Block-IV

Project & Operations Management

Introduction to Operations Management

Block

IV

INTRODUCTION TO OPERATIONS MANAGEMENT

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BLOCK IV: INTRODUCTION TO OPERATIONS MANAGEMENT

The fourth block of the course on Project & Operations Management deals with the fundamental concepts relevant to operations management. The block contains four units. The first unit explains operations management and operations strategy. The second unit focuses on the importance of forecasting in the field of operations management. The third unit discusses how to allocate resources to strategic alternatives in operations strategy. The fourth unit examines the design of production processes.

The first unit, *Operations Management and Operations Strategy*, discusses the definition of operations management and operations management decisions. The unit focuses on the evolution of operations management and the use of computers and advanced technology in the field. The unit also deals with the use of operations strategy as a competitive weapon, its elements, and the ways to develop it. The unit also provides an idea about the financial and economic analysis in operations.

The second unit, *Forecasting Demand*, deals with forecasting in operations, and its various components. The unit also explains the demand forecasting process and the different forecasting methods used. The unit discusses the steps involved in the demand forecasting process, and the ways to measure the forecasting accuracy. It also discusses how to monitor and control forecasts.

The third unit, *Allocating Resources to Strategic Alternatives*, provides an idea about allocation decisions in operations strategy. The unit explains the concept and use of linear programming in operations management. It discusses how to formulate linear programming problems, and how to find solution to such problems. The unit also discusses transportation problems in linear programming.

The fourth unit, *Design of Production Processes*, explains planning and design of production processes. The unit discusses the major factors affecting process design decisions, and the various types of process designs. It also examines the different process planning aids. The unit also discusses how to select the type of process design.

Unit 16

Operations Management and Operations Strategy

Structure

16.1 Introduction

In the previous unit we discussed about project closing. In this unit, we introduce you to operations management and operations strategy. Business organizations today are facing a highly competitive and challenging business environment. Firms face various barriers in the form of archaic technology, underdeveloped infrastructure, inappropriate payment systems, and ineffective scheduling and control systems. At the same time, they also face a threat from foreign companies. Therefore, it has become imperative for the operations managers of companies to reduce manufacturing costs, optimize productivity, and improve product quality to survive in the market.

Operations management is defined as the design, operations and improvement of the systems that create and deliver the firms' primary products and services.

Operations management can be defined as the management of direct resources such as machine, material, and manpower, which are required to manufacture goods and services. The process involves planning, organizing, controlling, directing, and coordinating all the activities of production systems which convert resource inputs into products or services. Operations management deals with the designing of products and processes, acquisition of resources, conversion of resource inputs into outputs, and the distribution of goods and services.

To succeed in a competitive business environment, an organization needs a sound strategy. Strategies are broad, long-term plans, conceived of to achieve business objectives and are developed at the corporate, business, and functional levels. Operations decisions are normally taken with the business objectives and functional objectives of marketing, finance, and human resources departments in mind. The nature of the goods or services to be produced and the markets to be served influences the operations strategies.

This unit will define operations management and operations management decisions. We will discuss the historical evolution of operations management and the use of computers and advanced technology in operations. We shall then move on to discuss the use of operations strategy as a competitive weapon, identify the elements of an operations strategy, and explain how to develop an operations strategy. Finally, we would discuss financial and economic analysis in operations.

16.2 Objectives

By the end of this unit, students should be able to:

- Define operations management and operations management decisions.
- Discuss the historical evolution of operations management.
- Computerization of operations and advanced operations technology.
- Recognize operations strategy as a competitive weapon.
- Identify the elements of an operations strategy.
- Explain how to develop an operations strategy.
- Financial and economic analysis in operations.

16.3 Operations Management Decisions

Operations managers have to take decisions regarding the designing and implementation of operational strategies, which indicate how the companies utilize their production capabilities to achieve their organizational objectives. The decisions taken by the operations managers can be classified into strategic, tactical, and operational decisions.

Strategic decisions are long term in nature and have a time period of five years or more. The strategic planning activities are done in mostly two broad areas. First area is designing of manufacturing and service process and the second area is related to the design of logistics that deliver the products and services. Decisions on technology and procedure selection, capacity planning, supply network planning, location of manufacturing and warehouse facilities, outsourcing decisions, selection of suppliers comes under strategic decisions.

Tactical decisions are medium term in nature and have a time period of one or two years. It mainly involves activities related to demand management and

forecasting as well as sales and operations planning. Decisions on manpower requirement, inventory levels, determining the reordering level and order quantity, identifying vendors, etc. come under tactical decisions. The operations managers have to ensure that the tactical decisions are properly aligned with the strategic decisions.

Operational decisions are short-term decisions and have a time period of less than a week. Operational decisions are mainly focused on scheduling production and shipment orders. Scheduling labors, adjusting production output, distribution of raw material comes under operational decisions.

Activity: Kevin works for a local mobile manufacturing company operating in Africa. The company had been facing a downturn due to the entry of foreign players. The top management of the company asked Kevin to suggest ideas to fight the competition. Kevin felt that the company was relying too much on outdated technology, was incurring huge costs, and had a faulty control system. He recognized that the company needed a good operations management team. Help Kevin in the process of explaining to the management about the importance and need for good operations management.

Answer:

16.4 The Historical Evolution of Operations Management

The concept of modern operations management evolved in the early eighteenth century when Adam Smith acknowledged the significance of division of labor. In his book, *The Wealth of Nations*, he said that to enhance productivity, jobs should be divided into sub-tasks, and these tasks assigned to workers based on their individual skills and capabilities. Frederick W. Taylor in his book *The Principles of Scientific Management*, a milestone in the field of operations management, adopted this concept. The term 'Production Management' was used till the early 1970s. But with the inclusion of purchasing, dispatch, and other allied activities and the growing influence of the service sector, it was replaced by a more general term 'Operations Management', that incorporated both production as well as service related concepts and procedures.

16.4.1 Scientific Management

The concept of scientific management was introduced by Taylor in his book *The Principles of Scientific Management.* According to the concept, the productivity

of a worker is governed by scientific rules and the management needs to study and apply these rules in its operations. Some of the key concepts are given here:

1. Each worker should be assigned a task based on his/her skill, strength, and ability to learn.
2. A standard output time should be set for each task, using stopwatch studies. This should be used to plan and schedule future tasks.
3. Instruction cards, routing sequences, and material specifications should be used for coordinating the activities in a shop, and work methods and work flow should be standardized.
4. There should be proper supervision by carefully selected and trained supervisors.
5. There should be incentive pay systems to motivate workers.

16.4.2 Moving Assembly Line

Henry Ford applied the principles of scientific management to a moving assembly line in 1911 while manufacturing the Model T Ford automobile, where he employed standardized product designs, mechanized assembly lines, specialized labor, and interchangeable parts in production units. This reduced the production time for the car chassis from twelve-and-a-half hours to ninety minutes. This was the first ever successful application of the principles of scientific management and it had the effect of increasing their popularity worldwide.

16.4.3 Hawthorne Studies

In 1927, a Harvard Business School research team led by George Elton Mayo carried out a study at the Hawthorne plant of Western Electric in Chicago. The team carried out illumination studies to study the relationship between the intensity of light on the shop floor and employee productivity. The team found that the employee productivity increased irrespective of the increase or decrease in the intensity of light. Through these observations, the team concluded that it was the attention and the importance received by the workers during the study that had resulted in the increased productivity and not the light or other physical conditions. The study initiated an extensive research into the behavior of employees in the working environment.

Activity: Syeda works for an engineering company. The management noticed that the productivity of the workers had been decreasing over the years and asked Syeda to find out the reasons for this. Syeda decided to carry out a study on the relationship between the increase in monetary or non-monetary benefits and employee productivity. Assist her in the process and also suggest ways in which the workers' productivity can be improved.

Answer:

16.4.4 Operations Research

World War II created problems of logistics control and weapon systems design and manufacture for many countries. To tackle these problems, the US and many European nations formed operations research teams in their military branches. These teams developed mathematical techniques to assist them in taking appropriate decisions in complex logistical situations. After the war, these operations research techniques were used by many businesses to make their decision-making processes more effective.

Check Your Progress - 1

1. On the basis of Hawthorne studies, Elton Mayo and his team concluded that _____had a major impact on employee productivity.
   a. Physical work conditions
   b. Importance and recognition given to employees
   c. Job content
   d. Fear of losing job
2. Which company first adopted the concept of scientific management in the assembly line production system?
   a. General electric
   b. Ford motors
   c. General motors
   d. Westinghouse
3. Decisions on production and process design, facility location and layout etc, are part of which decision category?
   a. Strategic decisions
   b. Tactical decisions
   c. Operational decisions
   d. All of the above
4. Which of the following decision do **not** fall within the basic scope of operations management?
   a. Analyzing the firm's financial position
   b. Designing a new assembly line
   c. Determining the location of a new distribution center
   d. Improving product quality
5. Division of labor or specialization is an outcome of _____.
   a. Industrial revolution
   b. World War II
   c. Scientific management
   d. Computerization of production systems

6. The decisions that operations managers take can be broadly classified into various categories. What is the usual time-frame for tactical decisions?
   a. Seven years or more
   b. One or two years
   c. Two to four months
   d. A couple of weeks
7. Operations Management deals with which of the following?
   a. Design of products
   b. Design of services
   c. Acquisition of resources
   d. All of the above
8. The term 'Production Management' was replaced by a more general term 'Operations Management' in the 1970s. What led to the enlargement of the field and use of the new term?
   i. Inclusion of purchasing function
   ii. Inclusion of dispatch and other related activities
   iii. Inclusion of services related concepts and procedures
   iv. Inclusion of manufacturing technologies
   a. i, ii, iii
   b. iii, iii, iv
   c. i, iii, iv
   d. i, ii, iii, iv
9. Who was involved in the Hawthorne experiments at the Western Electric plant?
   a. Frederick Taylor
   b. Henry Ford
   c. Elton Mayo
   d. Adam Smith

16.5 Computers and Operations Technology

Computerization of operations began in 1954 with the installation of the first computer at the General Electric Appliance Park. The only use that computers were put to then was to prepare salary and accounting statements. In the 1960s, operations managers began using computers to enhance the efficiency of the production system. In the 1970s, organizations began using manufacturing information systems for planning and controlling operations. During the 1980s with the growing complexity in software and hardware technologies, advanced production systems like computer-aided design (CAD), computer-aided

manufacturing (CAM), flexible manufacturing systems (FMS) and automated storage and retrieval systems (AS/RS) were developed. CAD is specialized software used for designing products and processes. Advanced CAD systems enable engineers to test the performance of their design through computer simulation. CAM is a specialized computer system used for translating CAD design information into instructions for numerically controlled automated machines. The use of CAM in manufacturing reduces the worker's involvement in the production process. The FMS is a set of automated machines controlled by a central computer. These systems can produce a large quantity of products that have similar processing requirements. AS/RS is a computer-controlled warehouse system which automates inflow and outflow of materials from the warehouse and the shop floor on the basis of production requirements.

In the 1990s, many new concepts and technologies like artificial intelligence and expert systems influenced manufacturing systems. Programmable machines like robots capable of tackling multiple tasks were introduced in the production process.

Activity: Sahiti works for a small automobile manufacturing company as an operations manager. The company manufactures two-wheelers manually, using few machines and equipment. The top management has decided to introduce new technology and to computerize its production processes with the profits gained in the previous financial year. Sahiti has therefore been asked by the management to identify the advanced computer technology tools that are available for enhancing production process. Can you assist Sahiti in this process?

Answer:

16.6 Operations Strategy as a Competitive Weapon

Any business organization aims to attract more customers than its competitors. Organizations thus identify their distinct competencies to gain a competitive advantage over others. The company's operations function determines its choice of products and markets and its competencies. The following topics indicate how operational strengths can be used effectively as competitive weapons:

16.6.1 Product/Process Expertise

To gain a competitive advantage over its competitors, an organization can use its expertise in product functionalities and process capabilities over its competitors.

16.6.2 Quick Delivery

With flexible capacity and an adaptive production process, an organization can produce a product quickly and satisfy customer needs.

Delivery reliability

Delivery reliability relates to the ability of a firm to deliver the product or service on or before the due date. This is a very important competitive dimension because any delay in the delivery of part or components may lead to shut down of assembly line/ machinery until the parts arrives.

16.6.3 Shorter Product Cycle

The first company that enters a market gains a greater market share than the subsequent ones. With a flexible and adaptable production system, the company can introduce a product into the market before its competitors can and take the advantage of the market demand, thus garnering a greater market share.

16.6.4 Production Flexibility

A highly flexible and responsive operations environment helps some organizations to achieve a competitive advantage over others. For example, IBM built an integrated infrastructure solution for DaimlerChrysler, which helped the latter to provide on-demand solutions. As a result, the operations of DaimlerChrysler became more flexible and more responsive to the environment.

16.6.5 Low-cost Process

With an efficient production system or access to low-cost resources, an organization can make standard products at lower costs than its competitors. For example, low cost airline companies such as Deccan Airways in India are providing no-frills, low price air travel to their customers. These airlines do not provide on board meals or other entertainment facilities that traditional airline companies do. Therefore the costs come down drastically for them and they pass these benefits on to customers in the form of low prices. This helps them to gain an edge over other airline companies that provide full services at high prices.

16.6.6 Convenience and Location

Facility location provides a substantial competitive advantage. For example, Reliance Infocomm has a deeper penetration into the rural areas than its competitors.

16.6.7 Product Variety and Facility Size

The variety of products offered and the size of operations can provide a competitive advantage in some industries. For example, grocery stores and supermarket retailers have larger stores and display a greater variety of products than the small traditional shops thus benefiting from the economies of scale.

16.6.8 Quality

A higher quality product, even if it is priced higher, helps an organization increase its sales volume compared to its competitors. Toyota is making the new Harrier model available through its Toyota dealers nationwide as of June 17, 2020. The car was environment friendly and gave good mileage and low emissions. Though the car was priced high, the demand for the car was also high due to the high quality standards maintained by the company.

The Notion of Trade-offs

The notion of trade-offs is central to the concept of operations strategy. The underlying logic is that a firm cannot excel on all competitive dimensions. Hence, the management of the company must decide upon selection one or a few combinations of the competitive dimensions which are critical to its success. Consequent management need to allocate the resource of the firm on these dimensions. If a company want to focus on delivery speed, it might not be able to offer product variety.

A sustainable competitive position is not achieved unless there are compromises on other positions. Trade off occurs when activities are incompatible and more of one activity necessitates the less of the other one.

For example: One of the main competitive dimensions of apple is quality which provides it the competitive edge over other competitors, but apple never focuses on being the low cost manufacturer. Hence, in case of apple products there is tradeoff between cost and quality.

Straddling

Straddling occurs when a firm seeks to match the competitive position of its competitors by adding new services, features or technologies to the activities it is already performing. This leads to the problems if trade off is required.

Check Your Progress - 2

10. The computerization of operations began when the first computer was installed in General Electric Appliance Park in 1954. What was the basic objective of computer applications then?
    a. Reducing manpower
    b. Reducing clerical costs
    c. Enhancing worker safety
    d. Increasing production
11. With a flexible and adaptable production system, the company can introduce a new product into the market faster than its competitors and take the

advantage of the market demand, thus garnering greater market share. Which operational strategy are we talking about in this context?

a. Quality
b. Low-cost process
c. Shorter product cycle
d. Convenience and location

12. HDFC Bank offers deposits, loans, insurance products, mutual funds, trading in stocks, etc, under one roof and positions itself as a financial supermarket. Which type of competitive advantage strategy does the bank seek to focus on?

a. Quality
b. Product variety
c. Convenience
d. Low cost

13. Which of the following is a computer-controlled warehouse system which automates inflow and outflow of materials from the warehouse and the shop floor on the basis of production requirements?

a. Computer-Aided Design (CAD)
b. Computer-Aided Manufacturing (CAM)
c. Flexible Manufacturing System (FMS)
d. Automated Storage and Retrieval System (AS/RS)

16.7 Elements of Operations Strategy

An operations strategy is a high-level integrated plan for business effectiveness or competitiveness. The following are the key components of operations strategy:

16.7.1 Designing the Production System

Designing the production system involves selecting the product design, the production system, and the inventory policy for finished goods for each product line.

Product Design - There are two types of product design: Customized product design and Standard product design. A customized product design is used when the level of customization is high and the quantity to be produced is low. For example, industrial products like boilers and turbines are customized products. A standardized product design is used when the organization produces a limited variety of products in large batch sizes. For example, consumer durables like refrigerators, fans, washing machines and televisions are standardized products.

Production systems – These can be classified into: Product-focused systems and Process-focused systems. Product-focused systems are used in mass production

organizations where groups of machines, tools, and workers are arranged according to their respective tasks in order to put together a product. Product-focused systems are used in the production of cars, televisions, computer systems, etc. Process-focused systems are used for supporting production departments which perform a single task like painting or packing.

Finished goods inventory policy – Policies regarding finished goods inventory are of two types: Produce-to-stock policy and Produce-to-order policy. In the produce-to-stock policy, products are produced in advance and stored in warehouses from where they are dispatched as per customer orders. Organizations that manufacture products, parts, or components that have seasonal demand like refrigerators, air coolers, or those which can be put to general use like bolts and nuts, use this policy. In a produce-to-order policy, the company starts production only after receiving orders from the customer. Organizations which produce high value products or components like the spare parts of an aircrafts or those meant for specific purposes like dyes, castings, etc. use this policy.

16.7.2 Product/Service Design and Development

Every product has a life cycle and goes through various stages of the life cycle namely, introduction, growth, maturity, and decline. The operations department plays an important role in the introduction stage of the product life cycle and its role diminishes as the product moves up the life cycle.

The following are the different stages involved in the development of new products:

- *Planning*: the planning phase is also referred to as "phase zero". This phase starts with development of corporate strategy and includes assessment of market objective and technology development.
- *Idea Generation* – The development of a new product starts with idea generation. Ideas are sourced from employees, customers, intermediaries, vendors, market research, etc.
- *Feasibility Studies* – Feasibility studies are conducted to test whether the idea generated is technically and economically feasible.
- *Prototype Design* – If the idea is feasible, a prototype of the product is developed. While the prototype is not a perfect replica of the final product, it has all its basic features.
- *Prototype Testing* – After the prototype has been developed, it is tested under standard conditions and the defects are listed. Based on the test results, necessary changes are then made to it. The prototype is tested again and again until it reaches an acceptable level of performance. After arriving at the final structure, the profitability of the prototype is evaluated.

- *Initial Design of Production Model* –The prototype enters the production design stage if the production of the model is profitable.
- *Economic Evaluation* – The initial production design model is tested for its economic feasibility before it is transformed into the final production design.
- *Market Testing* – The initial production design model is put through performance tests, production trials, and testing and test marketing before the final product is designed.
- *Final Design of Production Model* – After conducting the economic evaluation and market testing, the initial production design model reaches a stage where it performs satisfactorily and can be produced in the required quantities.
- *Production ramp-up*- In this phase, the product is manufactured using the intended production system. The main objective of this phase is to provide training to the work force and eliminate any remaining problems in the production process. The products produced in this phase are sometimes supplied to the close customer and feedback is taken to identify any remaining flaws. There is a gradual transition between production ramps up phase to the full scale production.

The product development process continues even after the launch of the product. The new product is modified or improved to constantly adapt it to the changing market conditions and/or to incorporate the latest technology in it.

Activity: Keerti works in the Research & Development wing of a pharma company. She is a part of a team involved in developing a new drug for reducing hypertension among old age people. The team has also been exploring various ways to keep the price of the drug low to make it affordable for everyone. Help Keerti in listing out the steps involved in developing this new product. Also suggest ways in which she and her team can reduce the manufacturing costs of the new drug so that they can pass on the benefit to the customers by pricing it low.

Answer:

16.7.3 Technology Selection and Process Development

After finalizing the product design, managers should determine the way in which the product will be produced. This involves detailed analysis and planning of the production processes and facilities.

16.7.4 Allocation of Resources to Strategic Alternatives

Manufacturing companies have to constantly deal with the problem of scarce resources like capital, machines, and materials. Operations managers should therefore plan to make optimal use of the resources by minimizing wastage and by allocating them to the best strategic use.

16.7.5 Facility Planning

The location of the production facilities is critical to the success of an organization. As the setting up of a production facility involves huge initial investment, operations managers have to tactically select the correct options from the available set of alternatives. They have to consider future decisions regarding capacity expansion plans and factors like availability of raw materials and market access. The operations managers should also make layout decisions such as the internal arrangement of workers and departments within the facility.

16.7.6 Innovation in Operations Strategy

Innovation is the application of better solutions that meet new requirements, in-articulated needs, or existing market needs. This is accomplished through more effective products, processes, services, technologies, or ideas that are readily available to markets, and society. It can be defined as something original and, as a consequence, new, that "breaks into" the market or society. Innovation differs from invention in that innovation refers to the use of a better and, as a result, novel idea or method, whereas invention refers more directly to the creation of the idea or method itself. Innovation differs from improvement in that innovation refers to the notion of doing something different rather than doing the same thing better.

As most of the resources of a manufacturing company are invested in operations, there is a competitive pressure to ensure that the operations are conducted efficiently. This calls for innovation in every link of the supply chain. The operations strategy, which is aligned with business and corporate strategies needs to encourage innovation in operations. Scarcity of resources is forcing innovation in locating alternative materials, simplification of designs, reengineering the products and remanufacturing. Many MNCs are resorting to circularity and reusing, recycling, recovering materials from waste with significant benefits. Innovative products like 3-D printers are expected to revolutionize the shop floor by enabling manufacturing at the place of design itself, with all associated advantages.

What is 3-D Printing?

3D printing is a process of producing a three-dimensional solid object of virtually any shape from a digital model. 3D printing is achieved using an additive process, where successive layers of material are laid down in different shapes. It is different from traditional machining techniques, which mostly rely on the removal of material by methods such as cutting or drilling. The technology has the potential to create any object of one's imagination, even human organs, with the help of IT.

Renault's circular economy model in Supply Chain Management consists of:

- Redesigning certain components to make them easier to dismantle and reuse.
- Converting materials and components from worn-out vehicles into inputs for new ones.
- Forming joint ventures with recyclers and waste management companies to obtain inputs for product design.
- Helping suppliers to redesign products and associated processes for greater efficiency such as coolants and lubricants.

Innovation has become inevitable in every activity of an organization. However as operations holds a majority of processes, innovation will be highly rewarding.

Check Your Progress - 3

14. Rainbow Electronics manufactures a limited number of models of television sets. What kind of product design system does the company have?
    a. Customized production design
    b. Standardized product design
    c. Stock-to-order
    d. Assemble-to-order
15. Selecting product design, production system, and inventory policy for finished goods fall under which component of operations strategy?
    a. Designing the production system
    b. Product/service design and development
    c. Technology selection and process development
    d. Allocation of resources to strategic alternatives
16. Which among the following products are generally customized as per user requirements?
    i. Industrial boilers
    ii. Turbines
    iii. Televisions
    iv. Ceiling fans

a. i and ii
b. ii and iii
c. iii and iv
d. iv and i

17. Pick the statement that pertains to the relationship between the role of operations department and the product life cycle.
    a. The role of operations department increases as the product moves up the lifecycle.
    b. The role of operations department decreases as the product moves up the lifecycle.
    c. There is no change in the role of operations department across the lifecycle.
    d. The role of operations department increases or decreases as the product moves up the lifecycle.
18. What is the basic use of a prototype during the new product development process?
    a. A prototype is used to test the technical and economical feasibility.
    b. A prototype helps test the product performance under standard conditions.
    c. A prototype is developed as part of test marketing.
    d. None of the above
19. Availability of raw materials and nearness to markets are some of the factors that are considered while making decisions regarding plant location. Which component of operations strategy deals with decisions such as plant location?
    a. Allocation of resources to strategic alternatives
    b. Technology selection and process development
    c. Product design and development
    d. Facility planning
20. Allocation of resources to strategic alternatives is a component of operations strategy. What is the main objective of this component?
    a. To minimize efficiency
    b. Optimize the use of resources for best strategic use
    c. Ensure capacity expansion
    d. Maintain proximity to resources

16.8 Developing an Operations Strategy

The operations strategy should always be in tune with the organizational strategy, which in turn, should be based on the corporate vision and mission.

Activity: Bobby is an operations manager of a company engaged in manufacturing tires for automobiles. The top management has made a suggestion that the existing manufacturing facility be expanded and a new plant set up to manufacture automobile accessories. As operations manager, Bobby has been given the task of selecting a proper location for setting up the new plant and also deciding on the expansion of the existing one. List out the various steps that he has to take to go ahead with the given job and also assist him in proper decision making regarding the two proposals.

Answer:

Operations strategy aims at accomplishing the long-term goals established by the business strategy.

The selection of markets is the key to any strategy. Operations managers should develop appropriate processes and designs to achieve the organizational objectives, after analyzing the markets based on their attractiveness. By utilizing its strengths and identifying ways to improve its competitive position, an organization can achieve its corporate objectives, which are a major focus of the organization strategies. A flexible operations strategy helps an organization to support a product or service throughout its life cycle and adjust to future changes in the market demand or business objectives. The operations strategy should also be consistent with the functional strategies in the areas of marketing, finance, and human resources.

With parallel technological growth, exponential changes are expected in manufacturing, services and how a manager utilizes the digital technologies for the benefit of productivity, reducing time and cost. Exhibit 16.1 presents some anticipated challenges for operations managers in 2021.

Exhibit 16.1: Operations Managers: Rising to the Challenges of 2021

After the pandemic ravaged globally, governments, entrepreneurs, and ordinary people are anticipating for ease of situation around the middle of 2021. The crisis will impact and continues to impact market ecosystems and supply chains, upending processes, organizations, and long- and short-term strategic visions. Industrial organizations rely on operations managers to navigate this environment complicated by possibly limited supplies, disrupted workforce availability, regulation, and fluctuating demand.

How can operations managers gear up?

Cost Management	• Cut costs, sometimes even to ensure the survival of the organization • Assess which capabilities, skills, and production assets will be needed after the recession • A deep thought to innovate processes and products and empower the workforce is crucial
Workforce:	• Continue transforming selected positions into digital-capable positions • Strategy to upskill and reskill, utilizing technology like AR/VR to make training even more effective and insightful • Unlock the power of DIY tools and solutions • Think of APIs • Health and safety must remain the top priority, and organizations have to continue building robust health and safety procedures and systems
Technology	• **Go deeper into u**nderstanding IT and industrial IoT • Identify or build meaningful use cases, calculate ROI, and aim at tangible benefits • Trends of 2021 will be around: implementing a collaboration platform, supply chain control tower, digital thread, or digital twin to improve transparency, efficiency, and resilience • Understand AI-powered technology and leverage the benefits. • Focus on machine learning , deep learning, cognitive AI and AI, and map potential use cases for deployment into various activities • IoT computing enables realtime processing of data allowing decisions at the data source (e.g., a shop floor) • Cloud computing-based complex models provide scalability and can handle predictive maintenance or predictive quality tasks
Processes	• Embed the full benefits of digital technology and automation in Processes • Ensure that digital technology outputs are properly utilized

	• Avoiding disconnects between information and action/reaction should be prioritized • Future workplaces will be human+machines and processes need to be designed accordingly
Environmental Sustainability	• Top strategic priorities include: initiatives to shrink carbon footprints, improve waste management, and use environmentally aware suppliers • Managers need to leverage communication and visualization tools, IoT, and AI-based analytical models to track and manage parameters • In addition to driving efficiency and reducing costs, focus on Environmental sustainability, human resources development, and digital transformation • To create a truly resilient organization, it is critical to fully align technology with people and processes

https://www.industryweek.com/operations/article/21152771/operations-managers-rising-to-the-challenges-of-2021

Activity: SuperFast is a seven-year old courier and parcel company operating in Asia and the Middle East. Two years ago, the company began operations in Africa. Though the company is strong in Asia and the Middle East, it has been facing stiff competition from SpeedCrew in Africa. Both the companies are equally quick in dispatching couriered mail and parcels and have strong infrastructure to support their businesses. However, as SpeedCrew is a local company, it has the added advantage of having deeper access to various part of Africa. Suggest various ways in which SuperFast can develop a competitive advantage over SpeedCrew and gain access to a wider market in Africa.

Answer:

16.9 Financial and Economic Analysis in Operations

Financial and economic analysis is used to evaluate the costs of operations and ascertain the profitability levels of the firm. Of the many methods, payback period method and net present value methods are two popularly used methods.

16.9.1 Payback Period Method

Payback period is the time taken to recover the investment made. Usually the initial investment and subsequent annual cash inflows are considered in this method. The mathematical representation of payback period method is

$$\text{Payback period} = \frac{\text{Net investment}}{\text{Net annual income from investment}}$$

The 'Net investment' is investment made in the business and the 'net annual income' is the expected annual revenue minus the expenses. This method ignores cash flow beyond the payback period, and does not take into account the time value of money.

Activity: Arvind Builders Ltd has decided to invest in a housing project. The company has three potential locations to choose from and wants to explore the possible pros and cons of these locations in order to select the best location. The following table gives the expected investments and the expected annual income for each location. Help Arvind Builders select the best location (in terms of best investment) using payback period method.

Location	Initial investment (Rs. Crores)	Expected annual income (Rs. Crores)
A	100	20
B	120	25
C	80	15

Answer:

16.9.2 Net Present Value

Net Present Value (NPV) helps calculate present value of future returns discounted at the marginal cost of capital, minus the present value of the cost of investment. Like payback period method, this method compares and analyzes multiple investment options. NPV for a project can be calculated using the formula.

$$NPV = \sum_{i=1}^{n} \frac{CF_i}{(1-r)^i} - I$$

Where CFi is the cash flow at time 'i', 'r' is the discounted rate of return, 't' is the time horizon, and 'I' is the initial investment.

Productivity Measurement

Productivity is an important measure of how well a business unit or industry is using its factor of production (resources). Since, the main objective of operations management is make best use of the available resources, productivity measurement is fundamental to assessing operations related performance. Broadly, productivity is defined as the ration of output to input.

$$\text{Productivity} = \frac{\text{Outputs}}{\text{Inputs}}$$

Companies want to achieve this ratio of output to input as large as possible to increase the productivity. Productivity is a relative measure and needs to be compared with respect to something else. This comparison can be done in two ways. First, a company can compare its productivity with the productivity of firms in the same industry. Second, a company can compare its own productivity over time i.e. the current productivity with respect to the productivity in last time period.

Productivity can be expressed as total measure, partial measure and multi factor measures. Total productivity is measured as the ratio of all outputs to all inputs, this measure can be used to measure overall productivity of an organization or even a nation. Partial productivity is measures as the ratio of some output to single input. Multi factor productivity is measured as the ratio of some outputs to a group of inputs (but not all inputs).

Examples of productivity measure:

Total measure- $\frac{\text{Outputs}}{\text{Inputs}}$ or $\frac{\text{Goods and servies produced}}{\text{All resources used}}$

Partial measure - $\frac{\text{Output}}{\text{Labor}}$ or $\frac{\text{Output}}{\text{capital}}$ or $\frac{\text{Output}}{\text{material}}$ or $\frac{\text{Output}}{\text{energy}}$

Multifactor measure - $\frac{\text{Output}}{\text{Labor} + \text{capital} + \text{energy}}$ or $\frac{\text{Output}}{\text{Labor} + \text{capital} + \text{material}}$

Check Your Progress - 4

(Questions 21 to 24) The given data below shows the initial investment of three projects and their payback periods. Use this data to answer the following **four** questions.

Project	Initial Investment	Expected Annual Income from the Project
A	Rs.10,00,000	Rs.2,00,000
B	Rs.12,00,000	Rs.2,50,000
C	Rs.8,00,000	Rs.1,50,000

21. Calculate the payback period for Project A
    a. 5 years
    b. 4 years
    c. 3 years
    d. 6 years
22. What is the payback period for Project B?
    a. 5.0 years
    b. 4.8 years
    c. 3.8 years
    d. 4.5 years
23. Calculate the payback period for Project C.
    a. 5.0 years
    b. 4.8 years
    c. 5.3 years
    d. 4.5 years
24. Based on the results for product A, B and C, which is the best investment in terms of faster returns?
    a. Project A
    b. Project B
    c. Project C
    d. Either project A or C
25. All the statements given below are **true** regarding payback period, except:
    a. It is the time taken to recover the investment made.
    b. It considers initial investment and subsequent annual cash inflows.
    c. It includes cash flows that are beyond the payback period.
    d. It does not consider the time value of money.
26. Which of the following statements are **true** regarding net present value?
    i. It compares and analyzes multiple investment options.
    ii. It refers to the time taken to recover the investment made.
    iii. It helps calculate present value of future returns discounted at the marginal cost of capital, minus the present value of the cost of investment.
    iv. It is calculated as net investment divided by the net annual income from investment.
    a. Only i and ii
    b. Only i and iii
    c. Only ii and iii
    d. Only iii and iv

16.10 Summary

- Operations management can be defined as the management of direct resources such as machine, material, and manpower, which are required to manufacture goods and services. The decisions taken by the operations managers can be classified into strategic decisions, tactical decisions, and operational decisions.
- The growing complexity in software and hardware technologies has led to the development of advanced production systems like computer-aided design (CAD), computer-aided manufacturing (CAM), flexible manufacturing systems (FMS), and automated storage and retrieval systems (AS/RS). Also, many new concepts and technologies like robotics, artificial intelligence, and expert systems have influenced manufacturing systems.
- Operations decisions are influenced by the nature of the goods or services to be produced and the markets to be served.
- Organizations should try to identify their distinct competencies to gain a competitive advantage over others.
- The key components of operations strategy are: designing the production system, designing and developing the product/service, selecting the technology and developing the process, allocating resources to strategic alternatives, and planning the facility.
- Designing the production system involves selecting the product design, the production system, and the inventory policy for finished goods for each product line.
- Operations strategy should always be in tune with the organizational strategy, which in turn, should be based on the corporate vision and mission.
- A flexible operations strategy helps an organization to support a product or service throughout its life cycle and to adjust to future changes in the market demand or business objectives.
- Financial and economic analyses helps compare and analyze the costs and benefits involved in various investments made by a company. Payback and Net Present Value (NPV) are two popular methods used to evaluate such investments.

16.11 Glossary

Automated Storage and Retrieval Systems: A computer-controlled warehouse system which automates inflow and outflow of materials from the warehouse and the shop floor on the basis of production requirements.

Computer-Aided Design: A specialized software used for designing products and processes. Advanced CAD systems enable engineers to test the performance of their design through computer simulation.

Computer-Aided Manufacturing: A specialized computer system used for translating CAD design information into instructions for numerically controlled automated machines. The use of CAM in manufacturing reduces the worker's involvement in the production process.

Customized product design: It is used when the level of customization is high and the quantity to be produced is low.

Flexible manufacturing system: A set of automated machines controlled by a central computer. These systems can produce a large quantity of products that have similar processing requirements.

Net Present Value: It helps calculate present value of future returns discounted at the marginal cost of capital, minus the present value of the cost of investment.

Operational decisions: Decisions that are short-term decisions and have a time period of less than a week.

Operations management: The management of direct resources such as machine, material, and manpower, which are required to manufacture goods and services.

Payback period: The time taken to recover the investment made. Usually the initial investment and subsequent annual cash inflows are considered in this method.

Process-focused systems: These are used for supporting production departments which perform a single task like painting or packing.

Produce-to-order policy: In this, the company starts production only after receiving orders from the customer.

Produce-to-stock policy: In this, products are produced in advance and stored in warehouses from where they are dispatched as per customer orders.

Product-focused systems: These are used in mass production organizations where groups of machines, tools, and workers are arranged according to their respective tasks in order to put together a product.

Scientific management concept: The productivity of a worker is governed by scientific rules and the management needs to study and apply these rules in its operations.

Standardized product design: It is used when the organization produces a limited variety of products in large batch sizes.

Strategic decisions: Decisions that are long term in nature and have a time period of five years or more.

Strategies: Broad, long-term plans, conceived of to achieve business objectives and are developed at the corporate, business, and functional levels.

Tactical decisions: Decisions that are medium term in nature and have a time period of one or two years.

16.12 Self-Assessment Exercises

1. Operations management has become a key discipline in management science and its scope has spread from the manufacturing sector to the service sector. Explain the importance of operations management in organizations.
2. Operations managers have to take decisions regarding the designing and implementation of operational strategies, which indicate how the companies utilize their production capabilities to achieve their organizational objectives. What are the different operations management decisions? Give examples of each category of decisions which are required to be taken by an operations manager.
3. The concept of modern operations management has evolved from the beginning of the eighteenth century. Explain the evolution process of operations management.
4. Computerization has resulted in a significant improvement in the overall performance of an organization. Explain the advantages and disadvantages of computerization of operations. Also explain the various technologies which aid in improving the performance of an organization.
5. Operations strategy has become an integral part of the strategic planning process of most companies in the current competitive scenario. Explain the uses of operations strategy. How can a business organization use operations strategy as a competitive weapon?
6. Operations strategy is a high-level integrated plan for business competitiveness. Explain the various elements of an operations strategy.
7. Operations strategy should always be flexible and in tune with organizational strategy. How can an organization develop an operations strategy?
8. Explain payback period and net present value methods.

16.13 Suggested Readings/Reference Material

1. Nigel Slack, Michael Lewis, Mohita Gangwar Sharma, Operations Strategy, Pearson Education; Fifth edition (8 May 2018)
2. Rob J Hyndman, George Athanasopoulos , Forecasting: Principles and Practice Paperback, Otexts; 3rd ed. Edition, 31 May 2021
3. Stephan Kolassa, Enno Siemsen, Demand Forecasting for Managers Paperback – 17, Business Expert Press, August 2016
4. Dr. Mohd. Parvez , Dr. Pallav Gupta , A Textbook on Manufacturing , IP Innovative Publication Pvt Ltd.; First Edition (15 June 2021)
5. Karl T. UlrichSteven D. EppingerMaria C. Yang, Product Design and Development , 7th Edition , McGraw Hill India, July 2020

16.14 Answers to Check Your Progress Questions

Following are the answers to the Check Your Progress questions given in the Unit.

1. (b) Importance and recognition given to employees

Elton Mayo in 1927 carried out studies at Western Electric's Hawthorne plant. The initial studies tried to examine the relationship between light intensity on the shop floor and employee productivity. Finally, Mayo and his team concluded that it was not light or other physical conditions, but the attention and importance the workers received during the study that was responsible for their increased productivity.

2. (b) Ford Motors

Henry Ford applied the concepts of scientific management of Taylor in the assembly line production system of Ford Motors in 1911.

3. (a) Strategic decisions

Strategic decisions are long-term and broad in nature and usually span five years or more. Long-term strategic decisions are concerned with production and process design, facility location and layout, capacity, expansion of existing facilities, etc. These decisions impact the long term profitability of an organization.

4. (a) Analyzing the firm's financial position

Analyzing the firm's financial position falls under the basic function of financial management and not operations management.

5. (c) Scientific management

Division of labor or work specialization is a development of scientific management. According to Taylor, each worker should be assigned a task based on his or her skill, strength and ability to learn.

6. (b) One or two years

Tactical decisions are medium-term in nature and have a time-frame of one or two years. These decisions are concerned with identifying manpower requirements, determining the appropriate inventory level for various materials, determining reordering level and order quantity, identifying vendors and so on.

7. (d) All of the above

Operations management, as a whole, deals with design of products and processes, acquisition of resources, transformation of resource inputs into outputs and distribution of goods and services.

8. (a) i, ii, iii

Inclusion of purchasing functions, dispatch, and other allied activities in this field and the influence of service-related concepts and procedures broadened the scope of this field of study. As the term 'Production Management' did not cover the entire field, it was replaced with 'Operations Management.'

9. (c) Elton Mayo

In 1927, Elton Mayo and his team carried out studies at Western Electric's Hawthorne plant. The initial studies tried to examine the relationship between light intensity on the shop floor and employee productivity. Finally, Mayo and his team concluded that it was not light or other physical conditions, but attention and importance the workers received during the study that was responsible for their increased productivity.

10. (b) Reducing clerical costs

The computerization of operations began when the first computer was installed in General Electric Appliance Park in 1954. The sole purpose of computerization those days was to reduce manual labor and the costs involved in tasks like preparing salary statements and accounts statements.

11. (c) Shorter product cycle

Shorter product cycle is one of the operational strategies that can be used by an organization as a competitive weapon. With a flexible and adaptable production system, the company can introduce a new product into the market faster than its competitors. Through this, the company can take the first mover advantage of the market demand, and in turn, gain a larger market share.

12. (b) Product variety

When an organization focuses on product variety as a competitive advantage it offers a large number of different products to various customer segments. This is true in the case of HDFC that offers different financial products to different segments.

13. (d) Automated Storage and Retrieval System (AS/RS)

AS/RS is a computer-controlled warehouse system which automates inflow and outflow of materials from the warehouse and the shop floor on the basis of production requirements. CAD is specialized software used for designing products and processes. Advanced CAD systems enable engineers to test the performance of their design through computer simulation. The FMS is a set of automated machines controlled by a central computer.

14. (b) Standardized product design

Standardized production is used when a company manufactures a limited variety of products in large batches to reduce costs.

15. (a) Designing the production system

Designing the production system is one of the key responsibilities of any operations manager. It involves selecting the product design, the production system and the inventory policy for finished goods for each product line.

16. (a) i and ii

Industrial products like boilers and turbines are made based on specific requirements of customers, while televisions and ceiling fans are produced in large numbers (also termed as standardized production) where customization of each piece is not possible.

17. (b) The role of operations department decreases as the product moves up the lifecycle.

As the product moves up the lifecycle, the organization's focus shifts towards increasing the market share and improving the quality of the product. Hence, the role of operations department decreases.

18. (b) A prototype helps test the product performance under standard conditions.

A prototype may not have all the features of the final product however it has all the product's basic characteristics. The prototype is tested under standard conditions and defects are noted. This would enable the organization to improve the product in terms of quality and performance. Once the final structure of the prototype is in place, the prototype design is evaluated for profitability.

19. (d) Facility planning

Facility planning deals with location of the facility and its layout. Decisions regarding facility location are based on the accessibility to raw material and nearness to markets. Allocation of resource deals with the allotment of existing resources like men, machines, material, etc, to different strategic alternatives. Technology selection and process development deals with selection of the most suitable technology for producing products and product design and development is used to develop new products.

20. (b) Optimize the use of resources for best strategic use

The main objectives behind allocating resources to different alternatives (which are also called strategic alternatives) include minimizing wastage in the facilities and employing resources to the best possible use.

21. (a) 5 years

Payback period = Net investment / Expected annual income

= 10,00,000/2,00,000 = 5 years

22. (b) 4.8 years

Payback period = Net investment / Expected annual income

= 12,00,000/2,50,000 = 4.8 years

23. (c) 5.3 years

Payback period = Net investment / Expected annual income = 8,00,000/1,50,000 = 5.3 years

24. (b) Project B

Of all the investments, Project B is the best option. Though Rs.12, 00,000 are invested in this project, the payback period is the shortest due to greater expected annual income.

25. (c) It includes cash flows that are beyond the payback period.

Payback period is the time taken to recover the investment made. This method ignores cash flow beyond the payback period and does not take into account the time value of money.

26. (b) Only i and iii

Options i and iii are true regarding net present value, while options ii and iv refer to payback period method.

Unit 17

Forecasting Demand

Structure

17.1 Introduction

In the previous unit, we have discussed the importance of conducting financial and economic analysis in operations. We have learnt that financial and economic analyses helps compare and analyze the costs and benefits involved in various investments made by a company. In this unit, we will discuss forecasting in operations.

Forecasting predicts the future value of a variable and helps managers in taking effective decisions and planning their activities accordingly. Demand forecasting is vital for the planning and control functions of an organization. Demand is the quantity of a product or service that buyers are able and willing to buy during a particular time period in a specific market environment. The primary step in planning involves estimating the future demand for products and the resources required to produce them to satisfy such demand.

Overestimating or underestimating future demand has a negative impact on the overall performance of the organization. Overestimation leads to a huge inventory of finished goods and results in locking up a large amount of working capital while underestimation leads to an increase in the supply lead-time and results in loss of orders and customers. Though it is difficult to make accurate forecasts, it

is essential for an organization to achieve good returns on its investments. Forecasts are never 100% accurate, but tracking the results and their accuracy will improve the accuracy of future forecasts. In this unit, we shall discuss forecasting, the various methods of forecasting, the reasons for their selection, and the measures of forecast accuracy.

This unit will introduce you to forecasting in operations, and explain the forecasting components. We will discuss the demand forecasting process, and then study the various forecasting methods. We shall then move on to discuss the steps involved in the demand forecasting process, and understand how to measure the forecasting accuracy. Finally, we would discuss how to monitor and control forecasts.

17.2 Objectives

By the end of this unit, students should be able to:

- Define forecasting in operations.
- Discuss the various forecasting methods.
- Select a forecasting method.
- Identify the measures of forecasting accuracy.
- Explain how to monitor and control forecasts.

17.3 Forecasting in Operations

Forecasting predicts the future demand for products or services and is used in process design, capacity and facilities planning, aggregate planning, scheduling, inventory management, etc. Though the predictions may be inaccurate, they provide vital information for strategic, tactical and operational planning, and decision-making. Operations managers forecast future events including both long-term estimates for aggregate demand and short-term demand estimates for each product or service. Short-term demand estimates for individual products are detailed and are used to plan and schedule the production operations while long-term estimates are used for making location, layout, and capacity decisions. Individual forecasts are made on the basis of aggregate forecasts which are used to plan and control operation subsystems. Accurate forecasts help in inventory management, production planning, work assignment, and overall management of costs associated with various stages of production process.

Forecasting time horizons

Short range - generally less than three months, used for purchasing, job scheduling, work force levels, production levels

Medium range - usually from three months up to three years, used for sales planning, production planning and budgeting, cash budgeting, analyzing operating plans;

Long range - usually three years or more, used for new product development, capital expenditures, facility planning, and R&D.

Types of forecasts

The three types are economic, technological, and demand;

- **Economic** refers to macroeconomic, growth and financial variables;
- **Technological** refers to forecasting amount of technological advance, or futurism;
- **Demand** refers to product demand.

Associative model and time-series model

A time series model uses only historical values of the quantity of interest to predict future values of that quantity. The associative model, on the other hand, attempts to identify underlying causes or factors that control the variation of the quantity of interest, predict future values of these factors, and use these predictions in a model to predict future values of the specific quantity of interest

17.4 Forecasting Components

There are different factors or components that a firm has to consider while making a forecast. Every forecast can be influenced by any of the six different components viz. – base demand, seasonal component, trends, cyclical component, promotions, and irregular component.

Base demand: Base demand is the average sales over a given period of time and this is applicable if the remaining components do not influence the demand.

Seasonal component: Seasonal component is the repeated increase and decrease in demand during a particular period, say season and off-season.

Trend component: Trend component is the long term pattern of movement of demand over time, which could be positive, negative or neutral. A positive trend implies increasing demand while a negative trend implies decreasing demand. An example of a positive trend is the demand for housing loans that is on the rise over the past few years.

Cyclic component: Cyclical component refers to repetitive changes in the demand patterns. This is different from the seasonal component in that the frequency is over longer periods, say more than one year. Trade cycle is an example, where the demand for certain goods is high during the boom period and low during the slump.

Promotional component: The promotional component refers to the promotional activities taken up by marketers to increase the sales of their products. This component has to be included whenever the firm expects to carryout a promotional campaign. This is usually found in the consumer goods industry.

Irregular component: The irregular component refers to all those variations in demand that cannot be attributed to any of the above five factors. This factor is difficult to predict because of its random nature. Firms strive to minimize the irregular component so as to develop a fairly accurate demand forecast.

Check Your Progress - 1

1. Which of the following is **not** a consequence of underestimation of demand?
   a. Increase in supply lead time
   b. Increase in loss of orders
   c. Increase in customer switching
   d. Increased locking up of working capital as inventory
2. Which of the following demand estimates are very detailed and used to plan and schedule production operations?
   a. Short-term demand
   b. Medium-term demand
   c. Long-term demand
   d. All of the above
3. Forecasting demand has a direct impact on which of the following two functions of management.
   a. Planning and organizing
   b. Directing and control
   c. Organizing and staffing
   d. Planning and controlling
4. For forecasting purposes, firms need to take into consideration various factors or components. Which of the following is associated with average sales over a given period of time?
   a. Trend component
   b. Seasonal component
   c. Cyclical component
   d. Base demand
5. The demand for luxury products may be linked with the business cycle, as sales usually increase during the boom phase and slow-down during recession. What component of forecasting is described here?
   a. Trend component
   b. Seasonal component
   c. Cyclical component
   d. Base demand

6. When LG increased the advertising budget by 40%, the sales of its televisions doubled. On this basis, LG prepared an aggressive demand forecast for the next year. What component of demand did LG consider as part of its forecast?
   a. Cyclical component
   b. Promotional component
   c. Trend component
   d. Irregular component
7. Which of the following is an example of the trend component of forecast?
   a. The demand for gold has reduced as the price of gold has increased
   b. The promotional expenditure of Airtel's GSM service was hiked based on demand forecast
   c. The demand for camera mobile phones in India has increased steeply since 2001
   d. The demand for wrist watches has been fluctuating for quite some time

17.5 Demand Forecasting Process

The process of demand forecasting involves five stages. They include understanding the objective of forecasting, integrating demand planning & forecasting, identifying the influencing factors, identifying the consumer segments, and determining the appropriate forecasting technique.

Understanding the objective of forecasting: Organizations make use of forecasting for decision-making in many managerial functions like developing production schedules, marketing planning, etc. Hence, it is important to understand the objectives of forecasting and the decisions that need to be implemented.

Integrate demand planning & forecasting: Integration of demand planning & forecasting has to be done right from the initial stages of forecasting. As forecast is the basis of all the planning activities like aggregate planning, production planning, promotion planning, etc., it is essential to integrate these aspects with the forecast.

Identify the influencing factors: In this stage, the firm has to identify all the influencing components of a forecast. Forecasting components like seasonal components, trends, etc, discussed earlier, have to be identified.

Understand and identify the consumer segments: Different consumer segments make up a market. Hence, the marketer has to understand the market and identify different consumer segments based on their needs and requirements.

Determine the appropriate forecasting technique: In the final stage, the most appropriate forecasting technique has to be selected. This depends on different aspects like stage of the product life cycle, geographical region, customer groups, etc.

17.6 Forecasting Methods

Forecasting methods/ techniques are classified under three categories: qualitative methods, time-series methods, and causal methods.

17.6.1 Qualitative Methods

Qualitative methods are based on judgments (regarding factors influencing demand) and opinions (about probability of the factors affecting the demand) and not on any mathematical models. These methods range from scientifically conducted opinion surveys to intuitive predictions about future events.

Executive Opinions

The subjective views of executives or experts from sales, production, finance, purchasing, and administration are averaged to generate a forecast about future sales. Usually this method is used in conjunction with some quantitative method, such as trend extrapolation. The management team modifies the resulting forecast, based on their expectations.

- The advantage of this approach: The forecasting is done quickly and easily, without need of elaborate statistics. Also, the jury of executive opinions may be the only means of forecasting feasible in the absence of adequate data.
- The disadvantage: This, however, is that of group-think. This is a set of problems inherent to those who meet as a group. Foremost among these are high cohesiveness, strong leadership, and insulation of the group. With high cohesiveness, the group becomes increasingly conforming through group pressure that helps stifle dissension and critical thought. Strong leadership fosters group pressure for unanimous opinion. Insulation of the group tends to separate the group from outside opinions, if given.

Delphi method: The Delphi method is a coordinated and interactive method of forecasting future events on the basis of independent opinions and predictions. These opinions and predictions are made by an expert panel and reviewed by a competent mediator. The method is mostly used for long-term forecasting. It involves the following steps:

- Selecting a group of experts, depending on the type of expertise required.
- Obtaining ideas and forecasts from all participants through a questionnaire.
- Summarizing the results and redistributing them along with appropriate new questions. Any member whose response deviates from the opinion of the majority is requested to reconsider or provide justification for the deviation.
- Summarizing the responses again, and developing new questions on the basis of the responses. This cycle is repeated till the results are in a range that is narrow enough to be used as a forecast.

- **Advantages**: This type of method is useful and quite effective for long-range forecasting. The technique is done by questionnaire format and eliminates the disadvantages of group think. There is no committee or debate. The experts are not influenced by peer pressure to forecast a certain way, as the answer is not intended to be reached by consensus or unanimity.
- **Disadvantages**: Low reliability is cited as the main disadvantage of the Delphi method, as well as lack of consensus from the returns.

Nominal group technique: The nominal group technique is a structured problem solving and decision making method developed by Andrew Van de Ven. Following are the steps involved in the technique:

- *Generation of ideas:* In this stage, group members write down their ideas regarding the question/problem posed by a mediator.
- *Round robin collection of ideas:* The ideas of the group are collected and recorded on a flip chart or a blackboard that is visible to all members. No discussion is permitted during this stage.
- *Discussion:* Each idea is discussed. To avoid any wastage of time, similar or duplicate ideas are clubbed together and discussed. The ideas are discussed in terms of their perceived importance, clarity, and logic. Members are allowed to make brief, impersonal comments on a voluntary basis on each idea.
- *Preliminary Voting:* Members are asked to cast their preliminary vote to select the best idea. If there is no consensus regarding the best idea, the ideas concerned are discussed further so that their meaning and logic are clarified.
- *Final voting:* Members are asked to cast their final vote. The result of the final vote is counted and the most preferred idea, solution, or forecast is identified.

Sales Force Polling

Some companies use as a forecast source salespeople who have continual contacts with customers. They believe that the salespeople who are closest to the ultimate customers may have significant insights regarding the state of the future market. Forecasts based on sales force polling may be averaged to develop a future forecast. Or they may be used to modify other quantitative and/or qualitative forecasts that have been generated internally in the company.

The advantages of this forecast are:

- It is simple to use and understand.
- It uses the specialized knowledge of those closest to the action.
- It can place responsibility for attaining the forecast in the hands of those who most affect the actual results.
- The information can be broken down easily by territory, product, customer, or salesperson.

The disadvantages include:

- Sales people's being overly optimistic or pessimistic regarding their predictions and inaccuracies due to broader economic events that are largely beyond their control.

Consumer Surveys

Some companies conduct their own market surveys regarding specific consumer purchases. Surveys may consist of telephone contacts, personal interviews, or questionnaires as a means of obtaining data. Extensive statistical analysis usually is applied to survey results in order to test hypotheses regarding consumer behavior.

Essential elements of Good Forecasting:

The essential elements to be covered in to a Good forecasting, includes:

- The forecast should be timely. Usually, a certain amount of time is needed to respond to the information contained in a forecast. For example, capacity cannot be expanded overnight, nor can inventory levels be changed immediately. Hence, the forecasting horizon must cover the time necessary to implement possible changes.
- The forecast should be accurate, and the degree of accuracy should be stated. This will enable users to plan for possible errors and will provide a basis for comparing alternative forecasts.
- The forecast should be reliable; it should work consistently. A technique that sometimes provides a good forecast and sometimes a poor one will leave users with the uneasy feeling that they may get burned every time a new forecast is issued.
- The forecast should be expressed in meaningful units. Financial planners need to know how many rupees will be needed, production planners need to know how many units will be needed, and schedulers need to know what machines and skills will be required. The choice of units depends on user needs.
- The forecast should be in writing. Although this will not guarantee that all concerned are using the same information, it will at least increase the likelihood of it. In addition, a written forecast will permit an objective basis for evaluating the forecast once actual results are in.
- The forecasting technique should be simple to understand and use. Users often lack confidence in forecasts based on sophisticated techniques; they do not understand either the circumstances in which the techniques are appropriate or the limitations of the techniques. Misuse of techniques is an obvious consequence. Not surprisingly, fairly simple forecasting techniques enjoy widespread popularity because users are more comfortable working with them.
- The forecast should be cost-effective: The benefits should outweigh the costs.

Check Your Progress - 2

8. Which of the following methods is judgmental and subjective in nature and based on the estimates and opinions of individuals?
   a. Time series methods
   b. Delphi method
   c. Exponential smoothing
   d. Regression analysis
9. Identify the correct sequence of steps taken as part of the demand forecasting process.
   a. Identify influencing factors – understand objectives – identify customer segments – select forecasting technique
   b. Identify influencing factors – identify customer segments – understand objectives – select forecasting technique
   c. Identify customer segments – understand objectives – identify influencing factors – select forecasting technique
   d. Understand objectives – identify influencing factors – identify customer segments – select forecasting technique
10. All the statements given below are **true** regarding the Delphi method, except:
    a. It is a coordinated and interactive method of forecasting future events on the basis of independent opinions and predictions.
    b. It is used for short-term forecasting.
    c. The opinions and predictions are made by an expert panel and reviewed by a competent mediator.
    d. The ideas and forecasts from all the participants are obtained through a questionnaire.
11. Given below is the sequence of activities that take place in the Delphi method. Identify the correct sequence from the options given below.
    i. Obtaining ideas and forecasts from all participants through a questionnaire.
    ii. Summarizing the results and redistributing them along with appropriate new questions.
    iii. Selecting a group of experts, depending on the type of expertise required.
    iv. Summarizing the responses again and developing new questions on the basis of the responses.

    The correct sequence is:
    a. i-ii-iii-iv
    b. i-iii-ii-iv
    c. ii-iv-i-iii
    d. iii-i-ii-iv

12. _____ refers to a structured problem solving and decision making method that involves the following steps – generation of ideas, round robin collection of ideas, discussion, preliminary voting and final voting.
    a. Delphi method
    b. Nominal group technique
    c. Linear regression technique
    d. Exponential smoothing method
13. In the nominal group technique, the group members write down their ideas regarding the question/problem posed by a mediator and then all the ideas are collected and recorded on a flip chart or a blackboard that is visible to all the members. Which of the following steps takes place after this?
    a. A group of experts is selected depending on the type of expertise required.
    b. Each idea is discussed in terms of their perceived importance, clarity, and logic.
    c. Members are asked to cast their preliminary vote to select the best idea.
    d. The results are summarized and redistributed along with appropriate new questions.

17.6.2 Time-Series Methods

Time-series forecasting methods assume that past data is a good indicator of the future. This assumption is mostly true and relevant data is always available. Hence, operations managers use a time series model to forecast the demand for their goods or services. Based on the complexity involved, time series methods can be divided into static forecasting methods and adaptive forecasting methods.

Static Forecasting Methods

Also known as basic time series forecasting techniques, these methods assume that the estimates of seasonal component and trends do not vary every year. These estimates are determined from the available historical data and are projected to get the future demand estimate. A forecast is obtained using the static forecasting method with the help of the following steps.

Deseasonalize or decompose the time series: This step involves identifying the seasonal variations in the time series and removing them using the seasonal index.

Estimate the trend and seasonal components: Once the time series is decomposed, the trend and seasonal components have to be calculated. The least square method is one such method.

Make the forecast: Here the trend level is calculated for all the time periods considered. It is then multiplied with either seasonal index, to get the seasonal effects, or/and cyclic index to include the cyclical effects in the forecast.

Adaptive Forecasting Methods

These methods are considered as advanced form of time series analysis. Adaptive forecasting methods do not assume that the estimates of seasonal and trend component remain same over years. The seasonal and trend components are adjusted after very demand period (i.e. after every year if the demand forecasting is made every year).

Some of the popularly used adaptive forecasting methods are simple moving average, weighted moving average and exponential smoothing.

Simple moving average (SMA): In this technique, demand is forecast on the basis of the average demand calculated from actual demand in the past. This method is effective when a product does not experience fluctuations in demand over a period of time and the past demand for the product was not seasonal. This method is useful for removing any random fluctuations in demand to get accurate forecasts.

$$F_t = \frac{D_{t-1} + D_{t-2} + D_{t-3} + ... + D_{t-n}}{n}$$

Where, F_t = forecast for the period t

n = number of preceding periods taken for averaging

D_{t-1}, D_{t-2} and so on = actual demand in the immediately preceding time periods

The length of the time period has to be considered while using the SMA method. If the moving average period is greater, the forecast will be less exposed to random variations. A larger time period is taken when the demand fluctuations are minimal while a small time period is taken when the demand fluctuations are high or when there is a need to identify short-term fluctuations.

Activity: The following table shows the demand for product X for the last six months from January to February. Calculate the demand for the product for the month of July, using the simple moving average.

Months	**January**	**February**	**March**	**April**	**May**	**June**
Demand (units)	85	90	75	80	88	82

Answer:

Weighted moving average (WMA): Due to some trend or seasonality in demand, the forecaster using a moving average may not want all the 'n' periods to be equally weighted. There is no set rule for calculating weights. Weights are assigned for a particular piece of data based on experience and trial and error methods. Each element is weighted by a factor and the sum of the weights should be equal to one.

$WMA_{t+1} = \sum_{t=1}^{n} C_t A_t$ Where WMA_{t+1} = Weighted Moving Average at the end of the time period t

A_t = Actual demand in time period t

C_t = Percentage weight given to time period t

$0 \leq C_t \leq 1$ and $C_1 + C_2 + C_3 + \ldots + C_t = 1$

Illustration 1

The following table shows the demand for product X for the last six months from July to December. Calculate the demand for the product for January the following year, using the simple moving average.

Months	July	August	September	October	November	December
Demand (units)	70	75	65	72	78	76

Solution:

Select the time period for which the moving average of the demand for the product X are calculated. For a three-month average, the forecast for the fourth period will be the average of first three periods. Therefore, forecast for the month of October will be the average of demand during July, August, and September.

For example, October = $F_4 = \frac{70+75+65}{3} = 70$

Month	Demand	3 Months Average
July	70	-
August	75	-
September	65	-
October	72	70 (F_4)
November	78	70.67 (F_5)
December	76	71.67 (F_6)
January		75.33 (F_7)

So, the estimated demand for the month of January is approximately 75 units.

Illustration 2

A company wants to make a sales forecast based on the WMA method. The forecasters of the company, based on their past experience and judgment, have assigned weights for the sales data taken from the last six months to predict the future demand. Following are the weights assigned for the sales data: 30% to the actual sales for the most recent month; 25% for the actual sales of two months ago; 20% to the actual sales three months ago; 15% to the actual sales four months ago; 10% to the actual sales five months ago; 5% to the actual sales six months ago. If the actual sales for the last six months are given as (starting from the most recent month) 140, 144, 148, 145, 146, and 142, forecast the sales for the seventh month.

Solution:

$WMA_6 = 140(0.30) + 144(0.25) + 148(0.20) + 145(0.15) + 146(0.10) + 142(0.05)$
$= 42+36+29.6+21.75+14.6+7.1 = 151$ units (approx).

Therefore, the sales forecast for the seventh month is 151 units.

Activity: Following are the weights assigned for the sales data for the past five months: 25% to the actual sales for the most recent month; 20% for the actual sales of two months ago; 15% to the actual sales three months ago; 10% to the actual sales four months ago; 5% to the actual sales five months ago. If the actual sales for the last five months are given as (starting from the most recent month) 210, 217, 220, 205, and 215, calculate the sales forecast of the company for the sixth month using the WMA method.

Answer:

Exponential smoothing: Though SMA and WMA are simple and effective, they suffer from a few drawbacks like the need to collect a large amount of historical data. In contrast, the exponential smoothing method is based on the assumption that the most recent data is a better indicator of future trends than past data. It is useful when used on data characterized by seasonal tendencies. This model has different variants based on periodic trends or variations. The advantages of the exponential smoothing method are:

- Availability of standard software packages
- Relatively little data storage and computational requirements
- Accuracy of forecasts
- Ease in understanding the results

The maximum weightage is given to the demand for the most recent time period and the weights assigned to the preceding periods decrease exponentially. For making the forecast, the data requires the most recent forecasts, the actual demand for that time period, and a smoothing constant (α). The value of α lies between 0 and 1.

First-order exponential smoothing: In this method, the demand forecast for the next period is given by

$$F_t = \alpha D_{t-1} + (1-\alpha)F_{t-1}$$

Where, F_{t-1} = Forecast for period t-1

D_{t-1} = Actual demand for period t-1

α = Smoothing constant, $0 \leq \alpha \leq 1$

The following equations are developed based on past actual demand and forecasted demand data. For the three immediately preceding periods, the forecasts can be calculated as follows:

$$F_t = \alpha D_{t-1} + (1-\alpha)F_{t-1} \qquad \text{(i)}$$

$$F_{t-1} = \alpha D_{t-2} + (1-\alpha)F_{t-2} \qquad \text{(ii)}$$

$$F_{t-2} = \alpha D_{t-3} + (1-\alpha)F_{t-3} \qquad \text{(iii)}$$

Substituting the value of F_{t-1} from equation (ii) into equation (i), we get,

$$F_t = \alpha D_{t-1} + (1-\alpha)[\alpha D_{t-2} + (1-\alpha)F_{t-2}] \quad \text{(iv)}$$

Again, substituting the value of F_{t-2} in equation (iv), we get,

$$F_t = \alpha D_{t-1} + (1-\alpha)[\alpha D_{t-2} + (1-\alpha)\{\alpha D_{t-3} + (1-\alpha)F_{t-3}\}] \quad \text{(v)}$$

Simplifying equation (v), we have,

$$F_t = \alpha D_{t-1} + \alpha(1-\alpha)D_{t-2} + \alpha(1-\alpha)^2 D_{t-3} + (1-\alpha)^3 F_{t-3}$$

From this equation, we can see that the weight assigned to the most recent observation is the value of the smoothing constant (α), and that the weights assigned to past observations decrease exponentially as we go back in the time period.

Illustration 3

A firm achieved actual sales of 1500 units in June when the forecast was 1200 units. Calculate the sales for July using a smoothing constant of 0.5.

Solution:

$$F_{July} = \alpha D_{June} + (1-\alpha)F_{June}$$

Substituting the values in the above equation, we have,

$F_{July} = 0.5 \times 1500 + (1\text{-}0.5) \times 1200 = 750 + 600 = 1350$

Thus, the forecast for the month of July is 1350 units.

Activity: A firm achieved actual sales of 150 units in August when the forecast was 130 units. Calculate the sales for September by using a smoothing constant of 0.2.

Answer:

Selecting a smoothing coefficient (α): The smoothing constant α shows the effects of past demand on future demand forecasts. It takes any value between 0 and 1.

The selection of α is critical as a high α results in assigning more weightage for the most recent demand and a low α results in a relatively lower weightage for it. A high α is more appropriate for new products for which demand is dynamic or unstable. If demand is stable and believed to represent the future, a low α can be selected to smooth out the effect.

Trend adjusted exponential smoothing (double smoothing): SMA and single exponential smoothing have the shortcoming of lagging behind actual data, which shows a steady trend, either upward or downward. Trend indicates a continuous increase or decrease in the average of the series over a period of time. The presence of a trend in a time series leads to forecasts that are above or below the actual demand. In trend adjusted exponential smoothing, both the average and the trend are smoothed. For this, two smoothing constants α and β are used. The following equations are used for calculating both the average and the trend:

$$A_t = \alpha D_t + (1-\alpha)(A_{t-1} + T_{t-1})$$

$$T_t = \beta(A_t - A_{t-1}) + (1-\beta)(T_{t-1})$$

$$F_{t+1} = A_t + T_t$$

Where, D_t = Demand in period t

A_t = Exponential smoothed average for period t

T_t = Exponential smoothed trend for period t

T_{t-1} = Trend estimate for period t-1

A_{t-1} = Actual demand for period t-1

F_{t+1} = Forecast for period t+1

α = Smoothing constant ($0 \leq \alpha \leq 1$)

β = Smoothing constant ($0 \leq \beta \leq 1$)

Estimates for the last period's average and trend, which are required for the first forecast, are obtained from historical data or by making an educated guess, in case no historical data is available. The procedure for finding the value of β is the same as finding the value of α.

Illustration 4

For a dealer in bikes, sales for the last six months averaged 50 units. The average increase in bike sales was 6 units per month. In the sixth month, 49 units were sold. Forecast sales for the next two months, using the trend adjusted exponential smoothing method. Take smoothing constants as $\alpha = 0.3$ and $\beta = 0.25$.

Solution:

From the information given, $A_0 = 50$, $T_0 = 6$, and $D_1 = 49$

$A_t = \alpha D_t + (1-\alpha)(A_{t-1} + T_{t-1})$

$T_t = \beta(A_t - A_{t-1}) + (1-\beta)(T_{t-1})$

$F_{t+1} = A_t + T_t$

$A_6 = 0.3(49) + (1 - 0.3)(50 + 6) = 14.7 + 39.2 = 53.9$

$T_6 = 0.25(53.9 - 50) + (1-0.25)(6) = 0.975 + 4.5 = 5.475$

$F_7 = 53.9 + 5.475 = 59.375 = 59$ (approx)

Forecast for the eighth month would be

$A_7 = 0.3(59) + (1-0.3)(53.9+5.475) = 17.7 + 41.5625 = 59.2625$

$T_7 = 0.25(59.2625 - 53.9) + (1-0.25)(5.475) = 1.340625 + 4.10625 = 5.446875$ (approx)

$F_8 = 59.2625 + 5.446875 = 64.709375 = 65$ units (approx).

Check Your Progress - 3

14. Which of the following demand forecasting techniques is divided into static and adaptive methods?
    a. Qualitative methods
    b. Time series methods
    c. Causal methods
    d. All of the above
15. Trend and seasonal components play an important role in demand forecasting. In which of the following forecasting methods are estimates of trend and seasonal components assumed to **not** vary from year to year?
    a. Exponential smoothing
    b. Static forecasting method
    c. Regression analysis
    d. Simple moving average

16. Identify the statistical techniques that use historical data collected over a period of time to predict future demand.

    a. Time-series methods
    b. Qualitative methods
    c. Nonparametric methods
    d. Causal methods

17. The sum of weights used in weighted moving average method should be equal to _____.

    a. 1
    b. 10
    c. 100
    d. Zero

18. How are weights in the weighted moving average method calculated?

    a. Simple moving average method
    b. Future forecast
    c. Trial & error
    d. Exponential smoothing

19. Which of the following forecasting methods are used when the demand for a product is influenced by seasonal tendencies?

    a. Delphi method
    b. Simple moving average method
    c. Exponential smoothing
    d. All of the above

20. Which of the following is **not** a benefit that an operations manager gains when using the exponential smoothing method?

    a. Easy availability of standard software packages
    b. Less computational requirements
    c. Larger data storage space
    d. Greater accuracy in forecasts

21. Maximum weightage is given in the exponential smoothing method for demand values in which of the following time periods?

    a. Latest time period
    b. Earliest time period
    c. Average of latest and oldest time periods
    d. Sum of latest and oldest time periods

22. What is the formula for calculating the weighted moving average?

    a. $WMA_t = \sum_{t=1}^{n} C_t A_t$

    b. $WMA_{t+1} = \sum_{t=1}^{n} C_t A_t$

    c. $WMA_{t+1} = \sum_{t=1}^{n+1} C_t A_t$

    d. $WMA_{t-1} = \sum_{t=1}^{n-1} C_t A_t$

23. Why is the constant α used in exponential smoothing method?

    i. To show effects of past demand

    ii. To smooth out the effects of any noise

    iii. To predict future trends in demand

    a. Only i

    b. Only ii

    c. i and ii

    d. i, ii, and iii

Exercise

A. The demand for generator sets for twelve consecutive months from January to December is given as 78, 80, 85, 82, 84, 85, 87, 88, 86, 89, 86, 87. Calculate the approximate demand for January of the next year using the simple moving averages method. Assume the time period to be a six month moving average.

Activity: For a dealer in refrigerators, sales for the last five months averaged 80 units. The average increase in refrigerator sales was 10 units per month. In the fifth month, 71 units were sold. Forecast sales for the next two months, using the trend adjusted exponential smoothing method. Take smoothing constants as $\alpha = 0.1$ and $\beta = 0.05$.

Answer:

17.6.3. Causal Quantitative Models

The demand for a product or service depends on various factors or variables like price, quality, availability of substitute and/or complementary products/services, income level of customers, number of competitors, etc. Organizations must identify the variables that affect the demand for a product or service. A causal method evaluates the relationship between different variables and their influence on each other. These include linear regression and multiple regression analysis.

Linear regression: Regression refers to the functional relationship between two or more correlated variables. Linear regression analysis establishes a relationship between a dependent variable, for which the future forecast is needed, and a group of other variables, known as independent variables, which influence the dependent variable. For example, the sale of televisions is dependent on the advertising budget and the number of retailers. Here, the sale of televisions is a dependent variable and the advertising budget and number of retailers are independent variables. In linear regression, the relationship between the dependent variable and one independent variable is defined by a straight line.

$Y = a + bX$

Where Y = Value of the dependent variable

X = Value of the independent variable

a = Y intercept (constant value)

b = Slope of the line

Here, 'a' is the Y-intercept and 'b' is the slope of the line which represents the variation in Y for a unit change in X. The value of 'a' defines the point at which the regression line crosses the Y-axis and the value of 'b' defines the trend of the dependent value. If 'b' is positive, then the trend line increases positively and if it is negative, the trend line decreases negatively.

Least square method: The least square method is used to generate a regression model by assigning data to a single line. In this method, past demand data is used to form a linear model by regressing the data points to a single line. After forming the linear equation, future demand (Y) can be predicted by substituting the value of X. The following equations are used to calculate the value of constants 'b' and 'a' in the regression model:

$$b = \frac{n(\sum XY) - (\sum X)(\sum Y)}{n(\sum X^2) - (\sum X)^2}$$

$$a = \frac{\sum Y}{n} - b\frac{\sum X}{n} \text{ or } \bar{Y} - b\bar{X}$$

Where n is the sample size.

Illustration 5

Using regression analysis, find the cost of advertising for achieving sales of 100 units of a product. Sales and advertising costs of previous months are given in the table:

Sales	9	25	11	20	35	20
Cost	6	5	10	7	14	8

Solution:

By using the least square method, we can calculate the regression equation.

X (Sales)	**Y (Cost)**	**XY**	**X^2**	**Y^2**
9	6	54	81	36
25	5	125	625	25
11	10	110	121	100
20	7	140	400	49
35	14	490	1225	196
20	8	160	400	64
120	**50**	**1079**	**2852**	**470**

Here, n = 6

$$\bar{X} = \frac{\sum X}{n} = \frac{120}{6} = 20,\ \bar{Y} = \frac{\sum Y}{n} = \frac{50}{6} = 8.33$$

$$b = \frac{n(\sum XY) - (\sum X)(\sum Y)}{n(\sum X^2) - (\sum X)^2} = b = \frac{\sum XY - n\left(\bar{X}\right)\left(\bar{Y}\right)}{\sum X^2 - n\left(\bar{X}\right)^2}$$

Substituting the values in the equation, we get b = 0.17. Substituting the value of b in the equation, $a = \bar{Y} - b\bar{X}$, we get a = 4.93. Substituting 'a' and 'b' in the straight line equation, we can obtain the value of the dependent variable on the basis of the independent variable.

Y = 4.93 + 0.17X

Given X = 100 units

Y = 4.93 + (0.17×100) = 4.93 + 17 = 21.93 or 22

So, to achieve a sales level of 100 units, the organization needs to spend 22 units of capital on advertising.

Activity: Using regression analysis, find the cost on advertising for achieving sales of 100 units. Sales and advertising costs are given in the table:

Sales	11	27	17	25	38	23
Cost	10	8	13	9	16	11

Answer:

Check Your Progress - 4

24. Demand for a commodity is most likely to depend upon which of the following?

    i. The price of the commodity

    ii. The prices of the available complementary goods

    iii. The customer tastes and preferences

    iv. Price of substitutes

    a. i and ii

    b. ii and iii

    c. i, ii, and iii

    d. i, ii, iii, and iv

25. Demand for a product is influenced by many factors. Which of the following is **not** a factor that influences product demand?

    a. Price of the product

    b. Price of the substitutes

    c. Income levels of the consumers

    d. Extent of accuracy of demand forecasts

26. In the equation Y = a + bX, what is 'a' termed as?

    a. Value of the dependent variable

    b. Value of the independent variable

    c. Slope of the line

    d. Y intercept or constant value

27. What is the relation between the slope of the line and the trend line in regression analysis?
    a. If the slope is positive, then the trend line increases positively
    b. If the slope is positive, then the trend line decreases negatively
    c. There is no relationship between the slope and the trend line
    d. If the slope is negative, then the trend line increases positively
28. Which of the following forecasting methods give 100% accurate forecasts?
    a. Qualitative methods
    b. Time series methods
    c. Causal methods
    d. None of the above

17.7 Selecting a Forecasting Method

If a good forecasting method is selected, it maximizes accuracy and minimizes biases. Therefore, the suitability of a forecasting method should be verified before it is selected. The selection of a method depends on the availability of data, the amount of data and its nature, the amount of variation expected, the forecast accuracy required, and the costs and technical expertise involved in forecasting. In general, the selection of a forecasting system depends on the time span, data availability, and cost and accuracy.

Time Span – The time span is one of the key issues to be considered here. Time series techniques such as moving averages and exponential smoothing are used for making short-range decisions like purchasing, job scheduling, project assignment, and machine scheduling. Medium-range decisions like capital and cash budgeting, sales planning, production planning, and inventory budgeting are made by using regression analysis. The Delphi technique, market research, etc. are used for making long-range decisions like product planning, facility location, and expansion, and capital planning.

Data Availability – Time series analysis like moving averages and exponential smoothing methods are used if historical data is available in plenty. Qualitative methods like the Delphi method or the nominal group technique are used if no data is available or if it is too expensive to collect data. Causal methods like regression analysis are used if a relationship exists between the different variables under review.

Cost and Accuracy –Inaccurate forecasts result in high inventory holding costs and operating costs. Accurate forecasting methods incur high implementation costs as they require data that is difficult to obtain, and skilled manpower to conduct the study.

17.8 Measures of Forecasting Accuracy

Forecasts are future predictions and so are subject to error. As the demand for a product depends on various factors and all of them cannot be represented in a forecasting model, it is difficult to get accurate results from forecasting methods. Forecasting error is the difference between the forecasted demand for a particular period and the actual demand in that period. To find out how well the forecasts from a forecasting model fit in with the actual demand pattern, the average error of the model is calculated. Using forecast errors, managers can compare the effectiveness of various forecasting models and can plan their functional activities in a way that minimizes the effect of forecasting errors. Forecasting errors occur due to the omission of relevant variables during forecasting, ignoring or misinterpreting seasonal variations, etc. Following are the measures of forecast accuracy, also known as measures of forecasting error.

17.8.1 Mean Absolute Deviation (MAD)

MAD is used to measure the dispersion or variation of observed values around the expected values. It is the mean of errors made by the forecast over a period of time without the direction of error being considered i.e., it does not determine whether the forecast was an overestimate or underestimate.

MAD is calculated by adding up the differences between the forecast value and the actual demand for each period of time, and dividing the sum by the number of periods. MAD is therefore described as the sum of deviations divided by the number of data points.

$$\text{MAD} = \frac{1}{n}\sum_{t=1}^{n}\left|A_t - F_t\right|$$

Where At = Actual demand in the period t

Ft = Forecasted demand for the period t

n = Number of periods considered

$\left|A_t - F_t\right|$ = Absolute value of deviation

The lower the value of MAD, the more accurate the forecasts are.

17.8.2 Mean Square Error (MSE)

MSE is a measure of forecast accuracy in which the mean of the squares of deviations of forecast values from actual result is calculated.

$$\text{MSE} = \frac{1}{n}\sum_{t=1}^{n}\left(A_t - F_t\right)^2 .$$

From the equation, it can be seen that large errors are penalized more than the small ones because of squaring.

17.8.3 Mean Forecast Error (MFE)

Demand is a function of several independent variables. These variables cause random fluctuations in actual demand which affect the accuracy of the forecasts. To negate or smoothen the impact of these fluctuations, the accuracy of a forecasting model is calculated over several time periods. In such cases, MFE is a useful tool to find the accuracy of the forecasting methods. The calculation of MFE is similar to that of MAD except that absolute values are taken in MAD while real values are taken in MFE.

$$\text{MFE} = \frac{1}{n}\sum_{t=1}^{n}\left(A_t - F_t\right).$$

An accurate forecast model does not consistently overestimate or underestimate the demand. The closer the value of MFE to zero, the more accurate the result is.

17.8.4 Mean Absolute Percentage Error (MAPE)

MAD, MSE, and MFE provide information on the extent of error in the forecast model but not the relative errors. MAPE indicates the relative errors.

$$\text{MAPE} = \frac{100}{n}\sum_{t=1}^{n}\frac{\left|A_t - F_t\right|}{A_t}.$$

17.8.5 Tracking Signal

A tracking signal (TS) is a measure of accuracy that assesses the accuracy with which forecasting methods are able to predict demand. It is the ratio between the running sum of forecast errors (RSFE) and MAD. RSFE is the cumulative forecast error.

$$\text{TS} = \sum_{t=1}^{n}\frac{\left(Actual\,Demand - Forecast\,Demand\right)}{MAD} = \frac{\text{RSFE}}{\text{MAD}}$$

TS is calculated each time the forecast model is updated with new data. It indicates how much the forecast has been varying above or below the actual data for ‘n’ periods in terms of MAD. A positive TS indicates that forecasts are lower than the actual demand while a negative value indicates that the forecasting method is overestimating i.e., the forecast values are higher than the actual values. TS will be very close to zero if the forecasting model makes accurate predictions and will deviate significantly from zero if the forecasting model makes inaccurate predictions. The performance of a forecasting model is monitored over time. If TS crosses a range of predetermined limits, it would indicate that the model is no longer appropriate.

Illustration 6

Calculation of measures of forecasting accuracy from the demand forecast data and the actual demand data given in the first two columns of the table:

Demand Forecast **F**	Actual Demand **A**	Deviation **(A – F)**	Absolute Deviation $\|A-F\|$	Squared Deviations $(A-F)^2$	Percentage Error $\left(\frac{A-F}{A}\right)\times 100$	Absolute Percentage Error $\left(\frac{\|A-F\|}{A}\right)\times 100$
90	80	-10	10	100	-12.5	12.5
80	75	-5	5	25	-6.67	6.67
70	70	0	0	0	0	0
80	90	10	10	100	11.11	11.11
95	97	2	2	4	2.06	2.06
85	86	1	1	1	1.16	1.16
Total		**-2**	**28**	**230**	**-4.84**	**33.5**

MAD = $\frac{1}{n}\sum_{t=1}^{n}|A_t - F_t|$

From the table, $\sum_{t=1}^{n}|A_t - F_t| = 28$

Therefore, MAD = $\frac{1}{6} \times 28 = 4.67$

MSE = $\frac{1}{n}\sum_{t=1}^{n}(A_t - F_t)^2$

From the table, $\sum_{t=1}^{n}(A_t - F_t)^2 = 230$

Therefore, MSE = $\frac{1}{6} \times 230 = 38.33$

MFE = $\frac{1}{n}\sum_{t=1}^{n}(A_t - F_t)$

From the table, $\sum_{t=1}^{n}(A_t - F_t) = -2$

Therefore, MFE = $\frac{1}{6} \times (-2) = -0.33$

$$MAPE = \frac{100}{n}\sum_{t=1}^{n}\frac{|A_t - F_t|}{A_t}$$

Therefore, MAPE = 33.5/6 = 5.583

$$TS = \frac{RSFE}{MAD}$$

From the table, RSFE = ∑ (Actual Demand – Forecast Demand) = ∑ (A – F) = -2. From the above calculation, we have found that MAD = 4.67

Therefore, $TS = \frac{-2}{4.67} = -0.428$

Activity: From the information given in the table, calculate the measures of forecasting accuracy.

Demand Forecast	Actual Demand
110	105
100	95
85	87
90	95
93	95
96	99

Answer:

Check Your Progress - 5

29. The numerical difference between forecast demand and actual demand is called _____.

    a. Standard deviation

    b. Forecast error

    c. Forecast variance

    d. Forecast noise

30. Which of the following is **not** considered by operations managers before selecting a method for forecasting the future demand?
    a. Cost and accuracy
    b. Data availability
    c. Projected time span
    d. Plant capacity
31. Which of the following measures provide information on the extent of forecast error in relative terms?
    a. Mean absolute deviation
    b. Mean square error
    c. Mean forecast error
    d. Mean absolute percentage error
32. Short-range decisions vary from purchasing, job scheduling, and project assignment to machine scheduling. Which of the following forecasting methods can be used for such decisions?
    a. Exponential smoothing
    b. Linear regression analysis
    c. Multiple regression analysis
    d. Delphi method
33. Identify the forecasting method that can be used when data collection proves very expensive.
    a. Moving averages method
    b. Delphi method
    c. Regression analysis
    d. Exponential smoothing
34. Identify the relationship between cost of forecasting and accuracy of forecasting.
    a. Cost is directly proportional to extent of accuracy
    b. Cost is indirectly proportional to extent of accuracy
    c. Accuracy is independent of costs
    d. Cost is inversely proportional to extent of accuracy

Exercises

(Questions B to F)

Use the data given in the table below to answer the following **five** questions related to forecast errors.

Demand Forecast	Actual Demand
500	510
510	510
520	515
540	550
550	545

B. Calculate the Mean Absolute Deviation (MAD).

C. The Mean Square Error (MSE) for the given data is _____.

D. Calculate the mean forecast error.

E. Mean Absolute Percentage Error (MAPE) for the given data is _____.

F. Calculate the Tracking Signal (TS).

17.9 Monitoring and Controlling Forecasts Methods

Accurate forecasts are improbable because of the frequently fluctuating sales and demand patterns. Forecasts should represent and follow variations in the patterns being studied. The continuous monitoring of forecast models reduces the cost of forecast errors. An accurate forecast made with the help of an appropriate model allows an organization and its departments to plan its activities better. As all the departments work on the basis of the same forecast, their efforts become mutually supportive. The reasons for the failure of the forecasting systems should be identified and avoided. An appropriate forecasting model should be used and the results of the selected model should be regularly monitored. The appropriateness of the model depends on the nature of the data available. As the nature of data changes constantly, the forecasts should be periodically reviewed and revised. The performance of the forecasting model can be monitored in many ways. One method involves comparing the actual data with the forecasted values. Another method is the use of TS to check whether the forecasting model is overestimating or underestimating the forecasted value.

Tracking signal

A tracking signal is a measure of how well the forecast actually predicts. Its calculation is the ratio of RSFE to MAD. The larger the absolute tracking signal, the worse the forecast is performing. Adaptive smoothing sets limits to the tracking signal, and makes changes to its forecasting models when the tracking signal goes beyond those limits.

Focus forecasting

It is a forecasting method that tries a variety of computer models, and selects the one that is best for a particular application.

Demand forecasting is necessary for all business groups, from small to big, for tasks such as financial planning, customer success management, and supply chain control. It helps to preventive loss in clients, become more agile as they adapt changes. Exhibit 17.1 presents demand forecasting in the retail space regardless of their organization size.

Exhibit 17.1 Demand Forecasting in 2021

Why is demand forecasting important in retail — especially in 2021

The Covid situation left many retailers to adapt to new consumer demands and forced many organizations to make structural changes faster than they had previously planned. One of the weaknesses identified was lack of proper demand forecasting in the retail space, which led 29 major retailers across the U.S. to file for bankruptcy.

How is demand forecasting done accurately?

There are 3 models of demand forecasting commonly used in the retail space. The most accurate way to forecast demand is by using both internal and external data. Internal KPIs (key performance indicators) involve the historical number of sales, the amount spent on ads, and store traffic (website or foot). External metrics take into consideration emerging customer trends, industry changes, and competitors' doings.

1. *Qualitative demand forecasting:* The sources of qualitative data generally include industry authorities or experts, focus consumer groups or even competitive analysis. It is mostly based on gut-feeling or intuition instead of researched statistics, or collected facts. It is widely used and recommended for retail businesses with no historical data to analyse.
2. *Causal model:* The data is split into controllable factors, such as product pricing, marketing efforts and location, and uncontrollable factors like trends, competition, political reforms and even natural catastrophes. The causal model thus combines data and intuition, and mainly used by data-driven retailers with available metrics.
3. *Time series analysis:* The time series approach is more dependent on appropriate quantitative previous data at hand, hard facts and statistics. It is a mathematical approach and is considered rigid**.**

Common demand forecasting pitfalls and how to avoid them

The most common mistakes in retail demand forecasting and budget preparation are identified as : Overestimating sales , Ignoring historical data , Relying only on gut-feeling , Lack of flexibility , Using multiple spreadsheets , and Not updating forecasts regularly

https://competera.net/resources/articles/demand-forecasting-retail Feb 2021

17.10 Summary

- Forecasting forms the basis for operations management. It predicts the future demand for products or services.
- Six different components viz. – base demand, seasonal component, trends, cyclical component, promotions, and irregular component are associated with forecasting.

- The forecasting process involves five stages. They include understanding the objective of forecasting, integrating demand planning & forecasting, identifying the influencing factors, identifying the consumer segments, and determining the appropriate forecasting technique.
- Forecasting techniques are classified as qualitative methods, time-series methods, and causal methods.
- Qualitative methods are subjective, judgmental, and based on judgments and opinions. The Delphi method and the nominal group technique are some of the qualitative methods used by operations managers.
- Time-series forecasting methods assume that past data is a good indicator of the future. These models are used to forecast the demand for goods or services.
- Time series methods can be broadly divided into static forecasting methods and adaptive forecasting methods. Trend and seasonal components are assumed to change for every demand period in adaptive forecasting methods while they are assumed to remain constant over years in static forecasting methods.
- Some common time-series methods under adaptive forecasting include simple moving average, the weighted moving average, and exponential smoothing.
- Causal methods evaluate the relationship between different variables and their influence on each other. Forecasting methods like linear regression and multiple regression analysis are used by operations managers.
- Forecasts are future predictions and so are subject to error. Forecasting error is the difference between the forecasted demand for a particular period and the actual demand in that period.
- The different measures of forecast accuracy, also known as forecasting error are: Mean Absolute Deviation, Mean Square Error, Mean Forecast Error, Mean Absolute Percentage error, and Tracking Signal.
- An appropriate forecasting model should be used and the results of the selected model should be regularly monitored.

17.11 Glossary

Adaptive forecasting methods: These methods do not assume that the estimates of seasonal and trend component remain same over years. The seasonal and trend components are adjusted after every demand period (i.e., after every year if the demand forecasting is made every year).

Base demand: It is the average sales over a given period of time and this is applicable if the remaining components do not influence the demand.

Causal method: It evaluates the relationship between different variables and their influence on each other.

Cyclic component: It refers to repetitive changes in the demand patterns.

Delphi method: It is a coordinated and interactive method of forecasting future events on the basis of independent opinions and predictions. These opinions and predictions are made by an expert panel and reviewed by a competent mediator.

Demand forecasting process: It includes understanding the objective of forecasting, integrating demand planning & forecasting, identifying the influencing factors, identifying the consumer segments, and determining the appropriate forecasting technique.

Demand: The quantity of a product or service that buyers are able and willing to buy during a particular time period in a specific market environment.

Exponential smoothing method: It is based on the assumption that the most recent data is a better indicator of future trends than past data. It is useful when used on data characterized by seasonal tendencies. **Forecasting error: It is the** difference between the forecasted demand for a particular period and the actual demand in that period.

Forecasting: It predicts the future value of a variable and helps managers in **taking effective** decisions and planning their activities accordingly. It predicts the future demand for products or services and is used in process design, capacity and facilities planning, aggregate planning, scheduling, inventory management, etc.

Irregular component: It refers to all those variations in demand that cannot be attributed to the base demand, seasonal, trend, cyclic, and promotional factors.

Least square method: It is used to generate a regression model by assigning data to a single line. In this method, past demand data is used to form a linear model by regressing the data points to a single line.

Linear regression analysis: It establishes a relationship between a dependent variable, for which the future forecast is needed, and a group of other variables, known as independent variables, which influence the dependent variable.

Mean Absolute Deviation: It is used to measure the dispersion or variation of observed values around the expected values.

Mean Absolute Percentage Error: It provides information on the relative errors in the forecast model.

Mean Forecast Error: It is used to find the accuracy of the forecasting methods. It helps in negating the impact of the random fluctuations caused by independent variables.

Mean Square Error: It is a measure of forecast accuracy in which the mean of the squares of deviations of forecast values from actual result is calculated.

Nominal group technique: It is a structured problem solving and decision making method developed by Andrew Van de Ven.

Promotional component: It refers to the promotional activities taken up by marketers to increase the sales of their products.

Qualitative methods: These are based on judgments (regarding factors influencing demand) and opinions (about probability of the factors affecting the demand) and not on any mathematical models.

Regression: It refers to the functional relationship between two or more correlated variables.

Seasonal component: It is the repeated increase and decrease in demand during a particular period, say season and off-season.

Simple moving average: In this technique, demand is forecast on the basis of the average demand calculated from actual demand in the past.

Static forecasting methods: These methods assume that the estimates of seasonal component and trends do not vary every year. These estimates are determined from the available historical data and are projected to get the future demand estimate.

Time-series forecasting methods: These methods assume that past data is a good indicator of the future.

Tracking Signal: It is a measure of accuracy that assesses the accuracy with which forecasting methods are able to predict demand.

Trend component: It is the long term pattern of movement of demand over time, which could be positive, negative or neutral. A positive trend implies increasing demand while a negative trend implies decreasing demand.

Weighted moving average: In this technique, moving average is calculated by assigning weights. There is no set rule for calculating weights. Weights are assigned for a particular piece of data based on experience and trial and error methods.

17.12 Self-Assessment Exercises

1. Forecasting predicts the future value of a variable and helps managers in taking effective decisions and planning their activities accordingly. Explain the need for forecasting in operations.
2. Forecasting in operations management involves the use of quantitative and qualitative tools for estimating and predicting future demand for products and services. What are the different methods of forecasting? Explain in detail.
3. Selecting a good forecasting method maximizes accuracy and minimizes biases. What are the factors to be considered for selecting a forecasting system?
4. As demand for a product depends on various factors and all of them cannot be represented in a forecasting model, it is difficult to get accurate results from forecasting methods. Explain the various measures of forecasting accuracy.
5. An appropriate forecasting model should be used and the results of the model should be regularly monitored. Why is it necessary to monitor and control forecasts? Also explain how an organization can monitor and control forecasts.

6. Components of forecasting play a major role in estimating the forecast and the accuracy of the forecast depends on the estimation of these components in a major way. Examine the various forecasting components and importance in the forecasting process.
7. Explain the following:
   - Delphi method
   - Static forecasting methods
   - Adaptive forecasting methods
   - Linear regression

17.13 Suggested Readings/Reference Material

1. Nigel Slack, Michael Lewis, Mohita Gangwar Sharma, Operations Strategy, Pearson Education; Fifth Edition (8 May 2018)
2. Rob J Hyndman, George Athanasopoulos, Forecasting: Principles and Practice Paperback, Otexts; 3rd Edition, 31 May 2021
3. Stephan Kolassa, Enno Siemsen, Demand Forecasting for Managers Paperback – 17, Business Expert Press , August 2016
4. Dr. Mohd. Parvez , Dr. Pallav Gupta ,A Textbook on Manufacturing , IP Innovative Publication Pvt Ltd.; First Edition (15 June 2021)
5. Karl T. UlrichSteven D. EppingerMaria C. Yang, Product Design and Development , 7th Edition , McGraw Hill India, July 2020

17.14 Answers to Check Your Progress Questions

Following are the answers to the Check Your Progress questions given in the Unit.

1. (d) Increased locking up of working capital as inventory

Working capital is locked up as inventory, only when there is excess production. Excess production happens when demand is overestimated. However, when demand is underestimated, production will not be sufficient to meet the demand. Hence, there are greater chances of locking- up of working capital in the form of inventory as a consequence of overestimation of demand rather than underestimation.

2. (a) Short-term demand

Short-term demand estimates for individual products are generally very detailed, and are used to plan and schedule production operations. Long-term and medium-term demand forecasts are used for making location, layout and capacity decisions.

3. (d) Planning and controlling

Forecasting demand is most important to the planning and control functions of management. Forecasting is a step in the planning process where plans are developed based on forecasts. Under the control function, actual results are compared with that of planned standards (based on forecasts) and deviations are identified and corrected.

4. (d) Base demand

Base demand is the average of sales over a given time period. This figure can be taken as the right forecast if the demand for a product is not impacted by seasonal, trend, cyclic, or promotional factors.

5. (c) Cyclical component

Cyclic component refers to changes in demand patterns, which exist for more than a year. These changes could either show an upward or downward movement. A good example is the demand for luxury products that is linked with the business cycle. Sales usually increase during the boom phase and slow-down during recession.

6. (b) Promotional component

The sales of LG televisions doubled when LG increased its advertising budget. Here, LG gave more weightage to the promotional component to arrive at an aggressive estimate.

7. (c) The demand for camera mobile phones in India has increased steeply since 2001

The demand for camera mobile phones has shown a positive trend over a period of time. The long-term pattern is clearly visible in this example. The prices of gold increased and decreased, leading to rise and fall in demand. Hence, it is cyclical. The Airtel example highlights the promotional component, and the demand for wrist watches displays the irregular component.

8. (b) Delphi Method

Qualitative methods are judgmental and subjective in nature and are based on the estimates and opinions of individuals like experts in case of Delphi method and consumers in case of market research method.

9. (d) Understand objectives – identify influencing factors – identify customer segments – select forecasting technique

The forecasting process starts with understanding its objectives. Then, all the major influencing factors are identified. Next, all possible customer segments in the market are marked out and their impact on the forecast has to be understood. Finally, a suitable forecasting technique has to be selected.

10. (b) It is used for short-term forecasting.

The Delphi method is a coordinated and interactive method of forecasting future events on the basis of independent opinions and predictions. These opinions and predictions are made by an expert panel and reviewed by a competent mediator. The method is mostly used for long-term forecasting.

11. (d) iii-i-ii-iv

The Delphi method is a coordinated and interactive method of forecasting future events on the basis of independent opinions and predictions. The steps involved in the method are (a) selecting a group of experts, depending on the type of expertise required; (b) obtaining ideas and forecasts from all participants through a questionnaire; (c) summarizing the results and redistributing them along with appropriate new questions; and (d) summarizing the responses again and developing new questions on the basis of the responses.

12. (b) Nominal group technique

The nominal group technique is a structured problem solving and decision making method developed by Andrew Van de Ven. The various steps involved in the technique are – generation of ideas, round robin collection of ideas, discussion, preliminary voting, and final voting.

13. (b) Each idea is discussed in terms of their perceived importance, clarity, and logic.

The nominal group technique involves the following steps – (a) generation of ideas; (b) round robin collection of ideas; (c) discussion; (d) preliminary voting; and (e) final voting. Options (a) and (d) are steps involved in the Delphi method.

14. (b) Time series methods

Time series analysis can be categorized into two broad categories, based on the complexity involved: static and adaptive. Static methods assume that estimates of trend and seasonal components do not vary from year to year. Adaptive forecasting is an advanced form of time series analysis, where trend and seasonal components are adjusted after each demand observation.

15. (b) Static forecasting method

Static forecasting methods assume that estimates of trend and seasonal components do not vary from year to year. In this method, estimates of trend and seasonal components are determined based on historical data, which is projected to obtain future demand data.

16. (a) Time-series methods

Time-series methods uses past (historical) data to predict future demand.

17. (a) 1

Each element in the weighted moving average method is weighted by a factor and the sum of the weights should be equal to one.

18. (c) Trial & error

Certain weights are assigned to each element and managers use past experience (not future forecast) as well as the trial and error method to calculate these weights. The simple moving average method and exponential smoothing are other types of time series forecasting methods like the weighted forecasting method.

19. (c) Exponential smoothing

The exponential smoothing method is based on the assumption that the most recent data is a better indicator of future trends than past data. The method is useful when demand for products exhibit seasonal tendencies. The simple moving average method is effective only when a product does not experience fluctuation in demand over a period of time and past demand for the product was not seasonal. Delphi method is a qualitative forecasting method

20. (c) Larger data storage space

The advantages of the exponential smoothing method are: availability of standard software packages; relatively little data storage and computational requirements; accuracy of forecasts and easy understanding of results.

21. (a) Latest time period

In the exponential smoothing method, the demand for the most recent time period is given maximum weightage. The weights assigned to the preceding periods decrease exponentially.

22. (b) $\mathbf{WMA_{t+1}} = \sum_{t=1}^{n} C_t A_t$

The formula for calculating the weighted moving average is

$$WMA_{t+1} = \sum_{t=1}^{n} C_t A_t$$

Where,

WMA_{t+1} = Weighted moving average at the end of the time period t, A_t = Actual demand in time period t, C_t = Percentage weight given to time period t, $0 \leq C_t \leq 1$ and $C_1 + C_2 + C_3 + ... + C_t = 1$

23. (c) i and ii

Smoothing constant 'α' shows the effects of past demand on future demand forecasts and helps smoothen out the effects of any noise. But, α is not used to predict future trends in demand.

24. (d) i, ii, iii and iv

Demand for a product is influenced by conditions like the price of the product, price of substitutes, price and availability of complementary products, income of consumers, their tastes and preferences, and their reactions to changes in price.

25. (d) Extent of accuracy of demand forecasts

Demand is influenced by conditions like the price of a product, and the price of its substitute and complementary products; the incomes of customers, their expectations regarding price changes, and their tastes and preferences; the number of customers and their travel costs to the point of purchase (PoP). Accurate forecasts of demand help organizations to suitably increase or reduce production. Therefore accurate forecasts, as such, do not influence the demand for the product. They instead help the management in decision-making relating to product demand.

26. (d) Y intercept or constant value

In linear regression, the relationship between the dependent variable and a single independent variable is defined by a straight line.

Y = a + bX where, Y = Value of the dependent variable, X = Value of the independent variable, a = Y intercept (Constant value), and b = Slope of the line, 'a' is the Y-intercept and its value defines the point at which the regression line crosses the Y-axis.

27. (a) If the slope is positive, then the trend line increases positively

If the slope is positive, then the trend line increases positively. If the slope is negative, then the trend line decreases negatively.

28. (d) None of the above

No forecasting method, either qualitative, time series or causal, gives 100% accurate forecasts. They can only be highly accurate and 100% accuracy is not possible.

29. (b) Forecast error

A forecasting error is the difference between the forecasted demand for a particular period and the actual demand in that period.

30. (d) Plant capacity

Plant capacity is not a factor that is considered to forecast demand. Operations managers may increase or decrease the running capacity of the plant depending on the demand. Hence, it cannot be considered a factor that influences demand. Rather plant capacity is influenced by the demand.

31. (d) Mean absolute percentage error

Mean absolute percentage error (MAPE) provides information on the extent of forecast error in relative terms while the other measures provide information in absolute terms.

32. (a) Exponential smoothing

For short-range decisions like purchasing, job scheduling, project assignment and machine scheduling, time series techniques like moving averages (SMA or WMA) and exponential smoothing are the most preferred forecasting methods. Regression analysis is used in medium range forecasting as well as long term forecasting. Linear regression analysis is useful in long term forecasting of major occurrences and aggregate planning.

33. (b) Delphi method

Delphi method is used when no data is available or if it is too expensive to collect data. The other three methods primarily require data to forecast demand.

34. (a) Cost is directly proportional to extent of accuracy

Accuracy of forecasts depends on data availability. Forecasts can be more accurate when more data is available. Also, it is costly to collect huge volumes of data. Hence, to avoid these costs, some organizations use readily available data at low costs and end up with inaccurate forecasts. Thus, accurate forecasts come at a dearer price.

Unit 18

Allocating Resources to Strategic Alternatives

Structure

18.1 Introduction

In the previous unit, we have discussed how to monitor and control forecasts. We have learnt that an accurate forecast made with the help of an appropriate model allows an organization and its departments to plan its activities better. In this unit, we will discuss how to allocate resources to strategic alternatives.

Resource allocation is a strategic procedure under which an organization decides where and how to minimize the scarcity of resources in their operational process. A resource can be anything such as man, machine, money, material or natural resources which is essential for the operation of their business. As every organization wants to invest wisely in selection of strategic alternatives under the restricted resources, which must be based on the critical requirement and its possibility of implementation under resource constraint. The implementation of the strategic alternatives under the restricted resources investment must consider the specific set of strategies under their characteristics of, profit, loss and response effects in the decision-making process. In addition to this, the role of the resource allocation in strategic alternatives guided the management in execution of their planning under the available resource. Hence, it is very important to make a decision with the strategic decision for resource allocation making.

Organizations focus on achieving their objectives of revenue maximization, capacity utilization, cost minimization, etc. by making effective use of the resources available to them. Resources are effectively utilized when they are

allocated to strategic alternatives that result in maximum benefits. In operations, the term resources means manpower, machinery and equipment, capital, materials (raw, semi-finished, and finished), spares, components, floor space, and others that are required for production. Allocating these resources to strategic alternatives is a complex task for an organization as it operates under various constraints like limited availability of resources and time and the need to fulfill social obligations.

This unit will discuss allocation decisions in operations strategy. We will discuss linear programming in operations management. We shall then move on to discuss how to formulate linear programming problems, and how to find solution to such problems. Finally, we would discuss transportation problems in linear programming.

18.2 Objectives

By the end of this unit, students should be able to:

- Discuss the allocation decisions in operations strategy.
- Use linear programming in operations management.
- Compute linear programming problems.
- Determine the solution of linear programming problems.
- Assess the transportation problem in linear programming.

18.3 Allocation Decisions in Operations Strategy

Allocation decisions in operations strategy is design and promotion to accomplish the strategic goal by achieving the objective of the organization. This decision helps management in nature and importance of the capacity planning to match with the market demand. There are several methods for decision making related to resource allocation, such as formulate a linear programming, constraint optimization model, decision tree etc. However, constrained optimization model is one of the popular methods which has been applied for over 100 years. This method was initially used to for imping the work efficiency in different organizations. Nevertheless, currently is has a diverse application for the different sectors such as for capacity management, optimal allocation of resource, clinical decision making etc.

Constrained optimization models are mathematical models that enable operations managers to compute the amount of resources to be allocated to each of the strategic alternatives. A model represents the key features of an object, system, or a problem, uncluttered by the finer details.

18.3.1 Components of Constrained Optimization Models

Constrained optimization models consist of three major components: decision variables, objective functions, and constraints.

- **Decision variables –** Decision variables are the physical quantities that can be controlled. The optimal values of these variables will be determined after the problem has been solved through a constrained optimization model.
- **Objective functions –** The objective function states the criteria on which the alternatives are to be evaluated. It is a mathematical function of the decision variables and states what is to be maximized (profit, sales revenue) or minimized (cost, distance to travel).
- **Constraints –** Constraints are practical limitations that restrict the choice of the decision variables of a problem. These constraints are mathematically represented as: less than (<), greater than (>), less than equal to (≤), equal to (=), or greater than equal to (≥). A ≤ constraint imposes an upper limit on the function of decision variables like utilization of the available raw materials or machinery. A ≥ constraint provides the lower limit on some function of decision variables. For example, the constraints may specify that the number of units to be produced should exceed the demand of the product. An = constraint states that the number of products to be manufactured must be equal to a certain quantity. For example, a firm produces three products X, Y, and Z, generating a profit of Rs. 10, Rs. 12, and Rs. 16 respectively from them. The operations manager of the firm wants to identify the right mix of products to be produced that will maximize the firm's profits. Assume that the firm has the raw material to produce only 12 units of Y and the time to produce only 5 units of Z. The objective is to maximize profits by considering all the constraints involved in the problem. Decision variables are the number of products to be produced of each product X, Y, and Z. Therefore, the objective function is Maximize Z = 10X + 12Y + 16Z, which is subject to the constraints Y ≤ 12 and Z ≤ 5.

18.3.2 Merits and Demerits of Constrained Optimization Models

Following are the merits and demerits of the models:

Merits

- An optimization model reduces the number of feasible solutions to a convenient number.
- These models provide an optimal solution for the organization as a whole.
- Optimization models help a decision-maker perform a 'what-if' analysis (sensitivity analysis).
- Optimization models also help a decision-maker solve problems mathematically.

Demerits

- The solution obtained from the model may not always be the optimal solution for the real problem as these models do not consider non-quantifiable criteria.
- The models may sometimes provide a solution that cannot be put into practice.

Mathematical modeling is aptly used in many business situations and linear programming is one similar approach. Exhibit 18.1 presents how a mathematical model can help business deal with eve disruption too.

Exhibit 18.1: How A Mathematical Optimization Model Can Help Business Deal With Disruption

To deal with disruption and move to profitability companies must have AI tools that take into account business situations, challenges and constraints.

With mathematical optimization, one can

(1) Represent complex business problems as mathematical models, to accurately reflect company's present-day reality by adjustment

(2) Use these models, up-to-date data and a mathematical optimization to help tackle real-world business problems and make the best possible decisions.

A mathematical optimization model is like a digital twin of the real-world business situation; mirroring the actual business landscape, and facilitates encapsulation of unique business issues in a software environment. The three key features are *Decision Variables, Constraints and Business Objectives.*

How Can A Mathematical Optimization Model Help You Handle Disruption?

A mathematical optimization application gives you the power to: **Visualize, Analyze and Decide.**

The most valuable AI tools like mathematical optimization , run on up-to-date data, to encompass the present-day reality, and empower decision-makers to respond to disruption in the most efficient and effective manner possible.

https://www.forbes.com/sites/forbestechcouncil/2020/08/24/how-a-mathematical-optimization-model-can-help-your-business-deal-with-disruption/?sh=14f5b426617b, Aug 2020

Check Your Progress - 1

1. Constrained optimization models consist of three major components. Which of the following is **not** a component of these models?
   a. Decision variables
   b. Nature of demand
   c. Objective functions
   d. Constraints
2. Constrained optimization models are useful techniques enabling operations managers to compute the amount of resources to be allocated to each strategic alternative. Which of the following is **not** a benefit of using a constrained optimization model?
   a. Feasible solutions are reduced to manageable numbers
   b. Provides optimal solution for the whole organization

c. Enables decision-makers to perform what-if analysis

d. Provides optimal solutions that are always practical

3. If the objective function is a maximizing function, which of the following can be considered for it?

a. Profits

b. Inventory

c. Advertising expenditure

d. Production costs

18.4 Linear Programming in Operations Management

Linear programming is a mathematical, constrained optimization model used to maximize or minimize the linear functions of a large number of variables, subject to certain constraints. The technique is used to allocate resources to strategic alternatives to ensure that they are utilized optimally. The technique specifies how to use limited resources to meet a particular objective of maximizing profits or minimizing costs, when the resources have alternative uses. As the output per unit of resource and the return per unit of output are known, the resource combination that optimizes the organization's objectives can be determined. Linear programming is widely used in various industrial and military operations.

18.4.1 Assumptions of Linear Programming

The following are the assumptions made in linear programming models:

- **Proportionality –** In linear programming problems, it is assumed that the contribution of individual decision variables in the objective function is proportional to their numeric value. Assume that variable X_j represents the number of units produced of product j and C_j is the raw material quantity utilized in producing a unit of the product. Producing 10 units of Product j consumes 10 times the raw material quantity C_j. Hence, the raw material consumption per unit product produced remains constant. This means that economies of scale do not play a role in linear programming problems.
- **Additivity –** The objective function and constraints include several decision variables. It is assumed that the total value of the objective function and each constraint is equal to the sum of the individual contributions from each decision variable. This means that the model does not consider any synergistic or anti-synergistic effects among the decision variables while calculating the total value for the objective function.
- **Divisibility –** Decision variables can be non-negative and real numeric values within the range specified by the constraints. The problems that involve fractional values for the decision variables should also be solved in the same way in which problems with decision variables as integers are solved. To

avoid fractional values in the final solution, operations managers use integer programming, a technique similar to linear programming, that allows only integer values in the solution.

- **Certainty –** It is assumed that all the constants C_j, A_{ij} and B_i have certain values and the solution is optimal for the problem only when the coefficients of variables have certain or definite values.

18.4.2 Characteristics of Linear Programming

Operations managers should be able to identify the problems for which the linear programming model can be applied. These models can be applied to problems with following characteristics:

- There is a well-defined single objective.
- There are alternative courses of action to solve the problem.
- The decision variables are continuous and they can accept any non-negative or fractional values within the specified range.
- All factors that affect the objective function should be written in the form of constraints.
- The objective and the constraints are linear functions.

Refer Table 18.1 for an example demonstrating how an operations manager can determine whether the linear programming technique is applicable to a particular problem. After ensuring that the linear programming can be applied to the problem, the next step is to formulate the problem.

Table 18.1: Recognizing Linear Programming Problem

As a part of its strategic planning process, the Gulf Coast Company must determine the mix of its products to be manufactured next year. The company produces two principal product lines for the commercial construction industry: a line of powerful portable circular saws and a line of precision table saws. The product lines share the same production capacity and are sold through the same sales channels. Although some product variety does exist within each product line, the average profit is Rs. 5 for each circular saw and Rs. 7 for each table saw. The production capacity is constrained by the capacities of two facilities: fabrication and assembly. A maximum of 13 hours of fabrication capacity is available per month. Each circular saw requires 2 hours and each table saw requires 3 hours of fabrication respectively. There is a maximum of 12 hours of assembly capacity available per month. Each circular saw requires 3 hours and each table saw requires 2 hours of assembling respectively. How many circular saws and table saws should be produced monthly next year to maximize profit?

1. Is there a single managerial objective?

   Yes, the objective is to maximize the profit.

Contd….

2. Are there alternative courses of managerial actions?

   Yes, the management can decide to produce only circular saws or only table saws or any mix of circular and table saws.

3. Is the achievement of the objective constrained by resources?

   Yes, profits are constrained by the maximum number of fabrication and assembly hours available per month.

Check Your Progress - 2

4. Identify the mathematical technique used to determine the optimal utilization of resources in an organization.
   a. Exponential smoothing
   b. Regression analysis
   c. Linear programming
   d. Decision tree analysis
5. While constructing a linear programming problem, certain assumptions are made. Which of these is not such an assumption?
   a. Proportionality
   b. Optimality
   c. Divisibility
   d. Additivity
6. The concept of linear programming does not consider any synergetic effects among decision variables while calculating their total value for the objective function or the constraints they are associated with. This is part of which assumption of linear programming?
   a. Proportionality
   b. Additivity
   c. Divisibility
   d. Certainty
7. Identify from the following, the characteristics of a linear programming problem.
   i. There is a well-defined single objective.
   ii. The decision variables are continuous and they can accept any non-negative or fractional values within the specified range.
   iii. All factors that affect the objective function should be written in the form of constraints.
   iv. The objective and the constraints are linear functions.
   a. Only i, ii, and iii
   b. Only i, iii, and iv
   c. Only ii, iii, and iv
   d. i, ii, iii, and iv

18.5 Formulation of Linear Programming Problems

Formulating a linear programming problem is the most vital and difficult aspect of solving a real problem. Though there is no fixed pattern for formulating such problems, the following procedure can be followed:

1. **Identify the Decision Variables** – The decision-maker should identify the variables that are under his/her control. These variables, which can be changed in order to optimize the objective function, are called decision variables and they should be defined completely and precisely.
2. **Define the Objective Function** – The objective of the problem and the criteria for evaluating alternative solutions should be well defined. The objective is generally written as a linear function of the decision variables, each multiplied by an appropriate coefficient.
3. **Identify and Express Relevant Constraints** – After defining the decision variables and the objective function, the operations manager should identify the constraints that affect the objective function. This process of formulation is generally iterative. Refer Table 18.2 for the steps involved in formulating the linear programming model for the problem given in Table 18.1.

The general form of a linear programming problem is

Maximize $Z = C_1x_1 + C_2x_2 + ... + C_nx_n$

Subject to the constraints

$A_{11}\ x_1 + A_{12}\ x_2 + \ ... \ + A_{1n}\ x_n \leq b_1$

$A_{21}\ x_2 + A_{22}\ x_2 + ... + A_{2n}\ x_n \leq b_2$

$A_{m1}x_1 + A_{m2}x_2 + ... A_{mn}\ x_n \leq b_m$

$x_1, x_2, ... x_n \geq 0.$

Where

$x_1, x_2, x_3, ... x_n$ = a set of variables whose numerical values are to be determined

C_{ij}, A_{ij}, and b_i = numeric coefficients that are specified in the problem.

It can be observed that Z is a linear function of variables x_i, i.e, when the value of a variable x_i increases by unity, the value of Z increases by C_i.

The linear programming model can also be used to minimize the objective function. In such case, the constraints are written with a sign '≥'. The constraints can also be written as linear equalities. Thus, the resulting set of decision variables (values for the n variables, x_1, x_2, $x_3 ... x_n$) optimizes (either maximizes or minimizes) the objective function, subject to 'm' constraints and the non-negativity conditions of x_j variables.

Table 18.2: Formulating a Linear Programming Problem

The problem illustrated in Table 18.1 can be formulated as a linear programming problem by adopting the following steps:

Step 1: Identify the decision variables - The variables that can be altered to optimize the profit of the Gulf Coast Company are the number of circular saws and table saws that are to be manufactured.

Let x_1 and x_2 represent the number of circular saws and table saws manufactured per month respectively.

Step 2: Define the objective function - The objective of the problem is to maximize profits. Each circular saw contributes Rs. 5 and each table saw contributes Rs. 7 toward profits. Hence, the objective function may be defined as;

Maximize $Z = 5 x_1 + 7 x_2$

Step 3: Identify the relevant constraints: The goal of maximizing profit is constrained by the number of fabrication hours, and the number of assembly hours. These constraints can be expressed as;

$2x_1 + 3x_2 \leq$ □ □ □ (Each circular saw requires 2 hours of fabrication and each table saw requires 3 hours of fabrication, but the total fabrication hours available are only 13).

Similarly, $3x_1 + 2x_2 \leq 12$.

(Each circular saw requires 3 hours for assembling and each table saw requires 2 hours for assembling. But the total assembly hours available are only).

The other constraint is a non-negativity constraint. Since a negative number of saws cannot be manufactured, x_1 and $x_2 \geq 0$.

Thus, the linear programming problem is finally formulated as:

Maximize $Z = 5x_1 + 7x_2$

Subject to

$2x_1 + 3x_2 \leq 13$

$3x_1 + 2x_2 \leq 12$

$x_1, x_2 \geq 0$.

Formulate a linear programing problem: Minimization case

Consider a problem of special diet. Assume that person A is on a special diet and he/she wants to know that his/her daily requirement of five nutrients. The nutrients need50milligrams (mg) of vitamin C, 9,00 1000 mg of calcium, 17 mg of iron, 15mg of niacin, and 350 mg of magnesium. The person needs two supplements to choose from: Vega Vita and Happy Health. Vega Vita costs 18 cents per tablet, and Happy Health costs 25 cents per tablet.

Contd….

Vega Vita contains 18 mg of vitamin C, 450 mg of calcium, 8mg of iron, 2 mg of niacin, and 50 mg of magnesium. Happy Health contains 25 mg of vitamin C, 230mg of calcium, 2 mg of iron, 9 mg of niacin, and 80mg of magnesium. How many of each tablet should that person should take each day to meet his/her minimum requirements while spending the least amount of money?

The information requirement, costs and amount of nutrients is presented in the table below:

	Minimum total requirement	Vega vita	Happy health
Vitamin C	50 mg	18	25
Calcium	900 mg	450	230
Iron	17	8	2
Niacin	15	2	9
Magnesium	350	50	80
Cost per tablet		$0.18	$0.25

With the above listed information, it's time to solve for the number of tablets that will minimize his/her cost using linear programming

Step 1: Choose variables to based on which you can take decision, which is known as decision variable.

In this problem the number of tablets required helps us to take decision, hence decision variable will be number of tablets.

Let X represents the number of Vega Vita and Y represents the Number of Happy Health tablets.

Step 2: Formulate the objective function. The goal is to minimize the necessary cost. As mentioned, cost per tablet is given for Vega Vita costs 18 cents per tablet, and Happy Health costs 25 cents per tablet.

Objective function will be:

Minimize: 0.18*X + 0.25*Y

Step 3: Write constraints in terms of inequalities using the variables. The linear inequalities or constraints are all in terms of meeting the daily requirements. In this case each requirement has *at least* in its form, so in such situations use the *greater thanor equal to* symbol in the equations.

From the problem statement and above table, start formulating constraints:

Constraint 1: Vitamin C requirement, as mentioned minimum 50 mg of vitamin C is required

$18*X+25*Y \geq 50$

Contd….

Constraint 2: Calcium requirement, as mentioned minimum 900 mg of calcium is required

$450*X+230*Y \geq 900$

Constraint 3: Iron requirement, as mentioned minimum 17 mg of iron is required

$8*X+2*Y \geq 17$

Constraint 4: Niacin requirement, as mentioned minimum 15 mg of Niacin is required

$2*X+9*Y \geq 15$

Constraint 5: Magnesium requirement, as mentioned minimum 15 mg of Magnesium is required

$50*X+80*Y \geq 350$

Because, number of Vega Vita and Number of Happy Health tablets cannottake any negative number, so that at last we have to add a constraint which is known as non-negativity constraint:

$X \geq 0$ and $Y \geq 0$

Thus the, linear programming problem can be presented as;

Objective function:

Minimize: $0.18*X + 0.25*Y$

Subject to constraint:

$18*X+25*Y \geq 50$

$450*X+230*Y \geq 900$

$8*X+2*Y \geq 17$

$2*X+9*Y \geq 15$

$50*X+80*Y \geq 350$

$X \geq 0$ and $Y \geq 0$

Check Your Progress - 3

8. Identify the correct sequence of steps to formulate a linear programming problem.

   i. Identify the objective function
   ii. Identify decision variables
   iii. Identify constraints

   a. ii, i, and iii
   b. i, ii, and iii
   c. iii, ii, and i
   d. ii, iii, and i

Exercises

(Questions A to E)

Atul Tele-Products manufactures two mobile phone models using two different raw material grades. One (x) is of superior quality and the other (y) inferior (second grade). The profit per unit for the model using superior quality raw material is Rs.200 and that of the other is Rs150. The maximum demand for both telephones is 600 units. Production should not exceed demand and total machine time available for both types of telephones together is 650 hours. Besides, one superior quality mobile phone can be produced in two hours while one unit of inferior quality mobile phone can be produced every hour. Answer the following five questions using the information given above.

A. If Atul Tele-Products wants to maximize profits, what should be the objective function?

B. What is the constraint on machine hours?

C. What is the constraint on demand?

D. If the number of superior quality mobilephones produced in a month is 200 and inferior quality mobilephones is 200, then what is the maximum profit (in rupees) that the company gets?

E. What is the appropriate production combination for the two models to gain maximum profits?

18.6 Solution of Linear Programming Problems

After formulating a linear programming problem, the following methods can be used to solve them:

18.6.1 Graphical Method

The graphical method explains the process of obtaining a solution to a linear programming problem in a simple way. Following is the procedure:

- Formulate the linear programming problem by identifying the decision variables, the objective function and the constraints.
- Convert the inequality constraints to their equalities and plot them on a graph (in linear form).
- Using the inequalities in each constraint, determine the feasible region.
- Write down the corner points of the solution area. Substitute the values in the objective function. The optimum solution is obtained at any of these points.

  Note: The graph must be constructed in 'n' dimension, where 'n' is the number of decision variables. This should give you an idea about the complexity of this step if the number of decision variables increases. So that, two variables problems can be solved using graphical method.

Example: Maximize $Z = 700x_1 + 400x_2$

Subject to

$2x_1 + x_2 \leq 3{,}000$

$x_1 + 2x_2 \leq 4{,}000$

$x_1 + x_2 \leq 2500$

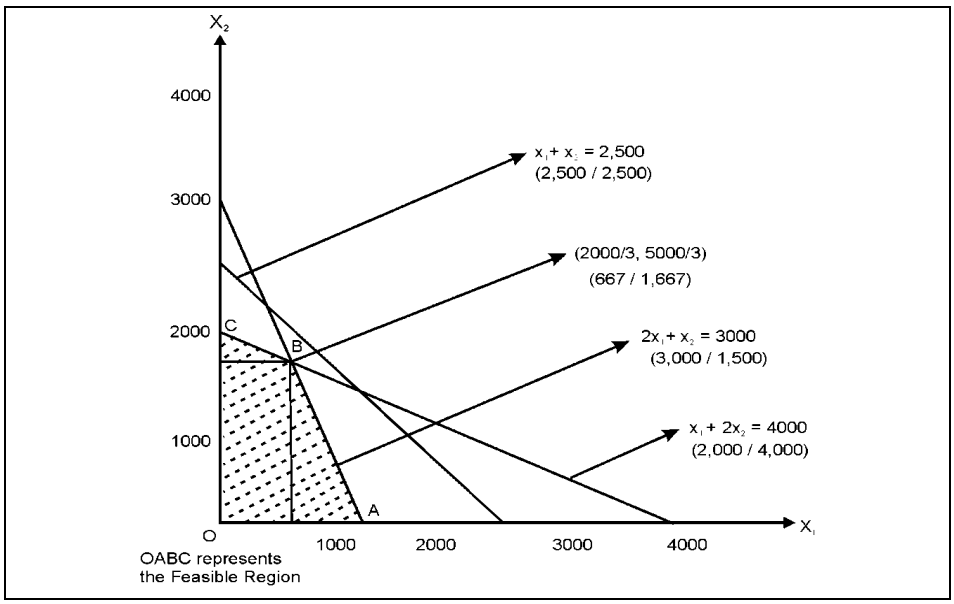
$x_1, x_2 \geq 0$

Find the optimum solution for the given problem using the graphical method.

Solution: Refer Figure 4.1 for the optimum solution to the given problem. The feasible solution area is OABC and the optimum solution is at the point (2000/3, 5000/3). The number of circular saws to be manufactured per month = 2000/3 = 667 and the number of table saws to be manufactured = 5000/3 = 1667. After representing the problem graphically, the operations manager should ensure that all the points in the feasible region satisfy all the linear programming constraints. The point at which the solution is optimum can also be found by moving the objective linear equation on the feasible region of the same graph. Starting at the origin or from any point, the objective function is moved parallel to itself in a direction away from the origin until the last point in the feasible region is reached. This is the point at which the value of the objective function is optimum.

The graphical method is applicable only to those problems in which a maximum of two decision variables are involved. Solving a graphical problem is tedious as the decision-maker has to identify the coordinates of all the extreme points in the feasible region, and then evaluate the objective function at each of them. Therefore, the simplex method is preferred to the graphical method.

Figure 18.1: Optimum Solution (Graphical method)



18.6.2 Simplex Method

The method overcomes the limitations of the graphical method and can be applied to problems with more than two decision variables. The algorithm for the simplex method is iterative in nature and determines the optimum solution for a problem in a systematic manner. The following points should be considered before solving a simplex problem:

- The value of the constraint in the right-hand side of each of the constraints should be non-negative. If not, it should be converted into a non-negative value.
- Each decision variable of the problem should be non-negative.
- Slack variables are introduced in each constraint equation as an idle source to convert inequalities to equalities.

Example: Maximize $Z = 8x + 6y$ subject to the constraints,

$4x + 2y \leq 60$

$2x + 4y \leq 48$

$x, y \geq 0$

Solution: The objective of the problem is to maximize the function $Z = 8x + 6y$

The constraints are:

$4x + 2y \leq 60$

$2x + 4y \leq 48$

$x, y \geq 0$

Adding slack variables S1, and S2 to the problem,

Maximize $Z = 8x + 6y + S_1 + S_2$

Subject to

$4x + 2y + S_1 = 60$

$2x + 4y + S_2 = 48$

$x, y, S_1, S_2 \geq 0$.

Refer to the initial simplex table. The highest element in the Index or $(C_j - Z_j)$ row is 8. Therefore, the x column becomes the key column and x is called the entering variable. The ratios are obtained by dividing the solution variables by the corresponding elements of the key column. The row with the minimum ratio is called the key row and the intersection element of the key row and the key column becomes the key element. Here, 'S_1' row is the key row and '4' is the key element. The variable S_1 is called the departing variable.

Initial Simplex Table:

C_j			8	6	0	0	Ratio
C_B	Basic Variables	Solution Variables	x	y	S_1	S_2	
0	S_1	60	4*	2	1	0	60/4 = 15
0	S_2	48	2	4	0	1	48/2 =24
Z_j			0	0	0	0	
$(C_j - Z_j)$			8	6	0	0	

** Key Element*

Now, the new simplex table is developed using the following procedure. All the values in the key row are divided by the key element to obtain the new values and the departing variable S_1 is replaced by the entering variable x.

Thus the values in the key row are:

15	1	0.5	0.25	0

The new values for each remaining row (other than the key row) can be computed by using the formula:

New row value =

= Old row value –

$$\frac{(\text{Corresponding value in the key row} \times \text{Corresponding value in the key column})}{\text{Key element}}$$

Thus the new values of 'S_2' row can be calculated as:

New Values:

New value for 48 = 48 – [(2×60)/4] = 18

New value for 2 = 2 – [(4×2)/4] = 0

New value for 4 = 4 – [(2×2)/4] = 3

New value for 0 = 0 – [(1×2)/4] = -0.5

New value for 1 = 1 – [(0×2)/4] = 1

Simplex Table 2:

C_j			8	6	0	0	Ratio
C_B	Basic Variables	Solution Variables	x	y	S_1	S_2	
8	x	15	1	0.5	0.25	0	15/0.5 = 30
0	S_2	18	0	3*	-0.5	1	18/3 = 6
Z_j			8	4	2	0	
$(C_j - Z_j)$			0	2	-2	0	

** Key Element*

Refer to simplex table 2. From the table, the largest positive value in the $(C_j - Z_j)$ row is 2 and it lies in the 'y' column. So, 'y' becomes the entering variable and the 'y' column becomes the key column. The ratios obtained by dividing the solution variables with the values in the key column are 30 and 6. Here, 6 is the minimum ratio. Therefore, the S_2 row becomes the key row and the variable S_2 becomes the departing variable. The key element is '3'. The departing variable is replaced by the entering variable y and the revised key row is obtained by dividing all the values in the key row by the key element.

Thus the values in the key row are:

6	0	1	-0.17	0.33

New Values:

New value for 15 = 15 – [(18×0.5)/3] = 12

New value for 1 = 1 – [(0×0.5)/3] = 1

New value for 0.5 = 0.5 – [(3×0.5)/3] = 0

New value for 0.25 = 0.25 – [(-0.5×0.5)/3] = 0.33

New value for 0 = 0 – [(1×0.5)/3] = - 0.17

Simplex Table 3:

C_j			**8**	**6**	**0**	**0**
C_B	**Basic Variables**	**Solution Variables**	**x**	**y**	**S_1**	**S_2**
8	X	12	1	0	0.33	-0.17
6	Y	6	0	1	-0.17	0.33
Z_j			8	6	1.62	0.62
$(C_j - Z_j)$			0	0	-1.62	-0.62

Refer to simplex table 3. Since there is no positive value in the $(C_j – Z_j)$ row of the table, the simplex table cannot be developed further. Therefore, the optimum solution is

x = 12, y = 6, and

The maximum value of the profit at this optimum solution is

$Z_{max} = 8x + 6y = 8(12) + 6(6) = 96 + 36 =$ Rs. 132

Activity:

Maximize Z = 10x + 12y, subject to

$x + y \leq 5$

$x \leq 2$

$y \leq 4$

$x, y \geq 0$

Answer:

Activity:

Minimize $Z = 80X_1 + 100X_2$, subject to

$80X_1 + 60X_2 \geq 1500$

$20X_1 + 90X_2 \geq 1200$

$X_1, X_2 \geq 0$

Answer:

Check Your Progress - 4

9. Where does the optimum solution lie on the graph in the graphical method of solving a linear programming problem?
   a. On the X axis
   b. On the Y axis
   c. In the feasible region
   d. Outside the feasible region
10. In the simplex method of solving a linear programming problem, the 'lesser than or equal to' inequality is converted into equality by _____ to the left hand side of the inequality.
   a. Adding a slack variable
   b. Subtracting a slack variable
   c. Adding a function
   d. Subtracting a function
11. Given below are the steps involved in the graphic method.
   i. Write down the corner points of the solution area, and substitute the values in the objective function.
   ii. Using the inequalities in each constraint, determine the feasible region.
   iii. Identify the decision variables, the objective function, and the constraints.
   iv. Convert the inequality constraints to the equalities and plot them on a graph.

   Identify the correct sequence of the above given steps.
   a. i-ii-iii-iv
   b. iii-iv-ii-i
   c. ii-iv-iii-i
   d. ii-i-iv-iii

12. Which of the following is not true regarding the points to be considered before solving a simplex problem?

    i. The value of the constraint on the right-hand side of each of the constraints should be negative.

    ii. Each decision variable of the problem should be non-negative.

    iii. Slack variables are introduced in each constraint equation as an idle source to convert equalities to inequalities.

    a. Only i and ii

    b. Only i and iii

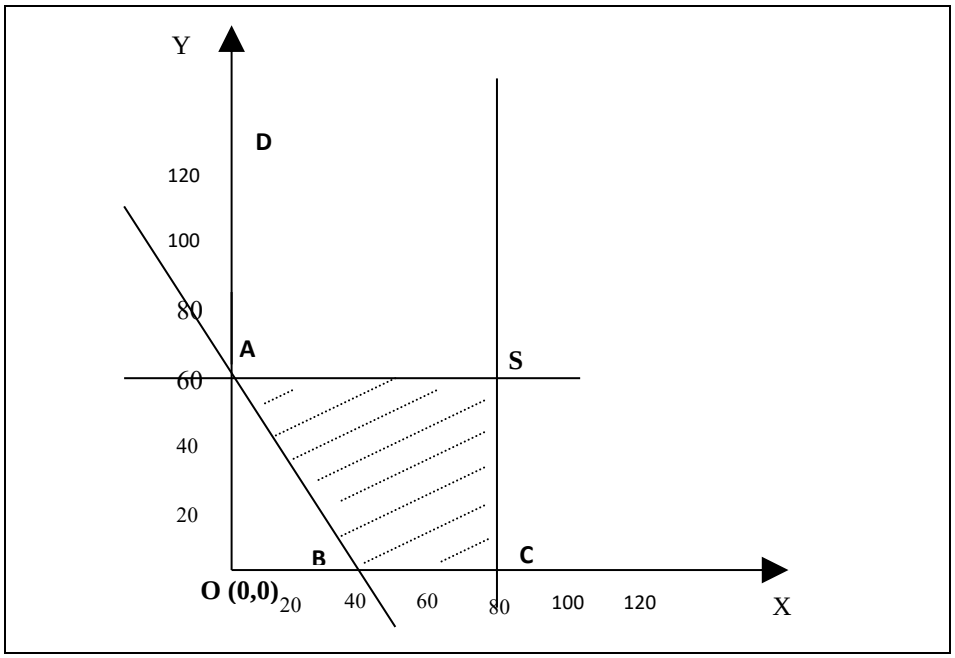
    c. Only ii and iii

    d. i, ii, and iii

Exercises

(Questions F to I)

The diagram represents the solution for a linear programming problem where ABCS is the feasible region. Use the diagram to answer the following four questions.



F. Identify the constraint represented by the line passing through the coordinates (40, 0) and (0,60).

G. Identify the corner points of the feasible region from the above diagram.

H. What is the equation of the line passing through (80,0)?

I. Find the minimum value of the objective function where minimize Z = 20x + 35y.

18.7 The Transportation Problem in Linear Programming

The transportation problem is a special case of linear programming. In the general form, it has a number of destinations. A certain quantity of commodity is produced at each origin and it is to be transported to destinations, each of which has certain requirements. The objective of the problem is to meet the requirements of the destination with supply from the sources and to ensure that the transportation costs are minimal. This method can be applied to situations which involve the physical movement of goods from plants to warehouses, warehouses to wholesalers, wholesalers to retailers, and from retailers to customers. These models can also be applied to production scheduling and inventory control. Such models are preferred as they reduce the computational effort involved in the simplex method. A transportation problem can be either balanced or unbalanced. It is said to be balanced if the quantity of goods produced is equal to the total requirement of all the warehouses. Otherwise it is considered as unbalanced. In an unbalanced problem, a dummy warehouse is added if the production capacity is more than the requirement; if the production capacity is less than the requirement a dummy origin is added with the desired quantity to make it a balanced one. The transportation problem can be formulated as a linear programming problem as shown:

X_{ij} is the quantity transported from plant P_i to a warehouse W_j. C_{ij} is the unit transportation cost from P_i to W_j. As the objective of a transportation problem is to minimize the total transportation cost, the objective function can be given as Minimize $Z = \sum C_{ij} X_{ij}$

Subject to the supply constraints, $\sum_{j=1}^{n} X_{ij} = S_i$ and $i = 1, 2...m$

Demand constraints, $\sum_{i=1}^{m} X_{ij} = D_j$ and $j = 1, 2...n$

Where

X_{ij} = the number of units shipped from origin i to destination j

C_{ij} = cost of shipping a unit from origin i to destination j

S_i = supply available at i^{th} origin

D_j = quantity demanded at j^{th} destination

And, $X_{ij} \geq 0$, for all i and j

Following is the procedure used for solving a transportation problem:

1. Define the objective function that is to be minimized.
2. Develop a transportation table with rows representing the origins and column representing the destinations.

3. Determine the initial feasible solution to the problem.
4. Examine whether the initial solution is feasible or not. A solution is feasible if the number of occupied cells in the solution is (m + n – 1) where 'm' is the number of origins and 'n' is the number of destinations.
5. Test the solution obtained for optimality by computing the opportunity costs associated with the unoccupied cells.
6. If the solution is not optimum, modify the allocation such that the transportation cost can be reduced further.

18.7.1 Developing an Initial Feasible Solution

Following are the methods used for developing an initial feasible solution:

North-West Corner Method

In this method, the allocation of products starts at the north-west corner (or the top left corner) of the transportation table. The procedure is given below:

1. Assign the maximum possible quantity of products to the top left corner cell of the transportation problem.
2. After the allocation, adjust the supply and demand numbers.
3. If the supply in the first row is exhausted, move down to the corresponding cell in the second row and assign the possible quantity of products to that cell. If the demand in the column is first satisfied, move horizontally to the next cell in the second column and assign the quantity of products.
4. Continue the same procedure till the entire requirements are met.
5. Check for feasibility of the solution.

Example: Given below is a table showing the distances between a factory and its warehouses and the demand at each warehouse. Find a solution for transporting the goods at the minimum cost for the given transportation problems using the North-West Corner method.

Factory/ Warehouse	W_1	W_2	W_3	W_4	W_5	Supply
F_1	17	7	8	14	11	150
F_2	9	11	12	7	9	250
F_3	13	6	15	10	10	300
Demand	100	120	140	160	180	

Solution: Following are the steps involved in solving the given problem using the North-West Corner method:

a) Assign the maximum number of goods that can be transported from 'F_1' to 'W_1', in the cell (F_1, W_1); i.e. 100.

b) Move to the cell (F_1, W_2) and assign the remaining goods being supplied by F_1 to W_2; i.e. 50.

c) Move to the cell (F_2, W_2) and assign the possible number of goods; i.e. 70.

d) Move to the cell (F_2, W_3) and assign the possible number of goods; i.e. 140.

e) Move to the cell (F_2, W_4) and assign the remaining goods being supplied by F_2 to W_4; i.e. 40.

f) Move to the cell (F_3, W_4) and assign the possible number of goods; i.e. 120.

g) The remaining goods are assigned to the cell (F_3, W_5); i.e. 180.

Factory/ Warehouse	W_1	W_2	W_3	W_4	W_5
F_1	100 (17)	50 (7)	(8)	(14)	(11)
F_2	(9)	70 (11)	140 (12)	40 (7)	(9)
F_3	(13)	(6)	(15)	120 (10)	180 (10)

The solution obtained is feasible as the number of occupied cells is 7, which is equal to the value of (m + n – 1). Transportation cost =

= (17×100) + (7 × 50) + (11 × 70) + (12 × 140) + (7 × 40) + (10 × 120) + (10 × 180) = Rs. 7780.

Least Cost Method

In this method, allocations are made on the basis of unit transportation costs. The following is the procedure:

1. Select the cell with the least unit transportation cost and allocate as many units as possible to that cell.
2. If the minimum cost exists in several cells, select a cell arbitrarily and assign the possible number of goods. Then consider the remaining cells of the same unit transportation cost.
3. Select a cell with the next higher unit transportation cost and continue the process till all requirements are met.

Example: Given below is a table showing the distances between a factory and its warehouses and demand at each warehouse. Find a solution for transporting the goods at the minimum cost for the given transportation problems using the least cost method.

Factory/Warehouse	W_1	W_2	W_3	W_4	Supply
F_1	2	3	11	7	6
F_2	1	0	6	1	1
F_3	5	8	15	9	10
Demand	7	5	3	2	

Solution: Following are the steps involved in solving the given problem using the least cost method:

a) Consider the cell which has the least unit cost of transportation; i.e. the cell (F_2, W_2) with a cost of Rs. 0.
b) The possible number of goods that can be assigned to the cell (F_2, W_2) is 1.
c) Move to that cell where the next higher unit cost of transportation exists and assign the possible number of goods.
d) Continue the process until all the goods have been assigned.

Factory/Warehouse	W_1	W_2	W_3	W_4
F_1	6 (2)	(3)	(11)	(7)
F_2	(1)	1 (0)	(6)	(1)
F_3	1 (5)	4 (8)	3 (15)	2 (9)

The solution obtained is feasible as the number of occupied cells is 6, which is equal to the value of (m + n – 1). Transportation cost = (2 × 6) + (5 × 1) + (0 × 1) + (8 × 4) + (15 × 3) + (9 × 2) = Rs. 112.

Vogel's Approximation Method

Vogel's Approximation Method is the most preferred method of the three methods as it results in an optimal or a near optimal solution. The following is the procedure:

1. Calculate a penalty for each row and column of the transportation table. The penalty for a row/column is the difference between the least cost and the next least cost of that row/column.
2. Identify the row or column with the largest penalty value; and assign the possible quantity of products to the cell with the least unit cost in that row or column. In case of a tie, select the row or column that has minimum cost.
3. Adjust the supply and requirement values after the allocation has been made.
4. Delete that row or column where the supply or requirement is zero.
5. Calculate the values of penalty to all the rows and column for the reduced transportation problem and repeat the procedure till the entire requirement has been met.

Example: Given below is a table showing the distances between a factory and its warehouses and the demand at each warehouse. Find the solution for transporting the goods at the minimum cost for the given transportation problems using the Vogel's approximation method.

Factory/Warehouse	W_1	W_2	W_3	W_4	W_5	Supply
F_1	20	28	32	55	70	50
F_2	48	36	40	44	25	100
F_3	35	55	22	45	48	150
Demand	100	70	50	40	40	300

Solution: Following are the steps involved in solving the given problem using the least cost method:

a) Compute the penalty for each row and column of the transportation problems. The penalty for the first row is (28 – 20) = 8. Similarly, the values of penalty for the second and the third row are 11 and 13 respectively. Similarly, the values of penalty for the first, second, third, fourth, and fifth columns are 15, 8, 10, 1, and 23 respectively.

b) Identify the row or column with the largest penalty value, i.e., the fifth column with a penalty value of 23.

c) The cell with the least cost is chosen and the possible number of goods is assigned to that cell. Therefore, assign 40 to the cell (F_2, W_5).

d) If the remaining row supply or column demand is zero, remove that row/column.

e) The process is repeated for the reduced transportation problem till the entire supply at the factories is assigned to satisfy the demand at different warehouses.

Factory/Warehouse	**W_1**	**W_2**	**W_3**	**W_4**	**W_5**
F_1	50(20)	(28)	(32)	(55)	(70)
F_2	(48)	60 (36)	(40)	(44)	40 (25)
F_3	50 (35)	10 (55)	50 (22)	40 (45)	(48)

The solution obtained is feasible as the number of occupied cells is 7, which is equal to the value of (m + n – 1).

Transportation cost = (20 × 50) + (36 × 60) + (25 × 40) + (35 × 50) + (55 × 10) + (22 × 50) + (45 × 40) = Rs. 9,360.

Stepping Stone Method

After computing the initial solution by using any of the three methods explained, the solution needs to be tested to see whether it is optimum or not by using the stepping stone method. In this method, the decision-maker calculates the net cost change obtained by introducing a unit of quantity in any of the unoccupied cells and checks for the possibility of improving the solution. This method describes the unused cells as 'water' and used cells as 'stones,' and the transportation refers to walking on a path of stones half submerged in the water. The following is the procedure:

1. Determine the initial basic solution by using any of the three methods: North-West method, Least Cost method or the Vogel Approximation method. Check the feasibility of the solution.
2. Select an unoccupied cell and trace a closed path starting from that cell using the most direct route through at least three occupied cells by making only horizontal or vertical moves.

3. Starting from the selected cell, assign + and – signs alternatively to the corner cells of the closed path.
4. Calculate the 'net cost change' of the selected cell by adding the unit cost values (with the signs assigned) along the closed path.
5. If the 'net cost change' is positive for all the unoccupied cells, we can conclude that the optimum solution has been arrived at.
6. If the 'net cost change' of an unoccupied cell is negative, the quantity of products to be assigned to that cell is equal to the minimum quantity of those cells with the minus sign in the closed path.
7. Repeat the procedure till the optimum solution has been reached.

Example: The initial feasible solution of a transportation problem is given below. Using the stepping stone method, test whether the solution is optimum. Calculate the optimum solution if the given solution is not the optimum one.

Factory/Warehouse	W1	W2	W3	W4
F1	(9)	(13)	25(1)	25(6)
F2	(12)	60(3)	(7)	10(9)
F3	30(6)	(14)	(10)	50(17)

Solution:

a) For the unoccupied cell (F_1, W_1);
The closed path is (F_1, W_1) – (F_1, W_4) – (F_3, W_4) – (F_3, W_1).
Net cost change = + 9 – 6 + 17 – 6 = 14 (+ve).
Therefore, nothing can be assigned to this cell.

b) For the unoccupied cell (F_1, W_2);
The closed path is, (F_1, W_2) – (F_1, W_4) – (F_2, W_4) – (F_2, W_2).
Net cost change = + 13 – 6 + 9 – 3 = 13 (+ve).
Therefore, nothing can be assigned to this cell.

c) For the unoccupied cell (F_2, W_1) ;
The closed path is, (F_2, W_1) – (F_2, W_4) – (F_3, W_4) – (F_3, W_1).
Net cost change = + 12 – 9 +17 – 6 = 14 (+ve).
Therefore, nothing can be assigned to this cell.

d) For the unoccupied cell (F_2, W_3);
The closed path is, (F_2, W_3) – (F_2, W_4) – (F_1, W_4) – (F_1, W_3).
Net cost change = + 7 – 9 + 6 – 1 = 3 (+ve).
Therefore, nothing can be assigned to this cell.

e) For the unoccupied cell (F_3, W_2);
The closed path is, (F_3, W_2) – (F_3, W_4) – (F_2, W_4) – (F_2, W_2).
Net cost change = + 14 – 17 + 9 – 3 = 3 (+ve).
Therefore, nothing can be assigned to this cell.

f) For the unoccupied cell (F_3, W_3);

The closed path is, (F_3, W_3) – (F_3, W_4) – (F_1, W_4) – (F_1, W_3).

Net cost change = + 10 – 17 +6 – 1 = - 2 (-ve).

So, some quantity of products should be assigned to this cell. Let us allocate 25 units to this cell taking it from cell (F_1, W_3). In the same way, reduce 25 units in cell (F_3, W_4) and add 25 units to cell (F_1, W_3). So the transportation table is changed to:

Factory/Warehouse	W1	W2	W3	W4	Supply
F1	(9)	(13)	(1)	50(6)	50
F2	(12)	60(3)	(7)	10(9)	70
F3	30(6)	(14)	25 (10)	25(17)	80
Demand	30	60	25	85	200

g) For the unoccupied cell (F_1, W_3);

The closed path is, (F_1, W_3) – (F_1, W_4) – (F_3, W_4) – (F_3, W_3).

Net cost change = + 1 – 6 + 17 – 10 = 2 (+ve).

Therefore, nothing can be assigned to this cell.

Therefore, this is the optimum solution for the given transportation problem.

Activity: A container manufacturer is considering locating two warehouses capable of absorbing 800 units (total) per week from the firm's plants. The unit transportation costs are shown below:

Plant Location	Warehouse		
	W1	W2	Supply
L1	100	120	400
L2	120	150	400
Demand	300	500	

Calculate the total transportation cost for an optimal allocation using the following methods:

- North-West Corner method
- Least Cost method
- Vogel's Approximation method

Also using the stepping stone method, verify if the solution obtained through the Vogel's approximation method is feasible or not.

Answer:

Activity: The initial feasible solution of a transportation problem is given below. Using the stepping stone method, test whether the solution is optimum. Calculate the optimum solution if the given solution is not the optimum one.

Factory/Warehouse	W1	W2	W3	W4
F1	(15)	10(18)	20(22)	(16)
F2	(15)	(19)	5(20)	35(14)
F3	20(13)	10(16)	(23)	(17)

Answer:

Activity: A company has to consider locating 6 warehouses capable of absorbing 700 units per week from the firm's plants. The unit transportation costs are given below:

Plant Location	W1	W2	W3	W4	W5	W6	Supply
F1	35	41	28	60	20	12	320
F2	14	21	28	30	15	24	180
F3	45	18	17	29	26	19	200
Demand	125	125	100	100	175	75	

Calculate the total transportation cost for an optimal allocation using the following methods:

- North-West Corner method
- Least Cost method
- Vogel's Approximation method

Answer:

Check Your Progress - 5

13. Identify the typical objective function of a transportation problem.
    a. To minimize the sum of all quantities transported
    b. To minimize the sum of all production costs
    c. To minimize the sum of all transportation costs
    d. All of the above
14. Given below are the steps involved in solving a transportation problem.
    i. If the solution is not optimum, modify the allocation such that the transportation cost can be reduced further.
    ii. Define the objective function that is to be minimized.
    iii. Determine the initial feasible solution to the problem.
    iv. Examine whether the initial solution is feasible or not.
    v. Develop a transportation table with rows representing the origins and columns representing the destinations.
    vi. Test the solution obtained for optimality by computing the opportunity costs associated with the unoccupied cells.

    Identify the correct sequence of the above given steps from the following options.
    a. iv-i-v-vi-iii-ii
    b. iii-iv-ii-vi-i-v
    c. ii-v-iii-iv-vi-i
    d. vi-ii-i-iv-iii-v
15. In the _____ method of obtaining initial feasible solution, allocations are made on the basis of unit transportation costs.
    a. Least cost method
    b. Vogel's approximation method
    c. North-West corner method
    d. Both (b) and (c)
16. Which among the following is **not** a method used in developing an initial feasible solution for a transportation problem?
    a. North-West corner method
    b. Least cost method
    c. Vogel's approximation method
    d. Stepping stone method

17. Of all the methods used to determine the initial feasible solution in transportation problems, which is said to be most effective?
    a. North-West corner method
    b. Lest cost method
    c. Vogel's approximation method
    d. Both (a) & (b)
18. In the _____ method, the decision maker calculates the net cost change obtained by introducing a unit of quantity in any of the unoccupied cells and checks for the possibility of improving the solution. This is done to test the solution obtained to see whether it is optimum or not.
    a. Least cost method
    b. Stepping stone method
    c. North-West corner method
    d. Vogel's approximation method

18.8 Summary

- The availability of resources are limited in nature. Therefore, operations managers should carefully assign these resources to strategic alternatives.
- To attain objectives of profit maximization or cost minimization, operations managers use constrained optimization models like linear programming.
- The first step in solving a problem using the linear programming model is to formulate the model.
- The linear programming problems can be solved by using the graphical method or the simplex method.
- The transportation model is a special case of linear programming and is applied to optimize the distribution system.
- In the transportation model, the initial feasible solution can be developed by using any of the three methods of North-West Corner method, Least cost method, and Vogel's Approximation method.
- To verify whether the solution obtained by these three methods is optimal or not, the stepping stone method is used.

18.9 Glossary

- **Constrained optimization models**: Mathematical models that enable operations managers to compute the amount of resources to be allocated to each of the strategic alternatives.
- **Constraints**: The practical limitations that restrict the choice of the decision variables of a problem. These constraints are mathematically represented as: less than (<), greater than (>), less than equal to (≤), equal to (=), or greater than equal to (≥).

- **Decision variables**: The physical quantities that can be controlled.
- **Least cost method**: Allocations are made on the basis of unit transportation costs.
- **Linear programming**: A mathematical, constrained optimization model used to maximize or minimize the linear functions of a large number of variables, subject to certain constraints. The technique is used to allocate resources to strategic alternatives to ensure that they are utilized optimally.
- **North-West Corner method**: The allocation of products starts at the north-west corner (or the top left corner) of the transportation table.
- **Objective functions**: The criteria on which the alternatives are to be evaluated.
- **Resources**: In operations, the term resources means manpower, machinery and equipment, capital, materials (raw, semi-finished, and finished), spares, components, floor space, and others that are required for production.
- **Stepping stone method**: This method is used to test whether the solution obtained by using North-West corner method, least cost method, or Vogel's approximation method is optimum or not.

18.10 Self-Assessment Exercises

1. Resources are effectively utilized by allocating them to strategic alternatives. Why is it important to allocate resources to strategic alternatives?
2. Constrained optimization models enable operations managers to compute the amount of resources to be allocated to each of the strategic alternatives. Explain the various components of the constrained optimization models. What are the advantages and disadvantages of using the models?
3. Linear programming is a constrained optimization model used to maximize or minimize the linear functions of a large number of variables, subject to certain constraints. Explain the linear programming model.
4. Formulating a linear programming problem is the most vital and difficult aspect of solving a real problem. Explain the process of formulating a linear programming problem.
5. After formulating a linear programming problem, the solution to the problem has to be found. What are the different methods of solving a linear programming problem?
6. A transportation problem is used to meet the requirements of a destination with supply from the sources and to ensure that the transportation costs are minimal. Explain the transportation problem of linear programming in detail.
7. After defining the objective function and developing a transportation table, the next step is to develop an initial feasible solution. Explain the various methods of developing an initial feasible solution in the transportation method of linear programming.

18.11 Suggested Readings/Reference Material

1. Nigel Slack, Michael Lewis, Mohita Gangwar Sharma, Operations Strategy, Pearson Education; Fifth edition (8 May 2018)
2. Rob J Hyndman, George Athanasopoulos, Forecasting: Principles and Practice Paperback, Otexts; 3rd ed. Edition, 31 May 2021
3. Stephan Kolassa, Enno Siemsen, Demand Forecasting for Managers Paperback – 17, Business Expert Press, August 2016
4. Dr. Mohd. Parvez, Dr. Pallav Gupta, A Textbook on Manufacturing, IP Innovative Publication Pvt Ltd.; First Edition (15 June 2021)
5. Karl T. Ulrich Steven D. Eppinger Maria C. Yang, Product Design and Development, 7th Edition, McGraw Hill India, July 2020

18.12 Answers to Check Your Progress Questions

Following are the answers to the Check Your Progress questions given in the Unit.

1. (b) Nature of demand

There are three elements of constrained optimization models: decision variables, objective functions and constraints.

2. (d) Provides optimal solutions that are always practical

One of the main drawbacks of these models is that the solution obtained may not always be the optimal one for the real problem. This is because these models do not take into account non-quantifiable criteria. Sometimes, models may provide a solution that cannot be put into practice.

3. (a) Profits

Profits can be maximized while inventory, advertising expenditure and production costs have to be minimized. Hence, profits can be considered for a maximizing function.

4. (c) Linear programming

Linear programming is used to allocate resources to strategic alternatives to ensure that they are utilized optimally. Exponential smoothing and regression analysis are methods to forecast demand for a product. Decision tree analysis is another operations technique helpful in decision-making like linear programming.

5. (b) Optimality

The assumptions that are made while constructing a linear programming problem are proportionality, additivity, divisibility, and certainty. Using these, problems are solved for achieving optimality, i.e., achieving an optimum solution. Hence, optimality is not an assumption but a result.

6. (b) Additivity

The objective function and constraints include several decision variables. Here, it is assumed that the total value of the objective function and each constraint is equal to the sum of individual contributions from each decision variable. It means that the model does not consider any synergistic or anti-synergistic effects among decision variables while calculating the total value for the objective function.

7. (d) i, ii, iii, and iv

Operations managers should be able to identify the problems for which the linear programming model can be applied. These models can be applied to problems with following characteristics – (a) There is a well-defined single objective; (b) There are alternative courses of action to solve the problem; (c) The decision variables are continuous and they can accept any non-negative or fractional values within the specified range; (d) All factors that affect the objective function should be written in the form of constraints; and (e) The objective and the constraints are linear functions.

8. (a) ii, i, and iii

The first and foremost step in formulating a linear programming problem is to identify the decision variables. Next is to identify the objective function, and finally comes identifying constraints present in the problem.

9. (c) In the feasible region

A feasible region is obtained when constraints are plotted on the graph. The optimum solution always lies in the feasible region.

10. (a) Adding a slack variable

A slack variable is always added to the left-hand side of the 'lesser than or equal to' inequality (constraint) to convert it to an equation.

11. (d) iii-iv-ii-i

The graphical method explains the process of obtaining a solution to a linear programming problem in a simple way. It consists of the following steps -- (a) Formulate the linear programming problem by identifying the decision variables, the objective function and the constraints; (b) Convert the inequality constraints to their equalities and plot them on a graph (in linear form); (c) Using the inequalities in each constraint, determine the feasible region; and (d) Write down the corner points of the solution area. Substitute the values in the objective function. The optimum solution is obtained at any of these points.

12. (b) Only i and iii

The following points should be considered before solving a simplex problem – (a) The value of the constraint in the right-hand side of each of the constraints should be non-negative. If not, it should be converted into a non-negative value; (b) Each decision variable of the problem should be non-negative; and (c) Slack variables are introduced in each constraint equation as an idle source to convert inequalities to equalities.

13. (c) To minimize the sum of all transportation costs

The objective of any transportation problem is to minimize the transportation costs.

14. (c) ii-v-iii-iv-vi-i

Following is the procedure used for solving a transportation problem – (a) Define the objective function that is to be minimized; (b) Develop a transportation table with rows representing the origins and columns representing the destinations; (c) Determine the initial feasible solution to the problem; (d) Examine whether the initial solution is feasible or not; (e) Test the solution obtained for optimality by computing the opportunity costs associated with the unoccupied cells; and (f) If the solution is not optimum, modify the allocation such that the transportation cost can be reduced further.

15. (a) Least cost method

The initial feasible solution to the transportation problem can be obtained using the North-West corner method, the least cost method, and the Vogel's approximation method. In the least cost method of obtaining initial feasible solution, allocations are made on the basis of unit transportation costs.

16. (d) Stepping stone method

While methods mentioned in options (a), (b), and (c) can be used to develop the initial feasible solution, the stepping stone method is used to test the solution for optimality.

17. (c) Vogel's approximation method

Vogel's Approximation Method is most effective and preferred over other methods as it usually results in an optimal or a near-optimal solution.

18. (b) Stepping stone method

After computing the initial solution, the solution needs to be tested to see whether it is optimum or not by using the stepping stone method. In this method, the decision-maker calculates the net cost change obtained by introducing a unit of quantity in any of the unoccupied cells and checks for the possibility of improving the solution.

Unit 19

Design of Production Processes

Structure

19.1 Introduction

In the last section of the previous unit, we have discussed the transportation problem in linear programming. We have learnt that the technique is a special case of linear programming that can be used to allocate resources to strategic alternatives to ensure that they are utilized optimally. In this unit, we will discuss how to design production processes.

Operations managers need to streamline their operations in order to compete in the highly competitive business environment. And apart from managing operations, they also have to manage the structure of the organization which includes number of plants, size of plants, their location, plant capacity, choice of equipment and process technology, production control, work force management, etc. Designing the production processes plays an important part in the structure of operations. In this unit, we will discuss the methodologies involved in planning and designing the production processes.

This unit will introduce you to process planning and design. We will discuss the major factors affecting process design decisions, and study the various types of process designs. We shall then move on to discuss process planning aids. Finally, we would discuss how to select the type of process design.

19.2 Objectives

By the end of this unit, students should be able to:

- Explain process planning and design.
- Discuss the major factors affecting process design decisions.
- Identify the various types of process designs.
- Assess the process planning aids.
- Select the type of process design.

19.3 Process Planning and Design

The complete delineation and description of the stages in the production process and the linkages between the stages that enable the production system to produce products or services is referred to as process planning and design. The products should meet quality standards and total costs should be within the budgeted limits. Process planning forms the basis for designing factory buildings and facility layouts and for selecting production equipment. It also has an impact on quality control, job design, and capacity in different facilities of the organization. Changes in market conditions, production capacity, and the availability of technologically superior equipment call for re-planning of the production processes. The selection of the process design depends on the operations strategy of the organization. The operations strategy is reflected in the production plan of the organization, which includes the planning and designing of the production processes. The product/service design also has an impact on the process design. An effective process design accommodates the product/service design. Both the process design and the product/service design should be compatible with each other. For process planning and design to be effective, it is necessary for operations managers to have a thorough knowledge of operations strategies, product/ service designs, technologies of the production system, and market conditions.

19.4 Major Factors affecting Process Design Decisions

Operations managers have to consider factors like the nature of demand, the degree of vertical integration, flexibility, degree of automation, and quality level and degree of customer contact while making process design decisions.

19.4.1 Nature of demand

Organizations have to produce products or services based on customer needs and preferences. They have to schedule their production so as to be able to meet the estimated future demand levels. Methods for estimating future demand consider factors like seasonality, growth trends, and other demand patterns that affect future demand levels.

Influence of demand patterns – The demand for a product rises or falls over a period of time and is influenced by factors like seasonal fluctuations that affect the design of the production process of the product. For example, the demand for products like air conditioners, refrigerators, etc. varies from season to season.

Influence of price level – The price-volume or the demand curve influences the process design. As customers are price-sensitive, they have a tendency to buy more of a product at a low price and less at a high price.

19.4.2 Degree of vertical integration

Vertical integration is the extent to which the production and the distribution chain is brought under the ownership of the organization. The degree of vertical integration determines the extent to which a product and its components are produced internally. Vertical integration is of two types: forward and backward. Forward integration is the expansion of ownership of production to the distribution chain, towards the market. And when it is expanded backward or toward the sources of supplies, it is referred to as backward integration. Vertical integration provides flexibility in manufacturing which results in increased profits due to centralized overheads, pooling of R&D and design efforts, and economies of scale. It reduces the over-dependency on the purchasing function. Vertical integration may not, however, always be desirable as the decision to produce the components instead of buying them could leave organizations stuck with outdated technology. Operations managers should evaluate the pros and cons of vertical integration before deciding on its implementation.

Activity: Sahasra is an agricultural food product company. The company takes the crop yield from the suppliers, purifies it, and packages it to sell it to the consumers through distributors. The company has realized that over the past few years, suppliers of other food product companies have been going in for forward integration. They have been acquiring food product companies and also their distributors. Sahasra's management is considering ways to fight competition from the suppliers, who have now become manufacturers and also distributors of food products. It has decided to integrate its operations with its suppliers and distributors. Should the company go in for both backward as well as forward integration? How should the company go about it? What factors should it take into consideration before deciding on integrating the operations?

Answer:

19.4.3 Flexibility

A flexible organization is one that responds quickly to the changing customer preferences or market conditions. Organizations have to be flexible in order to increase or maintain their market share. Flexibility can be broadly classified into:

Product/service flexibility – The ability of the production system to shift quickly from producing one product to another is referred to as product/service flexibility. This is necessary for organizations which produce different custom-designed products/ services in small lots using general-purpose equipment and multi-skilled employees.

Volume flexibility – The ability to increase or decrease production volumes rapidly in response to external changes is referred to as volume flexibility. This is necessary for organizations that produce products the demand for which fluctuates and for which it is uneconomical to maintain a high level of inventory.

19.4.4 Degree of automation

Operations managers in the past avoided automation due to the high costs involved in automating the processes and the difficulty in integrating them with other production processes. Of late, they have realized that automation can be used as a strategic weapon for competing with others. Though automation is expensive, it can reduce labor and related costs. Operations managers should decide on the degree of automation required for their production processes.

There are three types of automation- fixed automation, programmable automation and flexible automation.

Fixed automation: Fixed automation is the least flexible automation. It uses specialized and costly equipment for a fixed sequence of operations. The main advantage of fixed automation is high volume and lost cost. Its main limitation is minimal variety and high cost of incorporating any major changes in either the process or product.

Programmable automation: This automation involves the use of costly general-purpose equipment controlled by a computer program that provide specific details about each operations and sequence of operations. This automation is capable of producing a wide variety of low volume products in a small batch size at a lower cost.

Flexible automation: Flexible automation has evolved from programmable automation and involves equipment which is more customized than that of programmable automation. The main difference between these two automations is that flexible automation required much lesser changeover time as compared to programmable automation. This automation is capable of producing a wide variety of product without the need of producing in small batch size.

19.4.5 Quality level and degree of customer contact

The quality levels of a product or service decide its competitiveness in the market and affect the production process design at all stages of production. The desired level of quality has direct implications for the degree of automation and the extent of customer interaction and contact required for the production process.

Check Your Progress - 1

1. In the emerging business scenario, it has become essential for operations managers to manage the structure of their organizations, not merely their operations. What does the term 'structure' include?
   a. Number of plants and their individual capacities
   b. Choices in equipment and process technology
   c. Production control and workforce management
   d. All of the above
2. Which of the following forms the basis for designing factory buildings and facility layouts?
   a. Operations strategy
   b. Production planning
   c. Process planning
   d. Product design
3. Keeping other things constant, when the price of a commodity decreases, the demand for the commodity _____.
   a. Does not change
   b. Increases continuously
   c. Increases to a certain level
   d. Decreases
4. To attain its objective of profit maximization, L&T decided to acquire a mine in Australia thereby owning sources of raw material supplies. What is this process of expanding ownership called?
   a. Horizontal integration
   b. Forward integration
   c. Backward integration
   d. Diagonal integration
5. Organizations must be flexible to increase or maintain their market share. The ability of the production system to shift quickly from producing one product to another is called _____.
   a. Product flexibility
   b. Demand flexibility
   c. Volume flexibility
   d. Customer flexibility

6. When Hindustan Smelters Ltd. decided to manufacture lead ingots, the management decided to develop a process plan for the same. Which of the following factors should the operations manager at Hindustan Smelters Ltd. keep in mind while making process design decisions?
   a. Nature of demand
   b. Degree of vertical integration
   c. Employee skill level requirements
   d. Quality level and degree of customer contact
7. Demand for Pepsi cola is seasonal. It has a very high demand during summer and minimal demand during winter season. Which of the following assumptions is **false** with respect to the seasonality of demand of Pepsi cola?
   a. As demand is seasonal, Pepsi cola should not be produced in winter season.
   b. Pepsi cola should be produced throughout the year but with varying outputs.
   c. Finished goods inventory must be stocked to meet high demand during summer.
   d. All the above statements are false.
8. Identify which of the following is **not** an advantage of vertical integration.
   a. It reduces the over-dependency on the purchasing function.
   b. It helps decentralize the overheads.
   c. It helps in pooling the R&D and design efforts.
   d. It helps in achieving economies of scale
9. Assume that Eastside, a readymade garment retailer, acquired a textile mill to produce different fabrics. What kind of integration strategy has the retailer adopted?
   a. Forward integration
   b. Backward integration
   c. Horizontal integration
   d. Lateral integration

19.5 Types of Process Designs / Facilities Layout

Process design/ Layout refers to the arrangement of work centers, departments and equipment which facilitates smooth flow of material, work and information through the system.

The main purpose of process design/ layout is to fulfill following objective:

- To optimize the movements of material or workers
- To minimize transportation and material handling cost.
- To avoid bottlenecks

- To make efficient use of workers and space.
- To minimize customer service time or production time
- To ensure safety

Process designs are classified into product-focused, process-focused and fixed position group technology.

19.5.1 Product-focused

Product-focused production systems are used in production departments that are organized according to the type of product or service being produced. This kind of system is also called the *Line Flow Production System*. In this system, products or services tend to follow a linear path or a similar production sequence without backtracking or sidetracking. These systems require higher initial investments because of the use of specialized and expensive fixed position processing equipment in the production process. These systems produce a single or few varieties of products. Therefore, the variable costs remain low. Product-focused systems are used to produce bulk volumes and as the volume of output increases, the total cost of production decreases. The product layout helps in achieving a high degree of equipment and labor utilization which offsets the high equipment costs. The system is designed for the following three forms of production:

Discrete unit manufacturing – This refers to the production of distinct products like radio or television sets. These products can be made in batches and the system can be shifted to produce other products in similar batches.

Process manufacturing – This involves the movement of materials between operations such as screening, crushing, storing, mixing, milling, blending, cooking, fermenting, evaporating, and distilling. It is widely applied in the cement, paper, chemical, steel, and brewing industries.

Delivery of services – In this, services are administered to customers while they move in a queue or in a linear route. Waiters in restaurants use this system.

Some of the advantages of product focuses layouts are:

- Higher rate of output
- Lower unit cost due to high volume of production.
- Higher labor and machinery utilization
- Lower material handling cost because unit follows the same sequence of operation. Most of the time material handling is automated
- The scheduling and routing are established in the initial design of the layout and does not pose any challenges once the system is operating.

Some of the disadvantages of product focuses layouts are:

- The division of labor usually leads to repetitive and dull jobs that lacks job enrichment and lead to morale problems.
- Poorly skilled labors may not be focus upon the quality of output
- It is possible to implement individual incentive system
- The system is inflexible and cannot accommodate any changes in the volume or variety of output.
- The system is more prone to shutdowns caused by machinery or equipment breakdowns or labor absenteeism because of workstations are highly interdependent.

19.5.2 Process-focused

In process-focused production systems, all the operations are grouped according to the type of process. Process focused layout are designed to process product or provide service which requires a wide variety of processing requirement. Frequent adjustment to machinery and equipment is required to process variety of products leading to discontinuous work flow. This kind of system is also called an *intermittent production system* as production of products is carried out intermittently i.e. on a start and stop basis. It is also referred to as a *job shop* as the products move from one department to another in batches or jobs based on customers' orders. These systems produce small quantities or batches of different items on relatively general-purpose machinery. The diversity of customer orders is a primary criterion for adopting a process-focused production system. Processing equipment and personnel are located according to the functions and products flow through the facilities on irregular paths. The system allows sidetracking and backtracking in the product flow route.

Organizations use a mix of the above two approaches in order to cut production costs.

Some of the advantages of product focuses layouts are:

- The process focused layout can handle a wide range of processing requirement
- The systems are not vulnerable to machinery or equipment failure
- The cost of general purpose equipment used in process layout is less costly than the specialized equipment required in product focused layout
- It is possible to implement individual incentive system

Some of the disadvantages of product focuses layouts are:

- Scheduling and routing often poses challenges during operations.
- Lower utilization of machinery and equipment.

- Higher material handling cost than the product layout because the material handling is inefficient.
- Higher unit cost due to low volume of production.
- Job complexity may result in higher supervisory cost as compared to product layout.

Activity: Glad International is a company manufacturing 12 different consumer goods. The company currently adopts a product-focused production system, in which the production departments are organized based on the type of products the company produces. The company now wants to use a process-focused production system as well. If you were the operations manager of the company, what kind of suggestions would you make regarding the change that the management wants to undertake? Do you think the company can have the product focused and process focused production systems? Also give the management information regarding the different types of process designs and the conditions to be considered before selecting one.

Answer:

Fixed position layouts

In the fixed position layout the product remains stationary and material, equipment and labors are moved about as required. The products by virtue of its size, weight, bulk or some other factor makes it impossible or extremely difficult to move and hence requires this kind of arrangement. Fixed position layout are used in shipbuilding, production of large aircraft, space rockets and construction of buildings.

Combination Layouts

The three basic layouts discussed above are ideal models which are often altered to suit the requirement of a particular situation. The combination of these pure type layouts are not rare. For instance, the hospitals generally use the basic process arrangement, however, the intensive care units follow fixed position layout where the doctors, medical staffs, equipment and medicine are brought to the patient. Group technology and cellular manufacturing are some of the prominent combination layouts

19.5.3 Group Technology

In a group technology layout, dissimilar machines are grouped into work centers to work on products similar in shape and processing requirements. The layout is similar to both product and process layouts as each cell is dedicated to a limited range of products and is designed to perform a specific set of processes. This layout is also referred to as the parts classification and coding system. In group technology, each part manufactured is given a code which has several digits, each digit representing the physical characteristic of the part.

Benefits of Using Coding System in Group Technology:

- It is easy to route the parts in production as coding gives a clear picture of the steps involved in producing a part.
- Coding results in standardization of part designs.
- Parts with similar characteristics can be grouped into families as similar products are generally produced in similar ways, i.e., similar parts are made on the same machines using similar tools.

Cellular manufacturing: Cellular manufacturing is a type of group technology in which the total production area is divided into cells, each cell consisting of a group of similar machines. In cellular manufacturing, parts spend less time in waiting before they are processed. Hence, the in-process inventory levels get reduced. The benefit of cellular manufacturing is that the changeover times between batches of parts are greatly reduced as similar parts go to a particular cell. The costs of training workers can be reduced significantly, compared to a non-cellular group technology, the route of production through cells is more direct. This simplifies production planning and control (PPC), reduces the material handling costs, and also permits quicker shipment of products.

Service Layouts

Similar to manufacturing, service layouts can also be categorized into process, product or fixed position layout. In a fixed service layout, labor, material and equipment/machinery is brought to the customer’s premises. Interior decoration, appliance installation, copier services are some of the example of fixed position layout.

Process layout are mostly used in the services with high degree of variety in customers processing requirements. Vehicle repair centers, departmental stores, supermarkets and hospitals are example of process layout in services.Product layout is used when the service can be organized sequentially with all customers or work requiring the similar sequence. Cafeteria line and car wash are the example where product layout is used.

Although these layouts are common in manufacturing and services, the service layout requirement is different from manufacturing layout requirement. Degree

of customization and degree of customer contact are the two major factors in service layout. In case of high customization and high customer contact such as personal care and health care, the service environment is similar to job shop and it requires high personal care, high labor content and flexible equipment and a layout to facilitate. In case of high customization and low customer contact such as tailoring, costume designing, the layout should be arranged to facilitate equipment and workers. In case of low customization and high customer contact such as gas stations and supermarkets, self-service is a viable option where layout should consider ease of availing the service as well as customer service. In case of low customization and low customer contact, the customer and core services can be separated leading to high efficiency in operations. In case of highly standardized services such as online banking, ATM machine and web services, automation is the better option.

Activity: Kailash works for an electric tools company known for its quality management practices. Though it is satisfied overall with its performance, the company, feels that there are areas in which it could do even better. It wants to improve the quality of its products, reduce costs, and improve delivery. It aims to deliver what the customers needs in less lead-time. The company currently follows the batch system of manufacturing. To implement its goals, the company's management wants to go in for cellular manufacturing. Kailash has been asked by the management to research on cellular manufacturing and find ways in which the company can go about it. Assist Kailash in the process.

Answer:

Check Your Progress - 2

10. ABC Corp. to match the diversity in customer orders wants to produce products in small batches. Which type of process design would be economically feasible for ABC?
    a. Assembly line
    b. Continuous processing
    c. Discrete unit processing
    d. Job shop process

11. There are various types of process designs that are generally used by organizations. In which type of process design, products or services tend to flow along linear paths without backtracking or sidetracking?
    a. Product-focused systems
    b. Process-focused systems
    c. Group technology
    d. All the above
12. Steel and Chemical industries generally implement which type of process design?
    a. Discreet unit manufacturing
    b. Process manufacturing
    c. Job shop process
    d. Both a & c
13. Which of the following process design systems entail high initial investment?
    a. Product-focused systems
    b. Process-focused systems
    c. Group technology
    d. All of the above
14. What are the characteristics of process focused systems?
    i. Operations are grouped according to the type of processes
    ii. Production is performed on products on a start and stop basis
    iii. Products move from department to department in batches
    iv. Products are produced irrespective of diversity in customer orders
    - i and ii
    - iii and iv
    - i, ii, and iii
    - ii, iii, and iv
15. Which of the following is **not** an advantage of cellular manufacturing?
    a. Lesser machine changeover time
    b. Lower cost of training
    c. Reduction in material handling costs
    d. Increase in the in-process inventory
16. Which of the following is **not** true about a product-focused system?
    a. Presence of initial fixed costs
    b. Presence of low variable costs
    c. The total cost of production increases as the output volume increases
    d. Low variations in products

17. In what way is a typical product-focused system distinct when compared to a process focused system?
    a. Lower fixed costs and higher variable costs
    b. Higher fixed costs and lower variable costs
    c. Higher fixed costs and higher variable costs
    d. Lower fixed costs and lower variable costs

19.6 Process Planning Aids

Process planning is used for designing and implementing a work system that will produce the required quantity of goods and services. Assembly charts operation and route sheets and process charts are used to redesign, update, and evaluate production processes.

Assembly Charts – Assembly charts are used to obtain a general understanding of the entire process involved in producing products, which entails the assembling of a number of parts. They demonstrate the movement of components and sub-assemblies in the production process.

Operation and route sheets- Operations and route sheets specifies the process routing and operations for a part. This sheet conveys the information regarding the types of tools, equipment and specific operation required to complete the part.

Process Charts – Process charts are similar to assembly charts, except that they include information like a description of the various steps involved, their frequency of occurrence, the time each step takes, the distance traveled, etc. Non-productive activities like storage, delay and transport are also included.

19.7 Selecting the Type of Process Design

While selecting a production processing system, operations managers should consider the following factors:

19.7.1 Variety and Volume

The selection of a process design depends upon the product range i.e. the variety and volume of demand for each product model.

19.7.2 Investment

A product-focused production system requires huge investment. The system consists of inflexible equipment that is specialized for the product, and necessitates specific training of employees for producing the product. The choice of the production system is influenced by the capital investment required.

19.7.3 Economic Analysis

Each type of process design requires different amounts of funds for its implementation, as fixed and variable costs differ from one production system to

another. The higher the investments in fixed assets, the higher will be the fixed costs whereas the variable costs differ with the volume of products produced during a period. A process-focused system requires comparatively lower initial investment in fixed assets whereas the variable costs increase steeply with an increase in the volume of production. In cellular manufacturing, the fixed and the variable costs lie between both the product and process focused systems. Managers can select the process design based on the targeted production volume of the product if they have funds available.

A product is the output of a defined and designed process. Innovation, disruption type models are manifested at design level to deliver same products at lower costs and time schedules with higher quality or build totally new products with magnificent features. Exhibit 19.1 presents a product design process guide.

Exhibit 19.1: Product Design Process in 2021

The product design is the start of a new business way. An excellent product designing process combines both the business and user goals. It consists of four steps:

1. Product discovery (Business, user, and discovery goals, Stakeholder interviews)
2. User experience design (Information Architecture, Prototyping Wireframe)
3. User Interface Design (Design system, interface, Usability and likeability, Emotional design, responsive design)
4. User testing (In-depth interviewing of focus groups, usability testing, Usability reports)

However, the business world needs to keep an eye on likely product failure reasons

- The market may have been poorly priced or overpriced;
- Market research was conducted without the involvement of experts;
- The product was poorly designed;
- Focusing on only one idea and ignoring the ideas presented by the team;
- The product was misplaced;
- Poor customer analysis and understanding of their needs;
- Poor commercial communication;
- The company was production-oriented rather than consumer-oriented;
- The competition was poorly evaluated or was more aggressive than expected.

https://northell.design/blog/product-design-process-ultimate-guide-in-2021/ sept 2021

Check Your Progress - 3

18. Identify the statement(s) that **does not** hold true regarding assembly charts.
    a. They are used to obtain a general understanding of the entire process involved in producing products.
    b. They demonstrate the movement of components and sub-assemblies in the production process.
    c. They include information like a description of the various steps involved, their frequency of occurrence, the time each step takes, the distance traveled, etc.
    d. Both (a) and (b)
19. Which of the following factors should the operations manager consider while selecting a production processing system?
    a. The product range, i.e., the variety and volume of demand for each product model
    b. The capital investment required
    c. Economic viability of the process design
    d. All of the above

19.8 Measurement of Operations Performance:

That which is not measured cannot be managed. Measurement provides information about the status of a project or a process to know whether the planned objectives are under control. Operations encompass the entire value chain and performance entails the macro and micro level measurements. Organizations where ERP or other IT based systems are deployed, performance measurement is on-line. In other organizations, systems are implemented by identifying various metrics in line with operations objectives. Through a periodic review mechanism, performance is reviewed, deficiencies are analyzed and action plans are drawn for appropriate corrective and preventive actions. Even for discrete measurements, IT tools are available along with statistical techniques to identify shortfalls, localize root causes, find solutions and monitor improvements and effectiveness. To identify performance measures at every process level, global standards and benchmarks are available. The parameters generally monitored include quality, cycle times, costs, delivery performance, and process efficiency in terms of utilization, waste and productivity levels. Customer satisfaction is another measure but is usually not measured as a part of operations management but all customer feedback is routed to operations for necessary actions.

At organization level, both financial and non-financial performance is measured. The concept of Triple Bottom Line (TBL), which is adopted by many progressive companies, calls for measurement of financial, social and environmental

performance. Climate change concerns brought focus on environmental management and is now a part and parcel of organization performance measurement. With inclusivity as an agenda, many organizations are focusing on community development by way of Corporate Social Responsibility and Sustainability initiatives.

Balanced Score Card used by some companies suggests four perspectives, viz, financial, internal process, external customer and learning perspectives and expects measurements accordingly. Business Excellence Models like the Malcolm Baldridge National Quality Award (MBNQA), EFQM Business Excellence model and Deming Prize criteria insist on a holistic approach to performance measurement.

Thus a number of guidelines, standards, award criteria and templates are available for the measurement of organizational performance. The selection of the appropriate measures depend upon the complexity and nature of operations, the type of customers and the competitive environment. The measures chosen usually come under one or more of the Operational Performance parameters, namely, quality, cost, delivery and service.

19.9 Summary

- Process planning forms the basis for designing factory buildings and facility layouts.
- Various factors like the nature of demand, the degree of vertical integration, flexibility, etc., affect the process design decisions.
- Process designs can be classified as product-focused, process-focused, and group technology.
- Cellular manufacturing is a type of group technology in which the total production area is divided into cells, each cell consisting of a group of similar machines.
- Process planning is used for designing and implementing a work system that will produce the required quantity of goods and services.
- While selecting a production processing system, operations managers should consider various factors like variety and volume of demand for each product model, economic analysis of the process design etc.

19.10 Glossary

Assembly Charts: These are used to obtain a general understanding of the entire process involved in producing products, which entails the assembling of a number of parts.

Cellular manufacturing: A type of group technology in which the total production area is divided into cells, each cell consisting of a group of similar machines.

Discrete unit manufacturing: This refers to the production of distinct products that can be made in batches and the system can be shifted to produce other products in similar batches.

Forward and backward integration: Forward integration is the expansion of ownership of production to the distribution chain, towards the market. And when it is expanded backward or toward the sources of supplies, it is referred to as backward integration.

Process Charts: These include information like a description of the various steps involved, their frequency of occurrence, the time each step takes, the distance traveled, etc. **Process manufacturing**: This involves the movement of materials between operations such as screening, crushing, storing, mixing, milling, blending, cooking, fermenting, evaporati**ng, and distilling.**

Process-focused production system: In this, all the operations are grouped according to the type of process. It is also called an intermittent production system as production of products is carried out intermittently, i.e., on a start and stop basis. It is also referred to as a job shop as the products move from one department to another in batches or jobs based on customers' orders.

Product/service flexibility: The ability of the production system to shift quickly from producing one product to another.

Product-focused production system: It is used in production departments that are organized according to the type of product or service being produced. This kind of system is also called the line flow production system. In this system, products or services tend to follow a linear path or a similar production sequence without backtracking or sidetracking.

Vertical integration: It is the extent to which the production and the distribution chain is brought under the ownership of the organization

Volume flexibility: The ability to increase or decrease production volumes rapidly in response to external changes.

19.11 Self-Assessment Exercises

1. Designing the production processes plays an important part of the structure of the operations. What do you understand by process planning and design? Explain its importance.
2. Operations managers have to consider various factors while making process design decisions. What are the various factors affecting the decisions regarding process designs?
3. An organization has to decide on the type of process design which should be used to produce products or services. What are the different types of process designs? Explain in detail.

4. Process planning is used for designing and implementing a work system that will produce the required quantity of goods and services. What are the various planning aids that operations managers use to evaluate the production processes?
5. While selecting a production processing system, the operations managers should consider various factors. Explain in detail the factors to be considered for selection of the process design.

19.12 Suggested Readings/Reference Material

1. Nigel Slack, Michael Lewis, Mohita Gangwar Sharma, Operations Strategy, Pearson Education; Fifth edition (8 May 2018)
2. Rob J Hyndman, George Athanasopoulos, Forecasting: Principles and Practice Paperback, Otexts; 3rd ed. Edition, 31 May 2021
3. Stephan Kolassa, Enno Siemsen, Demand Forecasting for Managers Paperback – 17, Business Expert Press, August 2016
4. Dr. Mohd. Parvez, Dr. Pallav Gupta, A Textbook on Manufacturing , IP Innovative Publication Pvt Ltd.; First Edition (15 June 2021)
5. Karl T. UlrichSteven D. EppingerMaria C. Yang, Product Design and Development, 7th Edition , McGraw Hill India, July 2020

19.13 Answers to Check Your Progress Questions

Following are the answers to the Check Your Progress questions given in the Unit.

1. (d) All of the above

The term ‘structure’ has a broad meaning and includes issues like the number of plants, size of plants and their location, plant capacity, choice of equipment and process technology, production control, workforce management, etc.

2. (c) Process planning

Process planning forms the basis for designing factory buildings and facility layouts, and selecting production equipment. It also has a bearing on quality control, job design and capacity in different facilities of the organization.

3. (c) Increases to a certain level

As the price of a commodity decreases, demand increases as consumers buy more of the commodity. However, this is observed only until a certain point. Beyond this there will not be a proportionate increase in demand when prices are decreased.

4. **(c) Backward integration**

   Backward integration refers to gaining ownership over the source of raw material supplies and other materials required for production. Forward integration refers to gaining ownership of front-end activities (distribution networks through which products are distributed to the customers).

5. **Product flexibility**

   Product flexibility is the ability of the production system to shift quickly from producing one product to another. Some business strategies call for the production of many custom-designed products/services, in small lots. Product/service flexibility is required in such cases.

6. **(c) Employee skill level requirements**

   Operations managers generally make process-design decisions after taking into consideration several factors like nature of demand, degree of vertical integration, flexibility, degree of automation, quality level, and degree of customer contact. However, employee skill level requirements are dependent on the type of process plan decided and are considered only after developing the process plans.

7. **As demand is seasonal, Pepsi cola should not be produced in winter season.**

   Seasonality of demand is not directly linked to the production because companies focus on meeting annual demand. A company may bring down production capacity in the lean season and increase it to peak capacity during high demand. Also, production can be beefed up just before the season begins and inventory can be stocked to meet the excess demand.

8. **(b) It helps decentralize the overheads.**

   Vertical integration relieves an organization from excessive dependence on the purchasing function and provides flexibility in manufacturing. This can result in an increase in profits due to centralized overheads, pooling of R&D and design efforts, and economies of scale.

9. **(b) Backward integration**

   The raw material for a readymade garment retailer is fabrics. Hence, when Eastside acquired a textile mill, it gained ownership of a supplier leading to greater control over fabric production and supply. This is a backward integration strategy.

10. **(c) Discrete unit processing**

    Discrete unit manufacturing refers to the production of distinct products like radio or television sets. These products can be made in batches, and the system can be shifted to produce other products in similar batches. However,

assembly lines and continuous processing do not help in changing jobs. Job shop process is used to produce highly customized products where one job can be carried out at one point of time on one machine. The flexibility is minimal here. Hence, ABC must use discrete unit processing.

11. Product-focused systems

In this type of process design, products or services tend to flow along linear paths without backtracking or sidetracking. Items follow a similar production sequence, which can be anything from a pipeline (for oil) to an assembly line (for televisions or radios).

12. (b) Process manufacturing

Process manufacturing involves the movement of materials between different operations such as screening, crushing, storing, mixing, milling, blending, cooking, fermenting, evaporating and distilling. It is widely applied in the cement, plastic, paper, chemical, steel and brewing industries.

13. Product-focused systems

Product-focused systems require higher initial investments because of the use of specialized and expensive fixed position processing equipment in the production process.

14. (c) i, ii, and iii

In process-focused production systems, all operations are grouped according to the type of process. The system is also referred to as an intermittent production system because production is performed on products intermittently (that is on a start and stop basis). In this system, the products move from department to department in batches (jobs) that are usually determined by customers' orders. The diversity of customer orders is a primary criterion for adopting a process-focused production system.

15. (d) Increase in the in-process inventory

In cellular manufacturing, parts spend less time in waiting before they are processed. Hence, the in-process inventory levels get reduced.

16. (c) The total cost of production increases as the output volume increases

The product-focused systems require initial investments in the form of expensive machinery and this result in high initial fixed costs. But, as the product-focused systems produce a single or few varieties of products, the variable costs remain low. Product-focused systems are used to produce bulk volumes and as the volume of output increases, the total cost of production decreases.

17. **(b) Higher fixed costs and lower variable costs**

    Product focused systems need high initial costs (fixed costs); however operating variable costs remain low due to limited scope for product variety.

18. **(c) They include information like a description of the various steps involved, their frequency of occurrence, the time each step takes, the distance traveled, etc.**

    Assembly charts are used to obtain a general understanding of the entire process involved in producing products, which entails the assembling of a number of parts. Process charts include information like a description of the various steps involved, their frequency of occurrence, the time each step takes, the distance traveled, etc.

19. **(d) All of the above**

    While selecting a production processing system, operations managers should consider various factors like variety and volume of demand for each product model; the capital investment required; and the economic viability of the process design.

Project & Operations Management

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