	**10** X	4	**8** X	3	25	**1**
Requirements	30	45	25	**20**	**120**	
Cost Difference	3	**1**		4		

The greatest cost difference is of Row 0_2, the least cost cell in this row is 0_2D,, which has a requirement of 30 units, this can be allocated out of the remaining capacity of 35 units of 0_2 row. The requirement of this column are fully met, so this column is also deleted. And now recompute the cost differences of the remaining rows and column :

Table 11.6

Origin	*Destination*				*Capacity Difference*	*Cost*
	D.		*d₃*			
o,	*5* *X*	*3*	**6** *X*	*7*	*35*	*4*
02	©	**8**		*9*	*(60)*	*3*
03	**1** *X*	*4*	**8** *X*	© **3**	*25*	**1**
Requirements	*30*	*45*	*25*	**20**	**120**	
Cost Difference		**1**		*4*		

The greatest cost difference is of column D_4 and row O,, both have equal cost difference of 4, any of these can be selected Suppose, we are selecting column D_4, and allocate the requirements of 20 units to the least cell, which is 0,D_4, and the column has fully satisfied requirements. Now any one column is left., and there is no choice of allocations of the remaining balances of the capacities may be allocated to the different cells, which will have to satisfy the requirements of the column D_r In this way, the cell 0,D_2 is allocated 35 units. 0_2D_2 is allocated 5 units and the least $0_3D_2$is allocated 5 units. So we get the final tableau as per this method, which is presented as follows :

Tabl*e 11.7*

Origin	*Destination*				*Capacity*
	D,	*r-₃*	*r>₃*		
Ol	*5*	**0**	*/•* *o*	*7*	*35*
02	**2**	**8** ©	©	*9*	*60*
03	**10**	*4* *5*	*8*	**0**	*25*
Requirements	*30*	*45*	*25*	**20**	**120**

The initial feasible solution provided by the above Table 4.7 is basic feasible solution *also, because the number of occupied cells is equal to the number of columns plus number of rows minus one. Which is* **6**.

Total Transportation Cost (TTC) :

$TTC = O.D_2 + 0_2D, + 0_2D_2 + 0_3D_2 + 0_3D_4$

$= 35x3 + 30x2 + 5x8 + 25x1 + 5x5 + 20x3$

Vogel's approximation method, which is equal to the Lowest cost entry method, but less than the North-West Comer Method.

11.6 TEST OF OPTIMALITY

The optimality of the routes provided by the above methods can be tested through two methods :

4.5.(1) The Stepping Stone Method
4.5 *(2) The Modified Distribution Method (Modi)*

Design a New And Better Program

THE THIRD AND THE LAST STEP is to design a new and better program, if the second step shows that the routes provided by the initial feasible solution are not optimal. In this step, the new program and the new routes provided and chalked out by the two methods are used for checking optimality.

Now we are applying the above methods of checking the optimality upon the initial feasible solutions computed by the Lowest Cost Entry Methods or the Least Cost Method.

11.6.1 Stepping-Stone Method - A Test For Optimality

The Stepping-Stone Method is a very useful technique for testing the optimality of the transportation problem. This method is applicable when the initial feasible solution is the basic feasible solution, that is, the number of the occupied cells must be equal to the number of rows plus the number of columns minus one. In the next step, we calculate the opportunity cost of each and eveiy empty cell by framing its closed path. If the opprtunity cost of a single cell is positive, then the initial feasible solution is non-optimal and we have to design a new program which will be optimal. Now we are testing the optimality of the North-West Corner Method, as results provided in Table 3.2. The application of the Stepping-Stone Method is as follows :

Table 11.8

Origin	Destination				Capacity
	D,	d_2	d_3	d_4	
01	5 30	CO ©	**6** + **10**	7 + 16	35
02	**2** **-8**	**00** (D	©	9 + 13	60
03	**10** -7	4 0	**8** 5	©	25
Requirements	30	45	25	**20**	**120**

A closed path is that only squares currently used for shipping can be used in turning the corners of the route being traced. The closed path of 0_2D, is 0_2D, - 0_2D_2 - $0,D_2$ - 0,D,, similarily we can trace the closed path of the other unused squares, the closed path of $0,D_4$ as shown in the above Table 15.8. In the next step, we put a plus sign in the unused square of the closed path and alternative signs to other corner used squares as shown in the Table. All the closed paths of unused squares and their opportunity costs are presented in the following :

Table 11.9

Empty Cell	*Closed Path*	*Net Cost Change*	*Opportunity*	*Action Cost*
o₂d,	**0,0,-0,02+0,02-0,0,**	*+2-8+3-5"-8*	**8**	*Candidae for including next program*
	03D,-03D3+02D3-02D2+0;D2 -**0,0,**	*+10-8+l-8+3-5=-7*	*7*	*-do-*
°3d2	*o3D2-o3D3+o2D***3**-*C***2***D2* *o, Ds- 0, D2+OjD2- 02D3*	*+4-8+l-8=-l 1* *+6-3+8-1=10*	**11** **-10**	*-do-* *Do not include*
o2d4	*o2d4-o2d3+o3d3-o3d4*	*+9-1+8-3=13*	*-13*	*Do not include*
	o,d4-o,d2+o2d2-o2d3+o3d3 -o3d4	*+7-3+8-1+8-3=16*	*-16*	*Do not include*

In the Table 11.9, the opportunity cost of three empty cells is positive, which indicates the non-optimality of the solution provided by the North-West Method. For optimality, we move and in corporate the empty cell 0_3D_2, because it has the highest opportunity cost. This cell must be included in our next program and we allocate maximum capacity of the minimum of the negative sign number of the closed path which is 5 units. Now we again revise the program and calculate the opportunity cost of each and every cell as we did previously and find out the positive opportunity cost, if any, if not, then the solution is optimal and we have designed a new program. But by calculating the opportunity cost of the revised program we find that the opportunity cost of 0_2D, is positive, which is **8***, we include this into our new program and allocate similarly the minimum of the negative sign figures units of the closed path, which is 30. Now by calculating the opportunity costs, all are negative, hence the new designed program is optimal, which is :*

Table 11.10

Origin	*Destination*				*Capacity*
	Di	D₂	*d3*	*d4*	
o>	*5*	*3* ©	**6**	*7*	*35*
02	©	**8** ©	©	*9*	*60*
03	**10** **Q**	*4* *5*	**8**	©	*25 1*
Requirements	*30*	*45*	*25*	**20**	

Table 11.10 designed a new and a better program and the total transportation cost worked out to be is Rs. 310/-.

11.6.2 Modified Distribution Method (Modi Method)

The MODI method allows us to compute improvement indices quickly for each unused square without drawing all of the closed paths. Because of this, it can often provide considerable time savings over the Stepping-Stone Method for solving transportation problems.

The MODI method is applied after an initial and basic feasible solution is obtained. In this method, we calculate the values of the rows and columns, we apply the method in the following way :

Ui = value assigned to row i.

Vj = value assigned to column j.

Cij = cost in square ij.

For calculating the values of the rows and columns, we use the following formula :

Ui + Vj - Cij = Aij (Opportunity Cost)

Improvement Index = Cij - Uj - Vj

The improvement index is calculated for every unused square.

We shall illustrate the mechanics and rationale of the modified distribution method by solving the transportation problem for which a basic feasible solution is shown in Table 4.2.

From Table 4.2, we first write up an equation for each occupied square.

U_t + V, = 5 $U_2 + V_3 = 1$

U, + V_2 = 3 $u_3 + v_3 = 8$

$A_{2]}$ = U_2 V, - 2 - 5 - 5 = -8	**8**
^{A}3i = U_3 V, = 10 - 12 - 5 = -7	**7**
A_{32} = U_3 V_2 = 4 - 3 - (12) =-11	**11**
^{a}m = ^{U}i ^{V}4 = 7 - 0 - (-9) =16	**- 16**
^{A}24 " ^{U}2 ^{V}4 = 9 - 5 - (-9) =13	**- 13**
A_{13} = U, V_3 = 6 - (- 4) - 0 - 10,	**-10**

Since the opportunity cost of the three empty cells is positive, which indicates that the solution is not optimal. For optimality, the current program must be revised starting from the cell, which has the maximum positive opportunity cost, which is U3V2 and the procedure is the same as we did in the Stepping-Stone Method. But now we need the specific closed paths for those cells, whose opportunity cost is positive.

11.7 MAXIMIZATION CASE

For maximization problems, we substract each and every profit from the highest (profit), then solve the problem like the case of minimization.

11.8 DEGENERACY

Degeneracy in the transportation problem is of very grave concern. It occurs when no. of occupied cells is less than m + n - 1. This can be overcome by placing a zero in the *independent unused square, so that it may be treated as the occupied cell and proceed as earlier. The degeneracy problem is resolved.*

11.9 EXERCISES

Solve the following transportation problems, also apply the test of optimality and if necessary, design the new optimal program.

(i) *A Cement manufacturing Co. wishes to transport cement from its three factories P, Q and R to five distribution depots situated at A, B, C, D and E.The quantities produced at the factories per week, requirement at the depts per week and respective transportation cost in Rs. per ton are given in the table below :*

	Depots					Tons Available
Factories	A	B	C	D	E	
P	4	1	3	4	4	60
Q	2	3	2	2	3	35
R	3	5	2	4	4	40
Tons Required	22	45	20	18	30	135

Determine the least cost distribution program for the company, (ii)

Solve the following transportation problem :

	D1	D2	D3	Available (Quantity)
Q1	8	7	3	60
Q2	3	8	9	70
Q3	11	3	5	80
Required (Quantity)	50	80	80	

(Ans. 750)

(iii) *A company has three plants location A, B and C, which supply to warehouse located at D, E, F, G and H. Monthly plant capacities are 800, 500 and 900 units respectively. Monthly warehouse requirements are 400, 500, 400 and 300 units respectively. Unit*

transportation cost (in rupees) are given as :

From \ To	D	E	F	G	H
A	5	8	6	6	3
B	4	7	7	6	5
C	8	4	6	6	4

Determine the optimum distribution for the company in order to minimize the total transportation cost. (Introduce a dummy plant)

(iv) Solve the following transportation problem :

	A	B	C	D	Stocks (Qty.)
X	9	5	8	5	225
Y	9	10	13	7	75
Z	14	5	3	7	100
Qty. required	225	80	95	100	

(Ans. 2310)

(v) Solve the following transportation problem using Vogel's Approximation Method in order to minimize in the total transportation Cost :

	A	B	C	D	E	Availability
X	3	5	8	9	11	20
Y	5	4	10	7	10	40
Z	2	5	8	7	5	30
Requirements	10	15	25	30	40	

(Ans. 525)

(vi) ____ *A company has three factories A, B and C which supply to four warehouses situated at P, Q, R and S. The monthly production capacity (Tons) of A, B and C are 120, 80 and 200 respectively. The monthly requirements (Tons) for the warehouses P, Q, R and S are 100, 75, 150 and 75 respectively. The transportation cost*

	Factories		
Warehouses	*A*	*B*	*C*
P	4	3	7
Q	5	8	4
R	2	4	7
S	5	8	4

Using Vogel's Method determine the optimum transportation distribution of products to warehouse to minimize the total transportation costs.

11.10 SUGGESTED READINGS

1. *Cohen, S. S.* — *Operational Research (London, ELBS, 1987)*
2. *Loomba, N. P.* : *Management-A Quantitative Perspective (New York, Macmillan, 1978)*
3. *Render, B. & Stair R. M.* : *Quantitative Analysis for Management (London, Allyn and Bacon INC, 1988)*
4. *Sharma, K. K.* : *Quantitative Techniques and Operations Research (New Delhi, Kalyani, 1992)*
5. *Taha, Hamdy A.* : *Operations Research-An Introduction (New York, Macmillan, 1987)*
6. *Thierauf, Robert J.* : *An Introductory Approach to Operations Research* **(New York, Wiley, 1978)**

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SEQUENCING

STRUCTURE

12.1 INTRODUCTION

A sequence is the order in which the jobs are processed. Sequencing problems arise when we are concerned with situations where there is a choice as to the order in which a number of tasks can be preformed. A sequencing problem could involve.

(i) *Jobs in a manufacturing plant.*
(ii) *Aircraft waiting for landing and clearance.*
(iii) *Maintenance scheduling in a factory.*
(iv) *Programmes to be run on a computer.*
(v) *Customers In a bank & so-on.*

Most of these problems are solved automatically. Sometimes the ordering is determined by chance or on 'first come first serve' basis. But the solutions may not be appropriate in all the cases. We shall consider the sequencing problems in respect of the jobs to be performed in a concern and study the method of their solution. More specifically when we have 'n' jobs to be done each of which requires processing on some or all of the 'k' different machines. Here we are to select the sequence that minimises cost; time or optimizes effectiveness. The sequencing theory has been developed to deal with all such difficult situations and determine the optimal order or sequence in which series of tasks are to be performed. The basic objective of the sequencing theory is to determine the optimum order with minimising cost/time or maximising effectiveness.

12.2 IMPORTANT TERMS

Jobs : The jobs or items or customers or orders are the primary stimulus for sequencing. There should be a certain number of jobs say 'n' to be processed or sequenced.

Number of Machines : A machine is characterized by a certain processing capability or facilities through which a job must pass before it is completed in the shop. It may not be necessarily a mechanical device. Even human being assigned jobs may be taken as machines. There must be certain number of machines say 'k' to be used for processing the jobs.

Processing Time : Every operation requires certain time at each of machine. If the time is certain then the determination of schedule is easy. When the processing times are uncertain then the schedule is complex.

Total Elapsed Time : It is the time between starting the first job and completing the last one.

Idle time : It is the time the machine remains idle during the total elapsed time.

12.3 BASIC ASSUMPTIONS

Following are the basic assumptions underlying a sequencing problem.

(i) *No machine can process more than one job at a time.*
(ii) *The processing times on different machines are independent of the order in which they are processed.*
(iii) *The time involved in moving a job from one machine to another is negligibly small.*
(iv) *Each job once started on a machine is to be performed up to completion on that machine.*
(v) *All machines are of different types.*
(vi) *All jobs are completely known and are ready for, processing.*
(vii) *A job is processed as soon as possible but only in the order specified.*

These assumptions are considered to make the sequencing problem a simple one otherwise complicacy may arise.

12.4 TYPES OF SEQUENCING PROBLEMS

There can be many types of problems. But we will discuss the following types of problems in this chapter.

1. *Problems with 'n' jobs through one machine.*
2. *Problems with 'n' jobs through two machines.*
3. *Problems with n' jobs through three machines.*
4. *Problems with 'n' jobs through 'm' machines.*

Here the objective is to find out the optimum sequence of the jobs to be processed and starting and finishing time of various jobs through all the machines.

12.4.1 Processing 'N' Jobs through One Machine

In case 'n' jobs are to be processed on one machine where all jobs are available at once, the optimal sequence, minimisation of total processing time for all the jobs taken together is considered. The processing time is taken as sum of waiting time and operation time both. The shortest average processing time per job is determined and the job having shortest time is processed first and the job having next higher operation time should be second & so on. We shall consider a static job shop in which a number of jobs, n, with known processing times require processing on a single machine. The job shop is static in that new job arrivals do not disturb the processing of these n jobs. It may be assumed that new job arrive being considered in the next batch of jobs after the processing of the current accomplished.

Shortest Processing Time (SPT) Rule

Sequencing the jobs in a way that the job with least processing time is picked up first followed by the one with the next smallest processing time and so on. It is referred to as SPT sequencing. However where the importance of tasks or jobs is different we make use of another rule known as weighted-scheduling processing time rule (WSPT).

In this method, weight Wi is assigned to each job, where a larger value indicates the tasks has greater importance.

Example

Consider the 8 jobs with processing times, due dates and importance is given below

Tasks	*Processing time tl*	*Due dated dj*
1	*5*	*15*
2	*8*	*10*
3	*6*	*15*
4	*3*	*25*
5	*10*	*20*
6	*14*	*40*
7	*7*	*45*
8	*3*	*50*

The SPT sequence is 4-8-1-3-7-2-5-6 resulting in completion of these jobs at times 3,

6, *11, 17, 24, 32, 42 and 56 respectively. The mean flow time is thus*

3 + **6** + *11 + 17 + 24 + 32 + 42 + 56 191* **oo** *orrc* ^
--**----- = *23.875 hours*

8 8

12.4.2 Processing 'N' jobs through Two Machines

Let there be n' jobs each of which is to be processed through two machines say A & B, in the order AB. That is each job will go to machine A first and then to B. All 'n' jobs are to be processed oh A without any idle time. On the other hand the machine B is subject to its remaining idle at various stages.

Let A1 A2 ....An & B1 B2........ Bn be the expected processing time of n jobs on these

two machines.

Step 1 : Select the smallest processing time occurring in list Ai or Bi, if there is a tie select either of the smallest processing time.

Step 2 : If the smallest time is on machine A, then place it at first place if it is for the B machine place the corresponding job at last. Cross off that job.

Step 3 : If there is a tie for minimum time on both the machines then select machine A first **8***s machine B last and if there is tie for minimum on machine A then select anyone of these jobs first and if there is tie for minimum on machine B and select any of these job in the last.*

Step 4 : Repeat step 2 & 3 to the reduced set of processing times obtained by deleting the processing time for both the machines corresponding to the jobs already assigned. Step 5 : Continue the process placing the job next to the first or next to the last and so on till all jobs have been placed and it is called optimum sequence.

Step 6 : After finding the optimum sequence we can find the followings

(i) *Total elapsed time = Total time between starting the first job of the optimum sequence on machine A and completing the last job on machine B.*

Example

In a factory, there are six jobs to process, each of which should go to machines A **86** *B in the order AB. The processing timings in minutes are given. Determine the optimal sequencing* **8**& *total elapsed time.*

Jobs	1	2	3	4	5	6
Machine A	7	4	2	5	9	8
Machine B	3	8	6	6	4	1

The total elapsed time T is obtained as under:

Job Sequence	Machine A		Machine B		Idle time for Machine B
	IN	OUT	IN	OUT	
3	0	2	2	8	2
2	2	6	8	16	-
4	6	11	16	22	-
5	11	20	22	26	-
1	20	27	27	30	1
6	27	35	35	36	5

As shown above the first Job, Job 3 starts at time 0 on machine A and is over by time 2, when it passes to machine B to be continued till time **8**. *The job 2 starts on machine A at time* **2** *as the machine is free at that time, it is completed at time* **6** *and has to wait for* **2** *minutes before it is processed on machine B starting at time* **8** *when the machine is free. Similarly various jobs are assigned to the two machines and total elapsed time is obtained as 36 minutes. Total idle time for machine A 1 minute and for machine B is 2 + 1+5 =* **8** *minutes.*

Example :

A manufacturing company processes **6** *different jobs on two machines A and B. Number of units of each job and its processing times on A and B are given in table. Find the optimal sequence, the total minimum elapsed time and idle time for each machine.*

Job No.	No. of units of each job	Processing time	
		Machine A (minutes)	Machine B (minutes)
1	3	5	8
2	4	16	7
3	2	6	11
4	5	3	5
5	2	9	7.5
6	3	6	14

Solution:

By examining the processing times we find that the smallest value is 3minutes for job

4 *on machine A. Thus, job 4 is scheduled as first. By repeating the procedure, we get the following sequence :*

4 1 3 6 5 2

Job No.	*Unit no. of the Job*	*Machine A*		*Machine B*	
		Time in (minutes)	*Time out (minutes)*	*Time in (minutes)*	*Time out (minutes)*
4	**1***st*	**0**	*3*	*3*	**8**
	2*nd*	*3*	**6**	**8**	**12**
	3rd	**6**	*9*	*13*	*18*
	4 th	*9*	**12**	*19*	
	5th	**12**	*15*	*23*	
1	**1***st*	*15*	**20**	*28*	
	2*nd*	**20**	*25*	*36*	
	3rd	*25*	*30*	*44*	
3	**1***st*	*30*	*36*	*52*	
	2*nd*	*36*	*42*	*63*	
6	**1***st*	*42*	*48*	*74*	
	2*nd*	*48*	*54*	**88**	**1**
	3rd	*54*	*60*	**102**	**1**
5	**1***st*	*60*	*69*	*116*	**1**
	2*nd*	*69*	*78*	*123.5*	**1**
2	**1***st*	*78*	*94*	*131*	**1**
	2*nd*	*94*	**110**	*138*	**1**
	3rd	**110**	*126*	*145*	**1**
	4th	*126*	*142*	*152*	**1**

The total elapsed time for all the jobs including the number of units is 159 minutes. However, machine A remained idle for 17 minutes and machine B remained idle for 3 minutes.

12.4.3 Processing 'N' Jobs on Three Machines

Let there be 'n' jobs each of which is to be processed through three machines C in the order ABC. No passing off jobs is permitted and actual processing time in al machines is known. The problem again is to find the optimum sequence which mi (Processing Time)

Job	*Machine A*	*Machine B*	*Machine C*
1	*A,*	*B,*	*c,*
2	a_2	-	C_2
3	-	b_3	C_3
I	-	*I*	*I*
i	*A i*	*B.*	*C,*
I	*I*	*I*	*I*
n	*An*	*B*	c_n

No general solution is available at present for such a case. However previous method given by Johnson can be applied if the following two conditions are satisfied.

Condition 1 : The minimum of the times for different jobs on machine A is at least equal to the maximum of the times of different jobs on machine B.

Condition 2 : The minimum of the times for different jobs on machine C is at least equal to the maximum of the times of different jobs on machine B.

i.e. Find (i) Minimum of Ai (ii) Minimum of Ci (iii) Maximum of B j Check (i) Ai >= Bi and/or (ii) Ci >= Bi If the above two are not satisfied the method fails otherwise we can proceed.

Example:

A machine operator has to perform 3 operations, Turning, Threading & Knurling on three machines A, B & C in the order ABC. Find the optimum sequence when the time in hours are given

•Job	Turning Ai	Threading B,	Knurling **C**{
1	3	8	13
2	12	6	14
3	5	4	9
4	2	6	12
5	9	3	8
6	11	1	13

Solution :

Min of Ai = 2, Max. Bi = **8** *=> Not satisfied.*

Min of C_j = **8**, *Max. Bi =* **8** *'=> Satisfied.*

Since one of the conditions are satisfied, the above problem can be converted into 'n' jobs, **2** *machines*

Job	G-Ai + Bi	H=Bi + Ci
1	3 + 8=11	**8** + 13 = 21
2	**12** + o = 18	6+14 :=20
3	5 + 4=9	4 + 9=13
4	**2** + **6** = **8**	6 + 12 = 18
5	9 + 3- - 12	3 + 8 = 11
6	11+1=12	1 + 13 = 14

We get the optimum sequence as 4-3-.1-6-2-5

Job	Turning		Threading		Knurling	
	Hi	OUT	IK	OUT	IN	OUT
4	0	2	2	8	8	20
3	2	7	8	12	20	29
1	7	10	12	20	29	42
6	10	21	21	22	42	55
2	21	33	33	39	55	69
5	33	42	42	45	69	77

Thus the minimum elapsed time is 77 minutes idle for turning 35 = (77 - 42)
Threading = 2+1 + 11+3 + 32 = 49, Knurling = **8** *minutes.*

12.5 EXERCISE

1. *Seven jobs have arrived at one time to be processed on one machine. Find out the* **optimal job sequence when their operation time is given as follows:**

Jobs	*X*	*Y*	*z*	*P*	*Q*	*R*	*S*
Operation time	*12*	*10*	*9*	*7*	*4*	*2*	*1*

2. A certain manufacturer has to process 6 items through stages of production viz. assembling and polishing. The time taken for each of these items at different stages is given below. Find the optimal sequence so as to minimize the total processing time.

Items	**1**	**2**	*3*	*4*	*5*	**6**
Assembling	**8**	**10**	**6**	*7*	*9*	*14*
Polishing	*5*	*9*	**10**	**8**	**12**	**8**

3. Six jobs have to be processed at three machines A, B & C in the order ACB the time taken by each job on each machine is indicated below. Each machine can process any one job at a time.

Job	*J1*	*J2*	*J3*	*J4*	*J5*	*J6*
Machine A	**12**	**8**	*7*	**11**	**10**	*5*
Machine B	*7*	**10**	*9*	**6**	**10**	*5*
Machine C	*3*	*4*	**2**	*5*	*1.5*	*4*

12.6 SUGGESTED READINGS

- *Elwood S. Buffa, Modem Production Management, Wiley Series,* **8***th Edition.*
- *K. Ashwathappa, Production and Operations Management, Himalaya Publishing House, Mumbai, Reprint, 2007.*
- *N. D. Vohra, Quantitative Techniques in Management, Tara McGraw Hill Publishing Co. Ltd., New Delhi, 3rd Edition, 2007.*

MBA-CC (First Year)

Semester-II

Lesson No. 13

OM 204-B

OPERATIONS MANAGEMENT

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INVENTORY CONTROL MODEL-I

STRUCTURE

13.0 OBJECTIVE

The objective of the lesson is to study meaning, different types of investment control in order to select optional order.

13.1 INTRODUCTION

Inventory is defined as any idle resource of an enterprise. It is a stock of goods, commodities or economic resources that are kept for the purpose of future business affairs. Inventory may be' kept in any form-raw materials in process, finished product, packaging, spare and others-stocked in order to meet the expected demand. It is important to maintain some inventories for the smooth functioning of an enterprise. Suppose a firm is not maintaining inventories; if a sales order comes, it has to purchase the raw materials required, wait till these arrive and then start production. This increase the waiting time of customers to get the delivery goods.

13.2 MEANING OF INVENTORY CONTROL

Inventory control may be defined as 'the function of directing the movement of goods through the entire manufacturing cycle from the conversion of raw materials to the inventory of finished goods in an orderly manner to meet the objectives of maximum customer-service with minimum investment and low-cost plant operation.

There are two basic functions.

(i) *Maintaining an accounting record to handle the inventory transactions concerning each inventory item.*

(ii) *Deciding inventory replenishment decisions. There are two basic replenishment decisions :*

  (a) *When is it necessary to place an order (or produce) to replenish inventory? If the demand of an item is independent of that of other items, then the recorder point technique can be used to know the time of replenishment.*

(b) *How much is to be ordered (or produced) in each replenishment?*

The decision about the number of units to order (or produce) for replenishment depends on the types of inventory costs.

13.3 REASONS FOR CARRYING INVENTORIES

It is essential for any firm to have inventory because of the following reasons:

1. *It provides adequate service to customers.*
2. *It helps in smooth and efficient running of business.*
3. *It reduces the possibility of duplicating orders.*
4. *Timely shipment of customers' order will improve cash flow.*
5. *It takes care of economic fluctuations.*
6. *It helps in minimising the loss due to deterioration, obsolescence, damage and, so on.*
7. *It acts as a buffer stock when raw materials are received late and shop rejections are too many.*
8. *It takes advantages of price discounts by bulk purchasing.*
9. *It improves the manpower, equipment and facility utilisation because of better planning and scheduling.*

13.4 TYPES OF INVENTORIES

Basically, there are five types of inventories.

(i) Fluctuation Inventories (Buffer Inventories)

These are inventories to meet uncertainties of demand and supply. Buffer inventories in excess of those necessary to meet the average demand during lead time (the time lapsing between placing an order and having the goods in stock ready for use) and held for protecting against the fluctuations in demand and lead time, are termed as safety stocks or reserve stocks.

(ii) Anticipation Inventories

These are built up in advance for the season of large sales, a promotion programme, or a plant shut down period. It keeps men and machine ready for future needs. For example, keeping crackers well before Diwali or air coolers or air conditioners before summer.

(iii) Cycle (Lot Size) Inventories

These are built up in advance because the purchases are usually made in lots rather than for the exact amounts needed at a point of time.

(iv) Transportation Inventories (or Pipeline Inventories)

Such inventories exist because of the transportation of inventory items to various distribution centers and customers from the production centers. This type of inventory is also called process inventory where the significant amount of time is consumed in the transshipment of items from one location to another. To meet the demand it is essential to hold extra stock at various work stations.

(v) Decoupling Inventories

If various production stages operate successively, then the breakdown of one or many may affect the entire system. This kind of interdependence is not only expensive but also disruptive for the entire system. The inventories used to reduce the interdependence of various stages of the production system are known as decoupling inventories. These inventories may be classified as :

(a) *Raw materials and component parts : It is used to decouple the producer from the suppliers. That is, raw materials and component parts inventory could*

(i) *act as a buffer to take care of delays on the part of suppliers.*

(ii) *guard against seasonal variations in the demand of final product.*

(b) *Work-in-process inventory : As it takes time to convert raw material into finished product, work-in-process inventory is developed. This inventory takes the form of orders waiting to be transported between machines or of orders waiting to be processed on a particular machine. The level of such inventory can be increased by changing the production process, lot sizes, and so on.*

(c) *Finished good inventory : It is the inventory of final products which could be released for sale to the customers. The size of this inventory depends upon the demand and the ability of the firm to sell its products.*

(d) *Spare parts inventory : There are the parts which are used in the production process but do not become part of the product.*

Operating Constraints : The stock level of various items in the inventory is governed by various constraints such as limited warehouse space, limited budget available for inventory, customer service level to be achieved, and management attitude about the individual items in the inventory.

13.5 OPERATING DECISION RULES

Two types of decision need to be made in managing inventories:

(i) *How much (size) is to order when the inventory of that item is to be replenished?*

(ii) *When to place an order (or set up production) to replenish inventory?*

13.6. COSTS INVOLVED IN INVENTORY PROBLEMS

Various costs involved in inventory problems may be generally classified as follows :

1. Set-up Cost/Ordering Cost (Co)

These include the fixed cost associated with obtaining goods through placing in orders or purchasing or manufacturing or setting up a machinery before starting production. The costs include ordering of raw materials for production purposes, advertisements, postage, telephone charges, travel expenditure and so on. These are also called order costs or replenishment costs per production run. These are assumed to be independent of the quantity ordered or produced. Ordering cost may be calculated as :

*Order cost = (Cost per order) * (Number of orders)*

2. Purchase or Production CoBt

The cost of purchasing (or producing) a unit of item is known as purchase (or production) cost. Purchase cost per unit item is affected by the quantity purchased due to quantity discounts or price breaks.

Purchase cost = (Price per unit item) × (Demand per unit item)

When price break or quantity discounts are available for bulk purchase of a specified quantity, the unit price becomes smaller as size of order Q exceeds a specified quantity level. In such cases the purchase cost becomes variable and depends on the size of the order. In this purchase cost is given by *or carrying cost per unit of item for a unit of time. It is assumed to vary directly with the size of inventory as well as the time the item is held in stock. This cost generally includes :*

(i) Invested Capital Cost : This is the interest charged on the capital investment.
(ii) *Record-keeping and Administrative Cost : This shows that there is a need of funds for maintaining the records and necessary administration.*
(iii) *Handling Costs : These include all costs associated with movement of stock, cost of labour, and so on.*
(iv) *Storage Costs : These involve the rent for storage space or depreciation and interest even if own space is used.*
(v) **Depreciation, Deterioration, Obsolescence Costs : These costs arise due to the** *items in stock being out of fashion or the items undergoing chemical changes during storage, date expiring and so on.*

(vi) *Taxes and Insurance Costs : These costs require careful study and generally amount to* **1** *percent to* **2** *percent of the invested capital.*

4. Shortage (or Stock out) Cost

The shortage of items occurs when actual demand cannot be fulfilled from the existing stock. These costs arise due to shortage of goods, and may cause loss of salos. Goodwill may be lost either by a delay in meeting the demand or being unable to meet the demand. The shortage can be looked at in two different ways:

(i) *The supply of items is awaited by the customers, that is, the items are back ordered and therefore there is no loss in sale.*
(ii) *Customers are not ready to wait and, therefore, there, is loss of sale. In the case of shortage, cost shall be measured in terms of goodwill lost and lost profit on the unit which were demanded but were not available.*

5. Salvage Cost (or Selling Price)

When the demand for commodity is affected by the quantity stocked, the decision model of the problem depends upon the profit maximization criterion and includes revenue from selling. Generally, salvage value may be combined with the cost of storage and not considered independently.

6. Revenue Cost

When it is assumed that both the price and the demand of the product are not under the control of the organization, the revenue from the sales is independent of the company's inventory policy. It may be neglected expect when the organization cannot meet the demand and the sale is lost. The revenue cost may or may not be included in the study of inventory.

7. Total Inventory Cost

If the unit price of an item depends on the quantity purchased, that is, price discount is available, then we formulate an inventory policy that considers the purchase cost of the items held in stock. The total inventory cost is given as:

Total inventory cost = Ordering cost + Carrying cost + Shortage cost

8. Total Variable Inventory Cost

When price discounts are not offered, the purchase cost remains constant and is independent of the quantity purchased. Hence, TVC - CO + CC + SC

13.7 OTHER FACTORS IN INVENTORY ANALYSIS

1. Demand

Demand is the number of units required per period and may be known exactly or in terms of probabilities or be completely unknown. If demand is known, it may be either fixed or variable per unit time. Problems in which the demand is known and fixed are called deterministic problems. If the demand is assumed to be a random variable, then those problems are called stochastic or probabilistic problems.

2. Lead Time

The time gap between placing of an order and its actual arrival in the inventory is known as lead time. The Longer the lead time, the higher is the average inventory. Lead time has two components, namely administrative lead time-time from the initiation of procurement action to the placing of an order, and delivery lead time-time from placing of an order to the delivery of the ordered material.

3. Order Cycle

The time period between placements of two successive orders is referred to as an order cycle. The order may be placed on the basis of following two types of inventory review systems.

(a) *Continuous Review : The record of the inventory level is checked continuously until a specified point is reached where a new order is placed.*

(b) *Periodic Review : The inventory levels are viewed at equal time intervals and orders are placed at such intervals. The quantity ordered each time depends on the available inventory level at the time of review.*

4. Stock Replenishment

Actually, the replacement of stock may occur instantaneously or uniformly. Instantaneous replenishment occurs in case the stock is purchased from outside sources whereas uniform replenishment occurs when the product is manufactured by the company.

5. Time Horizon

The time period over which the inventory level will be controlled is called the time horizon.

6. Reorder Level

The level between maximum and minimum stock, at which purchasing (or production) activities start for replenishment is called reorder level.

Variables in Inventory Problem : The variables used in any inventory model are of two types :

(a) *Controlled variables*

(b) *Uncontrolled variables*

(a) *Controlled variables : The following variables are controlled separately or in combination.*

(i) *How much quantity to buy (purchase, production, so on)*

(ii) *The frequency or timing of acquisition-how often or when to replenish the inventory?*

(iii) *The completion stage of stocked items.*

(b) *Uncontrolled Variables : These include the holding costs, shortage or penalty costs, set up costs, demand, lead time, and supply of goods.*

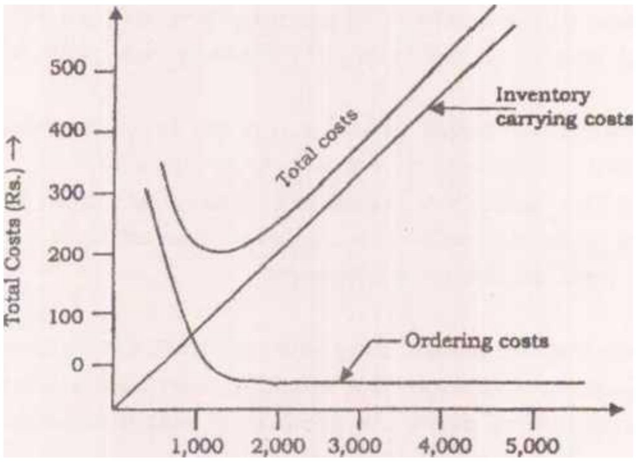
13.8 EOQ MODELS

13.8.1 Economic Order Quantity (EOQ)

The concept of economic ordering quantity was first developed by F. Harries in 1916. The inventory problems in which the demand is assumed to be fixed and completely predetermined as usually referred to as economic order quantity (EOQ). When the size of order increases, the ordering costs (cost of purchase, etc.) will decrease, whereas the carrying charges (cost of storage, insurance etc.) will increase. Hence, there are two opposite costs in the production process, one encourages increase in the order size and the other discourages.

13.8.2 Determination of EOQ by Graphical Method

The data calculated in tabular method can be graphed as below :



Number of units —>

Figure 13.1

The minimum total cost occurs at the point where the ordering costs and inventory carrying costs are equal. A disadvantage of the graphical method is that without specific costs and values, an accurate plotting of the carrying costs, ordering costs, and total costs is not feasible.

13.8.3 Determination of EOQ by Algebraic Method

It is based on following assumptions:

(i) *Demand is known and uniform*
(ii) *Lead time is zero*
(iii) *Production rate is infinite i.e. production is instantaneous*
(iv) *Shortage are not allowed*
(v) *Set-up cost per production is given*
(vi) *Holding cost/ Carrying cost can be expressed as a percentage of the value of average inventory.*

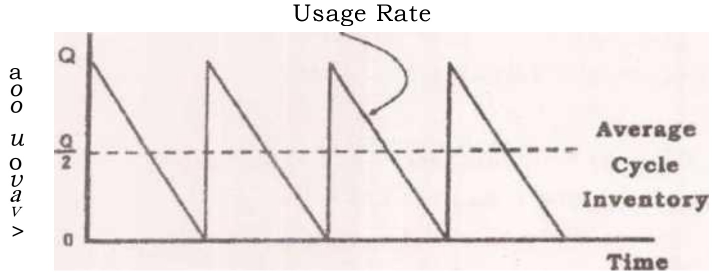


Figure 13.2

This method overcomes the problems of tabular and graphic method and is widely used. It is based on the fact that total cost would be minimum when carrying costs and ordering costs are equal. The step by step procedure to determine EOQ can written as :

(i) *Annual ordering cost (C_Q)*

*= No. of orders place/year * Ordering cost period*

*= (Annual Demand)/(No. of units in each order) * Ordering cost per period = $(DC_0)/Q$*

(ii) *Annual Carrying or holding cost =*

*= Average Inventory Level * Carrying Cost/Unit/Year = (Ordered Quantity/2) x Carrying cost/unit/year = $(Q/2).C_c$*

(iii) *Economic/Optimal Order Quantity is determined when ordering cost = Carrying Cost*

$2\ DC_0 = Q^2.CC$

■>2 = $Q^2 = 2DCJCC$

$Q = [(2DC_0)/C_c]^{1/2}$

(iv) *Total inventory cost or Total variable cost*

= (DCJ/Q + (Q/2). C

TVC $(2DC_0.C_c)^{1/2}$

(v) *Number of orders (N) = Total Demand/EOQ*

(vi) *Procurement Period/Time between Orders = EOQ/Demand per Annum*

(vii) *Ordering Cycle = (Time in no. of days/months/years)/No. of orders For example*

A company purchases raw material from outside suppliers for annual requirement. During the coming year, the company plans to manufacture at a constant 1,00,000 units of its products. The cost of placing each order is Rs. 160 for any item in inventory, the company incurs an carrying cost annually equal to 20% of the item cost. Find the following:

(i) *What is EOQ?*

(ii) *What is the total inventory cost?*

(iii) *How many orders will be placed in next year?*

Solution :

C_Q = 160; C_Q = Ordering Cost; C^ - Cost per unit - Rs. 20;

(i) EOQ =$((2DC_0)/C_c)^{1/2}$ I 20x100x160 *2828 units.*

(ii) *Total inventory cost*

= Material Cost + Total Material cost

$= D \times C_{pu} + (2DC_{o}.C_{c})^{1/2}$

= 100000 x 20 + 72x100000x4x20 =

200000 + 11314 = Rs. 2011314

(iii) *Number of Orders (N)*

-d/q

= 100,000/2828 = 35.36 orders = 35 Orders.

13.9 SELECTIVE INVENTORY CONTROL SYSTEMS

- **ABC Analysis**

ABC analysis is the process of dividing items into three classes according to their dollar usage so that mangers can focus on items that have highest dollar value. As figure indicates class A items typically represent only about 20 percent of the items but account for 80 percent of the dollar usage. Class B items account for another 30 percent of the items but only 15 percent of the dollar usage. Finally, 50 percent of the items fall in class C, representing a mere 5 percent of the dollar usage. The goal of ABC analysis is to identify the inventory levels of class A items and enable management to control them tightly.

Steps in Making an ABC Analysis

1. *Determine the annual usage value (AUV) for each item i.e. AUV = Annual demand Price*
2. *Calculate the AUV of each item*
3. *List the items according to their AUV (descending order)*
4. *Calculate the cumulative AUV and the cumulative percentage of items*
5. *Examine the annual usage distribution and group the items into A, B, C based on percentage of AUV*

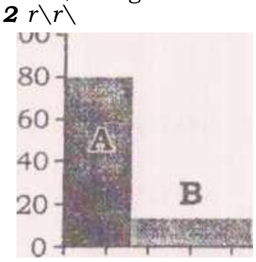
Different Controls used with different classes

A Items : High priority - Tight control including complete accurate records, regular and frequent review by management, frequent review of demand forecast and close follow-up and expediting to reduce lead time.

B Items : Medium priority - Normal Control

% Annual $ Usage

2 *r\r*



C

50

o 100

% of Inventory Items

Figure 13.3

- **XYZ Analysis**

  Based on the value of inventory undertaken during the closing of annual accounts X - High value; Y - Medium value; Z - Low value

- **HML Analysis**

  Items are classified according to the unit value as High, Medium, and Low. It is used to control the purchase value of items.

- **Movement Analysis (FSN Analysis)**

  Check stock rotations and identifies the obsolescence of items. This is particularly useful for spare parts

  Fast-, Slow- and Non-moving Analysis

- **Criticality criteria (VED Analysis)**

  Vital, Essential and Desirable

  This is in the point view of operation particularly useful for spare parts control. A vital equipment is one, which feeds a battery of equipments downstream.

- **SDE**

  Scarce item or single source item, Difficult to obtain or Easy to obtain as it is an off- the-shelf item. In this analysis 'S' refers to 'Scarce' items, generally imported and those which are in short supply. 'D' refers to 'Difficult' items which are available indigenously but are difficult items to procure. 'E' refers to items which are 'Easy' to acquire and which are available in local markets.

13.10 SUGGESTED READINGS

- *K. Aswathappa, Production and Operations Management, Himalaya Publishing House, Mumbai, Reprint 2007.*
- *S. A. Chunawalla & D. R. Patel, Production and Operations Management, Himalaya Publishing House, Mumbai, Reprint 2005.*
- *Elwood S. Buffa, Modern Production/ Operations Management, Wiley Series,* **8***th Edition.*
- *Donald Waters, Operations Management, Pearson Education, 2nd Edition.*

OPERATIONS MANAGEMENT

STRUCTURE

14.0 ECONOMIC ORDER QUANTITY MODEL WHEN DEMAND IS UNIFORM AND SHORTAGES ARE PERMITTED

When demand or consumption is in excess of supply or production, it will result in shortages. Such situations affect the goodwill of concern and may lead to permanent decline in sales and profit. In this case following formulas can be used :

(i) $EOQ = [(2DC_0)/C_c]^{1/2} * [(C_s + C_c)/ C_s]^{1/2}$

C_s = *Shortage Cost,* D = *Annual Demand*

C_Q = *Ordering Cost* C_c = *Carrying Cost*

(ii) *Back order units or shortage quantity (S) =* $EOQ * C_c/(C_S + C_c)$

(iii) *Total Shortage Cost =* $S * C_s$

(iv) *Total Variable Cost (TVC) =* $(2DC_0C_c)^{1/2} * [(C_S/(C_S + C_c)]^{1/2}$

(v) *Maximum Inventory Level = EOQ - S*

For Example

Oswal Sugar Ltd. has demand for 18,000 tonnes sugarcane per year. The sugarcane price is Rs. 1200 per tonne. The holding cost is 0.1 percent of sugarcane price and cost of shortage is Rs. 5 per tonne. The production set-up is Rs. 400 calculate.

Solution:

Demand (D) = *18,000 tonne*

Inventory price C_{pu} = *1200 per tonne Carrying cost* C_c =*0.1 % of 1200*

= 1.2

Shortage cost C_s = *Rs. 5 per tonne*

EOQ (Q) $= [(2DC_0)/C_c]^{1/2} * [(C_s + C_c)/ C_s]^{1/2}$

= *3857 tonnes Shortage quantity*

(S) = $EOQ * C_c/(C_S + C_c)$

14.1 EOQ Production Model

In this model, supply is finite i.e. inventory is not replenished immediately rather it builds up over time period because production rate (p) is greater than demand rate (d) i.e. p > d. It is based on following assumptions.

(a) *Demand is exactly known and uniform*
(b) *Shortages are not permitted*
(c) *Inventory is building up at constant (p - d) units per annum (t,)*
(d) *There is no replenishment during time t_2 following formulas are used to determine various parameters:*

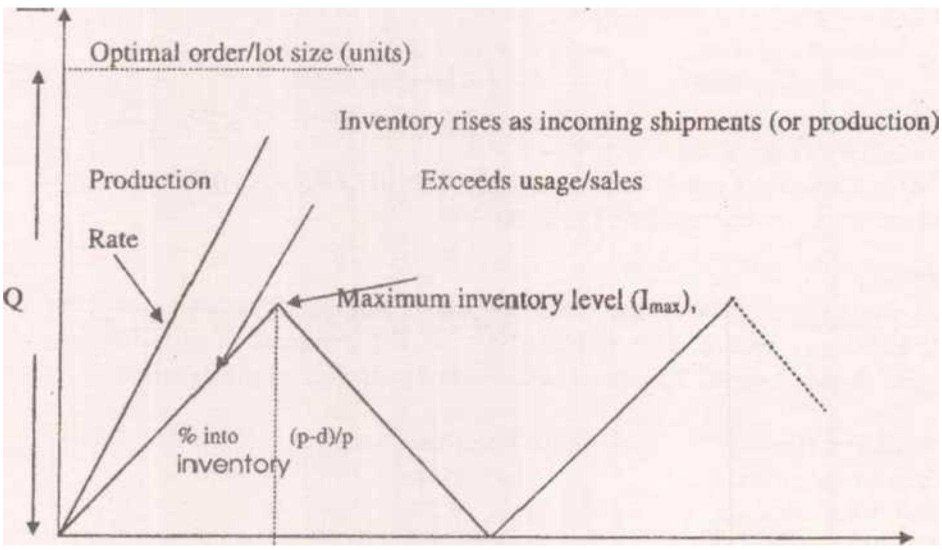
For example, if the production rate is 100 units per day and the demand is 5 units per day, the buildup is 95 (or 100-5) units each day. This buildup continues until the lot size Q, has been produced, after which the inventory depletes at a rate of 5 units per day. Just as the inventory reaches zero, the next production interval begins. The p-d buildup continues for Q/p days because Q is the lot size and p units are produced each day. For the given rate of buildup over the production interval, the maximum cycle inventory, I , is

Ui = (Q/P) (p-^{d}> - Q (P-^{d})/P

Cycle inventory is no longer Q/2, as it was with the basic EOQ method instead it is $I_{max}/2$.
Total cost = Annual holding cost + Annual ordering cost C = ($I_{m\_}$/2)(H) + (D/Q)(S)

= (Q/2)(p - d/p)(H) + (D/Q)(S)

Based on this cost function, the optimal lot size often called the economic production lot size (ELS) is



-> ■*-

Time-^

TBO

Figure 14.1

Example

A plant manager of a chemical plant must determine the lot size for a particular chemical that has a steady demand of 30 barrels per day. The production rate is 190 barrels per day, annual demand is 10,500 barrels, set up cost is $200, annual holding cost is $0.21 per barrel, and the plant operates 350 days per year. Determine

a. *The economic production lot size (ELS)*
b. *The total annual cost for this item*
c. *The time between order (TBO) or cycle length*
d. *The production time per lot*

Solution :

a. $ELS = (2DS/H)^{1/2} \cdot (p/(p-d))^{1/2}$

- $(2 * 10{,}500 * 200/0.21)^{1/2} * [190/(190-30)]^{1/2} = 4{,}873.4$ barrels

b. *The annual total cost is*

$C = (Q/2)(p-d/p)(H) + (D/Q)(S)$

$= (4873.4/2) * (160/190)(0.21) + (10500/4873.4)(200)$

$= \$861.82$

c. $TBO = ELS/D$

$= (4873.4/10500) * 350$ days/year = 162.4 or 162 days

d. *The production time during each cycle*

- $ELS/p = 4873.4/190 = 25.6$ or 26 days.

14.2 EOQ PRODUCTION MODEL WHEN SHORTAGES ARE PERMITTED

(a) $EOQ = Q = \sqrt{\dfrac{2DC_0\, r}{(r-D)} \cdot \dfrac{C_s + C_c}{C_s}}$

Where D = annual demand/consumption rate r = Production rate

(b) Shortage quantity (S) = $EOQ * (r - D)/r * C_c/(C_s + C_c)$
(c) Usage Cycle/Time between orders = EOQ/Demand per day
(d) Manufacturing Time = EOQ/production per day
(e) $TC = [2DC_0C_c * (r-D)/r\; C_s/(C_s + C_c)]^{1/2}$
(f) Maximum inventory Level = $(r - D)/r * (EOQ - S)$

For example :

For the following data:

Demand per year (D)	= 35000 Units
Production rate (r)	= 45000 Units per year
Inventory price (C_{pu})	= Rs. 75 per unit
Ordering Cost (C_Q)	= Rs. 400 per order
Carrying Cost (C_c)	= Rs. 25 per unit per year

Shortage Cost/Back order Cost (C_s) = Rs. 65 per unit Number of working days in a year = 300 days

(v) *Total cost*
(vi) *Maximum inventory Level*

Solution :

(i) EOQ $Q = \sqrt{\frac{2DC_0\ r\ C_s + C_c}{C_s\ r - D\ C_s}}$

= *2642 units*

(ii) Back Order Units (S) = *EOQ * (r - D)/r * C_c/(C_s + C_c)*

= *163 units*

(iii) Manufacturing time - *EOQ/production per day*

17.61 = 18 days

(iv) Consumption Time = *EOQ/Demand per day*

= *22.65 = 23 days*

(v) TC = *(2DC$_0$ C$_s$ * (r - D)/r * C$_c$/(C$_s$ + C$_c$))$^{1/2}$*

10599 Rs.

(vi) *Maximum Inventory Level = (r-D)/r * (EOQ - S)*

= 423 units.

14.3 QUANTITY DISCOUNTS

Quantity discounts, which are price incentives to purchase large quantities, create pressure to maintain a large inventory. For example, a supplier may offer a price of $4 per unit for orders between 1 and 999 units, a price of $3.50 per unit for orders between 1000 and 1999 units and a price of $3.00 per units for orders of more than 2000 units. The item's price is not fixed as assumed in EOQ derivation; instead if the order quantity is increased enough the price is discounted. In such cases, the total annual cost includes :

*Holding Cost * (Q/2)(H) Ordering Cost = (D/Q)(S) Cost of purchased materials = PD*

Where, Q-lot size

H-holding cost of one unit D-demand

S-set up cost P-

Total cost - (Q/2)(H) + (D/Q)(S) + PD

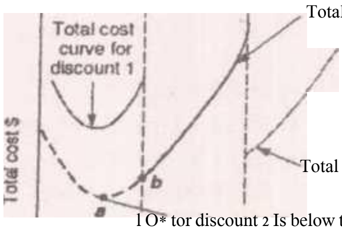


Figure 14.2

The total cost equation yields U-shaped curve and adding the annual cost of materials to the total cost equation raises each total cost curve by a fixed amount as shown in the Figure 12.2. There are three cost curves-one for each price level. The relevant or feasible total cost begins with the top curve, then drops down curve by curve at the price breaks which occur at Q=1000 and Q=2000. The result is a total cost curve, with steps at the price breaks. The EOQs shown in the figure do not necessarily produce the best lot size for two reasons :

1. *The EOQ at a particular price level may not be feasible- the lot size may not lie in the range corresponding to its per-unit price. For example, the \$4.00 price level is greater than the first price break, so the price charged would be only \$3.50.*
2. *The EOQ at a particular price level may be feasible but may not be the best lot size*
   i. *e. the feasible EOQ may have a higher cost than is achieved by the EOQ or price break quantity on a lower price curve. For example, 1750 units is the feasible EOQ for \$3.50 curve as shown in the figure, but its total cost is higher than the 2000 unit price break quantity for the \$3.00 price level.*

Thus, the following two-step procedure may be used to find the best lot size.

Step 1 : Beginning with the lowest price, calculate the EOQ for each price level until a feasible EOQ is found. It is feasible if it lies in the range corresponding to its price. Step 2 : If the first feasible EOQ found is for the lowest price level, this quantity is the best lot size. Otherwise calculate the total cost for the feasible EOQ and for the larger price break quantity at each lower price level. The quantity with the lowest cost is optimal. Example

A supplier has introduced quantity discounts to encourage larger order quantities of an item.

Order Quantity	Price per Unit
0-299	\$60.00
300-499	\$58.80
500 or more	\$57.00

The supplier estimates that its annual demand for the item is 936 units, its ordering cost is \$45 per order, and its annual holding cost is 25 percent of the item's unit price. What quantity of the item should the company order to minimize total costs?

Solution :

Step 1 : Find the first feasible EOQ, starting with the lowest price level:

EOQ (\$57.00) = $\{(2DS)/(H)\}^{1/2} = \{(2*936*45)/(0.25*57)\}^{1/2}$ *= 77 units A 77 unit order actually costs \$60.00 per unit, instead of the \$57 per unit used in the EOQ calculation, so this EOQ is not feasible. Now,*

EOQ (\$58.80) = $\{(2DS)/(H)\}^{1/2} = \{(2*936*45)/(0.25*58.80)\}^{1/2}$ *= 76 units This quantity also is infeasible because a 76 unit order actually costs \$60.00 per unit. So try the highest price level:*

EOQ (\$60.00) = $\{(2DS)/(H)\}^{1/2} = \{(2*936*45)/(0.25*60.00)\}^{1/2}$ *= 75 units This quantity is feasible, because it lies in the range corresponding to its price, P = \$60.00*

Step 2 ; The first feasible EOQ of 75 does not correspond to the lowest price level. Hence, we must compare its total cost with the price break quantities (300 and 500 units) at the lower price

*C (75) = (75/2)(0.25*60.00) + (936/75)(45) + 60*936 = $57,284*

*C (300) = (300/2)(0.25*58.80) + (936/300)(45) + 58.80*936 = $57,382 C (500) = (500/2)(0.25*57.00) + (936/500)(45) + 57*936 = $56,999*

The best purchase quantity is 500 units, which qualifies for the deepest discount.

14.4 INVENTORY CONTROL SYSTEMS

The EOQ and other lot-sizing methods answer the important question: How much to order? An inventory control system also answers the question: When to place an order? In selecting an inventory control system for a particular application, the nature of the demands imposed on the inventory items is crucial. An important distinction between types of inventory is whether an item is subject to dependent or independent demand. This chapter discusses inventory control systems for independent demand items which is influenced by market conditions and is not related to the inventory decisions for any other item held in stock. The two inventory control systems: continuous review system and the periodic review system have been discussed below.

14.4.1 Continuous Review (Q) System

This system also known as fixed order-quantity system, tracks the remaining inventory of an item each time a withdrawal is made to determine whether it is time to reorder. In practice, these reviews are done frequently and often continuously (after each withdrawal). At each review a decision is made about an item's inventory position. When the inventory position reaches a predetermined minimum level, called the reorder point (R), a fixed quantity Q of the item is ordered. In a continuous review system, although the order quantity Q is fixed, the time between orders can vary.

14.4.1.1 When demand is certain

Suppose that the demand for cards at a gift shop is always 18 per week, the lead time is constant two weeks and the supplier always ships on time the exact amount ordered. With both demand and lead time certain, the buyer can wait until the inventory drops to 36 units, to place a new order. Thus, in this case, the reorder point,

R = demand during lead time,

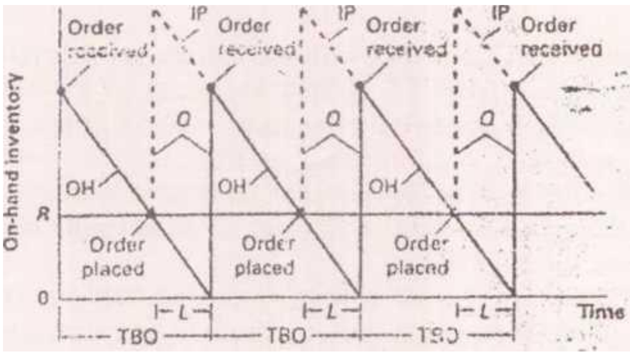


Figure 14.3

The Figure 12.3 shows how the system operates when demand and lead time are constant. The downward sloping line represents the on-hand inventory which is being depleted at a constant rate. When it reaches reorder point R, a new order for Q units is placed. The on-hand inventory continues to drop throughout lead time L until the order is received.

At that time, which marks the end of the lead time, on-hand inventory jumps by Q units. A new order arrives just when inventory drops to zero. The time between orders (TBO) is the same for each cycle. The inventory position, IP, shown in the Figure 12.3 corresponds to the on-hand inventory, except during the lead time. Just after a new order is placed, at the start of the lead time, IP increases by Q, as shown in the dashed line.

14.4.1.2 When demand is uncertain

In reality, demand and lead times are not always predictable. For instance, the buyer of gift shop knows that average demand is 18 cards per week and that the average lead time is two weeks i.e. a variable number of cards may be purchased during the lead time, with an average demand during lead time of 36 cards. This situation gives rise to the need for safety stocks. Suppose that reorder point R is set at 46 units, thereby placing orders before they are needed. This approach will create a safety stock, or stock held in excess of expected demand of 10 units to buffer against uncertain demand. Thus,

Reorder point = Average demand during lead time + Safety stock

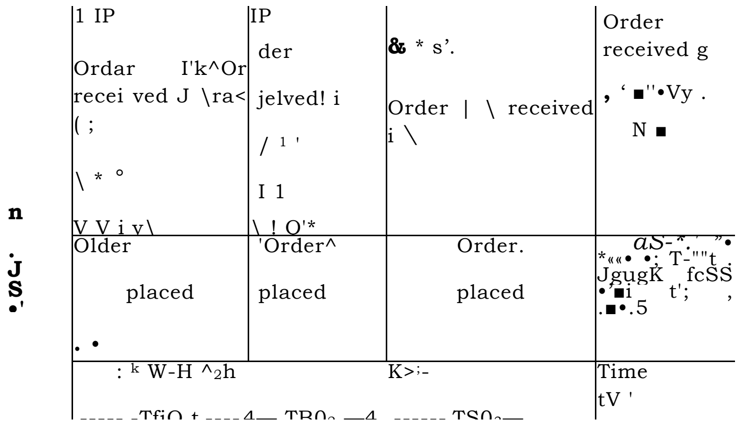


Figure 12.4

Figure 12.4 shows how the Q system operates when demand is variable and uncertain. The wavy downward-sloping line indicates that demand varies from day to day. The changing demand rate means that the time between orders changes so TBOl ? TB02 ? TB03. Because ' of uncertain demand sales during lead time are unpredictable, and safety stock is added to hedge against lost sales. It explains why on-hand inventory usually does not drop to zero by the time replenishment arrives. The greater the safety stock, and thus the higher the reorder point R, the less likely a stockout.

14.4.1.3 Advantages of Continuous Review (Q) System:

- *The review frequency of each item may be individualized. Tailoring the review frequency to the item can reduce total ordering and holding costs.*
- *Fixed lot sizes, if large enough, may result in quantity discounts.*
- *Lower safety stocks result in savings.*

14.4.1.4 Two-Bin System

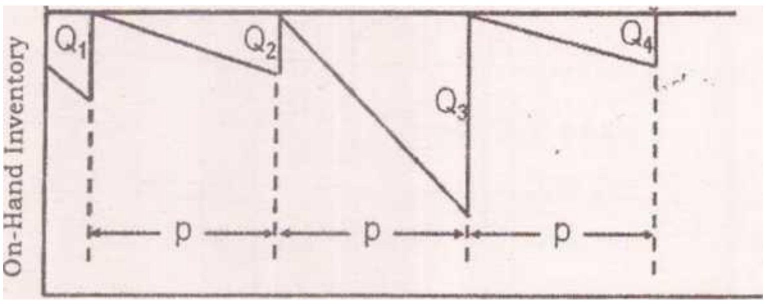
The concept of Q system can be incorporated in a visual system i.e. a system that allows employees to place orders when inventory visibly reaches a certain marker. A visual system version of the Q system is the two-bin system in which an item's inventory is stored at two *different locations. Inventory is first withdrawn from one bin. If the first bin is empty, the second bin provides backup to cover demand until a replenishment order arrives. An empty first bin signals the need to place a new order. When the new order arrives, the second bin is restored to its normal level and the rest is put in the first bin. The two-bin system operates like a Q system, with the normal level in the second bin being the reorder point R.*

14.4.2 Periodic Review (P) System

In this system, also known as fixed interval reorder system, an item's inventory position is reviewed periodically rather than continuously. A new order is always placed at the end of each review, and the time between orders (TBOJ is fixed. Demand being a random variable, varies between reviews. In this system, the lot size Q may change from one order to the next but the time between orders is fixed. For example, a soft drink supplier making weekly rounds of grocery stores. Each week, the supplier reviews the store's inventory of soft drinks and restocks the store with enough items to meet demand and safety stock requirements until the next week. The assumptions of periodic review system are as:

- *no constraints on the size of the lot*
- *holding and ordering costs are the only relevant costs*
- *decisions of one item are independent of decisions for other items*
- *there is no uncertainty in lead times or supply*

Target maximum



Time
Figure 12.5

Figure 12.5 shows the periodic review system when demand is uncertain. The downward-sloping line represents on-hand inventory. When the predetermined time, P, has elapsed since last review an order is placed to bring the inventory position, up to target inventory level. The lot size for the first review is Q,, for second review is Q,$_2$ and for third review the lot size is Q_3. Figure 12.5 shows that lot sizes vary from one order cycle to the next. Because the inventory position is lower at the third review, a greater quantity is needed to achieve the target inventory level.

14.4.2.1 Advantages of Periodic Review (P) System

- *Administration of the system is convenient because replenishments are made at fixed intervals. Fixed replenishment intervals also allow for standardized pickup and delivery times.*
- *Orders for multiple items from the same supplier may be combined into a sVngle purchase order. This approach reduces ordering and transportation costs.*
- *The inventory position needs to be known only when a review is made whereas in Q system it is to be known continuously.*

14.5 EXERCISE

1. *Izmir Wine Co. bottles 5000 cases of a particular rose wine annually. The set-up cost per run is 90 MU. Factory cost is 5 MU per case. Carrying costs on finished goods inventory is 20 %. Production rate is 100 cases per day and sales amount to 14cases/day. How many cases should be bottled per production run?*
2. *A plastics moulding firm produces and uses 24 000 Teflon bearing inserts annually. The cost of setting up for production is 70 MU and the weekly rate is 1000 units. If the production cost is 5.50 MU per unit and the annual carrying cost is 1.50 MU per unit, how many units should the firm produce during each production run?*
   What is the maximum inventory that the firm will stock?

3. *The Ege Creamery Co. produces ice-cream bars for vending machines and has an annual demand for 72000 bars. The Co. has the capacity to produce 400 bars per day. It takes only a few minutes to adjust the production set-up cost estimated at 7.50 MU per set up for the bars, and the firm is reluctant to produce too many at one time because the storage cost (refrigeration) is relatively high at 1.50 MU/bar/ year. The firm supplies vending machines with its " Ege bars ” on 360 days of the year.*
   (a) *What is the most economical number of bars to produce during any one production run?*
   (b) *What is the optimal length of the production run in days? c) What is the total inventory cost?*
4. *A contractor h&s to supply 10 000 bearings per day to an automobile manufacturer. He finds that, when he starts a production run, he can produce 25000 bearings per day. The cost of holding a bearing in stock for one year is 0.02 MU and the set-up cost of a production is 18 MU. How many times should the production runs occur?*
5. *Azim, Corporation is currently purchasing sales units faster than it is able to sell them as a result; management has requested a re-evaluation of its ordering policy. An analysis of the current sales market reveals the following; anticipated annual demand 10000 units, daily sales 300 units, daily arrivals of units 400 units. The relevant cost data, obtained from the sales office is: order cost 15 MU/order, Unit cost 1.50 MU, carrying cost 20% at unit cost. Determine the order policy that Azim should use.*

14.6 SUGGESTED READINGS

- *K. Aswathappa, Production and Operations Management, Himalaya Publishing House, Mumbai, Reprint 2007.*
- *S. A. Chunawalla & D. R. Patel, Production and Operations Management, Himalaya Publishing House, Mumbai, Reprint 2005.*
- *Elwood S. Buffa, Modem Production/Operations Management, Wiley Series, 8th Edition.*
- ***Donald Waters,** Operations Management, Pearson Education, **2nd Edition.***