WOLLO UNIVERSITY

BUSINESS AND ECONOMICS

DEPARTMENT OF MANAGEMENT

Distance Program

A Module for Distance and Continuing Education program for the Course Operation Management (MGMT 3152)

Credit Hours: 4

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May, 2020,

Dessie, Ethiopia

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Introduction to the Course

Dear student! Welcome to the course Operations management. Who comes to mind when you think of successful organizations? Perhaps Amazon.com for their level of customer service, Apple and Samsung for their innovative electronics, Toyota for their reliable automobiles,

Dell for their ability to customize PCs to individual requirements, Andersen Consulting for their brand image, Sky TV for the variety of television programs available, or McDonald's for sheer ubiquity, come to mind. These companies or others you may have thought of have come to dominate their market segments through offering the best goods or services, or have provided you with product or service that you think are excellent. High-recognition firms like these are heavily marketed and constantly brought to our attention. Marketing excitement alone isn't enough, however, to create excellence, organizations have to deliver on their promises or face disappointed (and, increasingly, litigious) customers.

In each case, the organization cannot be excellent without excellent operations. This is true for all organizations those that help and protect us, such as hospitals, fire, police, ambulance and coastguard emergency services; those who provide general public services, such as schools, public utilities, transportation, and universities; and those who provide goods and services to customers and other organizations. Operations are at the forefront of service delivery in each case. Successful operations management contributes substantially to organizational success or failure: operations is where, to use a metaphor, that is why Operations Management is called the heart of all management disciplines which bring competitive advantage and market focus for all business organization.

The aim of any service, public sector or retail or industrial operation is to deliver goods and services of the quality, quantity, cost and availability that will satisfy the customers' needs while at the same time making most effective use of resources. This can only be achieved by giving attention to the design of products, processes and work for employees, and through competent planning and control. This is what Operations Management is about. This module presents the fundamental principles of operations management in a different and structured way that is appropriate to the needs of contemporary Operations Managers, and students in this field. Operations management covers decision making in the organization, from top level management issues such as developing an operations strategy congruent with the company's business and marketing strategies, to the immediate control of operations. It is, therefore, more than operational management. Each chapter develops an understanding of the theory and practice of key operational concepts to enable delivery of the strategy.

Thus, the course covers Meaning of operations and production management, operations management as competitive weapon, design of an operations system, product and service design, quality and quality control, capacity planning, location decision, layout decision, aggregate planning, scheduling, work design, and time-based operations.

Course Objectives:

At the end of this course, students should be able to:

- Define operations management
- Identify operations strategy and competitiveness in the market place
- Examine the various types of facility location and layout decision
- Determine capacity planning for an organization
- Differentiate aggregate planning and scheduling
- Describe operations management, its scope and activities
- Describe the decision involved in designing and controlling the operations system.
- Apply selected quantitative tools, techniques and models in the analysis of decisions for the designing, planning and controlling of operation system.

Delivery Methods

The course is going to be imparted to distance students through individual assignment and tutorial offering.

Evaluation

Evaluation type	Frequency	Weight
1. Assignment (industry visit report)	One	35%
2. Tutorial attendance	Twice	5%
3. Final exam		60%
4. Total		100%

CHAPTER ONE

NATURE OF OPERATIONS MANAGEMENT

Chapter Objective

After completing this chapter, you will be able to:

- Define operations management;
- Explain the role of operations management in business;
- Describe decisions that operations managers make;
- Describe the differences between service and manufacturing operations;
- Identify major historical developments in operations management;
- Identify current trends in operations management;
- Define productivity and identify productivity measures; and
- Compute productivity measures.

1.1 Introduction

Dear students! Production is the creation of goods and services. The field of production management in the past focused almost exclusively on manufacturing management, with a heavy emphasis on the methods and techniques used in operating a factory. In recent years, the scope of production management has broadened considerably. Production concepts and techniques are applied to a wide range of activities and situations *outside* manufacturing; that is, in *services* such as health care, food service, recreation, banking, hotel management, retail sales, education, transportation, and government. This broadened scope has given the field the name *production/operations management*, or more simply, **operations management**, a term that more closely reflects the diverse nature of activities to which its concepts and techniques are applied.

1.2 Historical Development of Operation Management

1.2.1 The evolution of operations management

Operations management will now be now set within its rich historical context. Operations systems have always been in existence, although in different configurations to what one might expect to find today. Consider the ingenuity and industry involved in the following projects from history: Stonehenge on Salisbury Plain in the UK, the Egyptian Pyramids, the Axumite civilization, the Great Wall of China; the cities, aqueducts and roads of the Roman Empire; and the programmer of shipbuilding that that preceded the sailing of the Spanish Armada in 1588. These would not have materialized without some form of operations management thinking. Prior to 1750 products were manufactured quite differently than they are today. Most production took place in the homes, cottages and workshops of independently trading craftsmen, hence the descriptive terms we tend to use nowadays of ‘the cottage system’ and ‘cottage industries’. Production before the advent of the Industrial Revolution can be characterized by direct contact between producers and consumers, little mechanization, and the production of tailored, custom-made and personalized products.

The Industrial Revolution began in England in the 1700s. The early years can be summarized by two principal developments.

- Firstly there was a substitution of machine for human power.

The inventors of machine power gave rise to the ‘Process School’ and their activities gave rise to the various engineering professions. Foremost amongst the early process developers were

James Watt with the further development of the steam engine in 1764, Hargreaves and the ‘spinning jenny’, Cartwright’s ‘power loom’ and Maudsley’s ‘screw cutting lathe’. These inventions gave the Industrial Revolution its initial impetus. This led to the increasingly widespread establishment of the ‘factory system’.

Adam Smith’s ‘The Wealth of Nations’ (1776) proclaimed the benefits of the division and specialization of labour. Thus production activities came to be broken into small, specialized tasks assigned to workers through the manufacturing process, as opposed to the craftsman’s ‘make-complete’ approach. Increased capital intensity through mechanization and new ways of planning and controlling production workers using the principles of specialization led to a move away from the cottage system to that of factory working.

Two notable developments occurred in the nineteenth century.

First was the concept of *interchangeability*. One of the earliest attempts at production using interchangeable parts was successfully accomplished by Eli Whitney, a manufacturer of rifles for the US government, in 1790. Whitney designed and built on an assembly line such that parts were produced to tight tolerances enabling every part to fit right first time into a rifle assembly.

Previously parts were hand crafted, or else they were merely sorted from large batches to find those components that fitted together neatly or only required minor modifications. The concept of interchangeable parts was not easily grasped at first, but is today taken for granted. Consider where we would be without interchangeable light bulbs to holders and interchangeable discs for CD and DVD players.

Operations management in context By 1850 the cottage system was almost completely replaced by factory working. Industrial empires were being constructed by a new class of entrepreneurs and businessmen. By 1900 the high level of capital and production capacity, the expanded urban workforce, new Western markets and increasingly effective transportation and communication set the stage for the great production output explosion of the twentieth century.

Around 1900 the Scientific Management approach was being developed. This was initially based upon the pioneering work of Frederick Winslow Taylor (1856–1915), outlined in his ‘Principles of Scientific Management’ (Taylor, 1911). At the time, scientific management represented a concerted attack on the prevailing techniques used in the management of production.

The work of Taylor, Lilian and Frank Gilbreth and Henry Gantt, amongst others, was analytical and stressed the need for the development of standards for work and improved efficiency.

There was little consideration, however, of human feelings and most practitioners of scientific management viewed operators as mere extensions of their machines working within a wider, controlled system.

A number of ideas and techniques were developed at this time including piecework payment systems, time and motion study, the principles of efficiency, standards and management by exception. Criticized as scientific management is today, and in many respects rightly so, its development constituted the first truly rigorous and structured theory of production management to replace the more general and less analytical methods of factory management used before. Scientific management principles culminated with the opening of the Ford Motor Company’s Rouge plant in Detroit for the production of the Model-T (see Womack *et al.*, 1991 for an interesting discussion of the rationale behind early Ford systems). The Rouge plant featured standardized product designs using interchangeable parts; mass production;

Ford was an adapter rather than an inventor of scientific management and the Rouge plant formed the model for factory design and work organization well into the twentieth century (the approach now commonly known as ‘Fordism’). So, around the 1920s, was born the era of mass manufacture and standardized, low variety products.

In the 1930s an opposing view to scientific management began to emerge in which behavioral issues were identified as being important to productivity. Knowledge of psychological and sociological features started to influence job design, strategies for worker motivation and management control policies. The organizational forms of production and service companies have been influenced by a number of '*behaviouralist*' theories and practical approaches. A influential programme of research was the *Hawthorne Studies*. These were a series of experiments conducted by researchers from the Harvard Business School at Western Electric Company which illustrated the importance of human aspects in determining output and productivity (Roethlisberger and Dickson, 1939). These were later followed by further theories of motivation (see, e.g., Maslow, 1943; McGregor, 1960; Likert, 1961; and Herzberg, 1966).

A major contribution to our understanding of operations management was made by the *socio technologists*. On the evidence of development of work design in the British coal mining industry, the teamwork approach to flow line assembly at Philips, Eindhoven, and the experiences of Volvo in Sweden with autonomous group working, theorists (most predominantly from the Tavistock Institute) stressed the need for the parallel development of social and technical systems for the success of manufacturing operations (see, for example, Gyllenhammar, 1977). More recently the need for flexible labour to cope with changes in the market and environment has been identified. Atkinson's (1984) model of the 'Flexible Firm' was developed as an explanation of flexible organization. 'Post-Fordism' has developed whose supporters argue that the era of mass production is now over with more flexible and less rigid work structures now developing (Murray, 1989). The argument for

'Flexible Specialization' has been forwarded which sees a revival of craft-forms of production and the need for multi-skilling in the workforce (Piore and Sabel, 1984).

In terms of tools and techniques for operations management, we are indebted to the Operational Research (OR) School. OR originated in the military and defence organizations of Britain and the USA in the 1940s, during World War Two, to help solve problems of civilian defence, bombing strategies, transportation and military logistics. Subsequently OR theorists turned to business and industry to apply their techniques. The spin-offs for operations management included new quantitative techniques for stock control, scheduling, forecasting, project management, quality control, simulation and linear programming, to name just a few. In the 1950s OR was responsible for the introduction of computers in the management of operations. OR seeks to replace intuitive decision making for large complex problems with approaches that identify 'optimal' or 'best' solutions through analysis. It is in its logical and methodological approach that OR has contributed to the developing theory of operations management. (For more detail on the history and the techniques of OR see Duckworth *et al.*, 1977.)

Computers are now a highly cost effective and efficient means of managing and distributing the information required to plan and operate production and service systems. New computer technologies have also had a profound impact on the design of new processes with the development of flexible and programmable systems. Most significantly, the control afforded by computer technology has made possible the manufacture of products in mass volumes, but in a wide variety and, in some instances, configured to suit individual customer requirements.

There has been a vast expansion in the service and public sector industries since 1960. During this time manufacturers and service operators have come to realize that they have a considerable amount to learn from one another and that there are innumerable areas of similarity in the management of their operations. Note also that all products will have an element of tangible good and service associated with them. Conversely many services also have a tangible product content (e.g. a MacDonald's burger is both a physical 'good', but also is associated with a 'package of service elements'). The need to manage service operations efficiently and effectively is just as necessary as the productive management of manufacturing, especially as many service operations have high visibility for the customer or client. Many principles and concepts are transferable. For example, all service operators will have inventories to manage, quality to control, work to schedule, output to deliver, facilities to layout, employees to remunerate, and so on. However the lessons are not one-way. Manufacturing organizations are learning much in terms of customer care and service reliability and flexibility from the service industries.

The economic expansion of Asia, and most notably Japan, since the 1960s has stimulated the development of alternative operations theory and practice. New concepts such as 'just-in-time' management, new approaches to quality and design management (such as Total Quality and Kaizen) and the encapsulation of these principles into 'lean operations' were evolved, in Japan particularly. This served warning of a new challenge to the traditional Western manufacturers (Hayes and Wheelwright, 1984; Schonberger, 1986; Womack *et al*., 1990). Another recent development has been the shift in emphasis from techniques and systems at the operating level to a broader and more balanced strategic perspective of operations. The works of Wickham Skinner (1985) and Terry Hill (1985) in the area of strategic management and its interface with operations are germane here. As indicated earlier in this chapter, operations management is not merely confined to low level, limited impact decision making, but has a strategic consequence. Businesses that expect to remain competitive now need to grasp this, and ensure that product service and delivery live up to the claims made in advertising and promotion campaigns. In the 1800s the prime focus was the management of the factory, but as scientific management practices became more widespread in the early twentieth century the discipline changed from general factory management to production management. The wider operational perspective brought in by OR to encompass transportation, logistics and supply plus the growing need to incorporate and learn from service operations has broadened the discipline further. Now, subject to the influence of computer developments and Japanese approaches, the theory and practice of operations and quality management continues to develop under the influence of a number of different, and often conflicting, schools and paradigms.

For over two centuries operations and production management has been recognized as an important factor in a country’s economic growth

The traditional view of manufacturing management began in eighteenth century when **Adam Smith** recognized the economic benefits of specialization of labor. He recommended breaking of jobs down into subtasks and recognizes workers to specialized tasks in which they would become highly skilled and efficient. In the early twentieth century, F.W. Taylor implemented

Smith’s theories and developed scientific management. From then till 1930, many techniques were developed prevailing the traditional view. Brief information about the contributions to manufacturing management is shown in the Table 1.1.

Date	Contribution	Contributor
1776	Specialization of labour in manufacturing	Adam Smith
1799	Interchangeable parts, cost accounting	Eli Whitney and others
1832	Division of labour by skill; assignment of jobs by skill; basics of time study	Charles Babbage
1900	Scientific management time study and work study developed; dividing planning and doing of work	Frederick W. Taylor
1900	Motion of study of jobs	Frank B. Gilbreth
1901	Scheduling techniques for employees, machines jobs in manufacturing	Henry L. Gantt
1915	Economic lot sizes for inventory control	F.W. Harris

1927	Human relations; the Hawthorne studies	Elton Mayo
1931	Statistical inference applied to product quality: quality control charts	W.A. Shewart
1935	Statistical sampling applied to quality control: inspection sampling plans	H.F. Dodge &H.G. Roming
1940	Operations research applications in World War II	P.M. Blacker and others
1946	Digital computer	John Mauchlly and J.P. Eckert
1947	Linear programming	G.B. Dantzig, Williams & Others
1950	Mathematical programming, on-linear and stochastic processes	A. Charnes, W.W. Cooper & others
1951	Commercial digital computer: large-scale computationsAvailable	Sperry Univac
1960	Organizational behavior: continued study of people at work	L. Cummings, L. Porter
1970	Integrating operations into overall strategy and policy, Computer applications to manufacturing, Scheduling and control, Material requirement planning (MRP)	W. Skinner J. Orlicky and G. Wright
1980	Quality and productivity applications from Japan: robotics, CAD-CAM	W.E. Deming and J. Juran

Production management becomes the acceptable term from 1930s to 1950s. As F.W. Taylor's works become more widely known, managers developed techniques that focused on economic efficiency in manufacturing. Workers were studied in great detail to eliminate wasteful efforts and achieve greater efficiency. At the same time, psychologists, socialists and other social scientists began to study people and human behavior in the working environment. In addition, economists, mathematicians, and computer socialists contributed newer, more sophisticated analytical approaches. With the 1970s emerge two distinct changes in our views. The most obvious of these, reflected in the new name **operations management** was a shift in the service and manufacturing sectors of the economy. As service sector became more prominent, the change from 'production' to 'operations' emphasized the broadening of our field to service organizations. The second, more suitable change was the beginning of an emphasis on synthesis, rather than just analysis, in management practices.

1.2 What is Operations Management?

Dear students! In this section we will try to define operations management.

Operations management is the set of activities that creates goods and services through the transformation of inputs into outputs. Activities creating goods and services take place in all organizations (firms), the production activities that create goods are usually quite obvious. In them, we can see the creation of a tangible product such as cement or cloth.

In organizations that do not create physical products, the production function may be less obvious. An example is the transformation that takes place at a bank, hospital, airline, or college. Regardless of whether the end product is good or service the production activities that go on in the organization are often referred to as operations or *operations management.*

An operation is responsible for supplying the product or service of the organization. Operations managers make decisions regarding the operations function and its connection with other functions.

Every business is managed through three major functions: finance, marketing, and operations management. Figure 1.1 illustrates this by showing that the vice presidents of each of these functions reports directly to the president or CEO of the company. Other business functions—such as accounting, purchasing, human resources, and engineering—support these three major functions. *Finance* is the function responsible for managing cash flow, current assets, and capital investments. *Marketing* is responsible for sales, generating customer demand, and understanding customer wants and needs. Most of us have some idea of what finance and marketing are about, but what does operations management do?

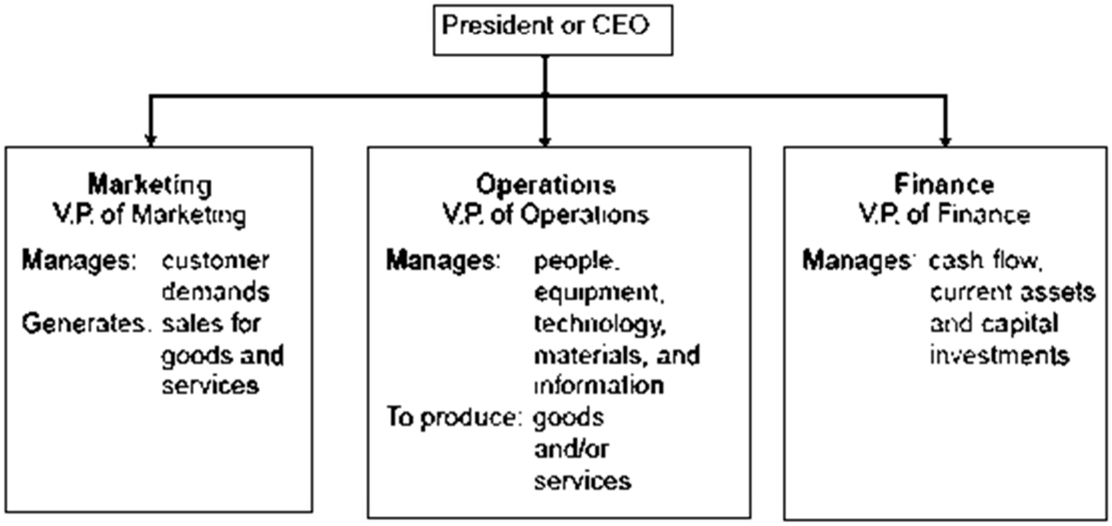

FIGURE 1-1 Organizational chart showing the three major business functions

TABLE 15–1 Components of Some Typical Production Systems

Production System	Primary Inputs	Purpose of Conversion Subsystem	Outputs
1. Pet food factory	Grain, water, fish meal, personnel, tools, machines, paper bags, cans, buildings, utilities	Converts raw materials into finished goods	Pet food products
2. Public accounting firm	Supplies, personnel, information, computers, buildings, office furniture, machines, utilities	Attracts customers, compiles data, supplies management, information, computes taxes	Management information, tax services, and audited financial statements
3. College or university	Students, books, supplies, personnel, buildings, utilities	Transmits information and develops skills and knowledge via lectures, exams, computerized instruction	Educated persons

Source: Adapted from Norman Gaither, *Production and Operations Management*, 5th ed. (Fort Worth, TX: The Dryden Press, 1992), pp. 22–23.

Operations management is the study of decision-making in the operations function.

Three points in this definition deserve emphasis:

1. **Decisions-** Decision-making is an important element of operations management. There are four major decision responsibilities in operations management.

- Process
- Quality
- Capacity
- Inventory

2. **Function-** Operations is a major function in any organization, along with marketing and finance.

- The operations function is responsible for supplying or producing products and services for the business.

- In a manufacturing company, the operations function is typically called the manufacturing or production department.
- In service organizations, the operations function is called the operations department.
- In general the term "operations" refers to the function that produces goods or services.

3. **System-** The transformation systems produce goods and services. Using the systems view, we consider operations managers as managers of the conversion process in the firm.

   Operations management is defined as the ***design***, ***operation***, and ***improvement*** of the *production system* that creates the firm's primary *products (goods* and/or *services)*.

   It is a set of activities that creates goods and services through the transformation of inputs into outputs. The set of interrelated management activities, which are involved in manufacturing certain products, is called as **production management**. If the same concept is extended to services management, then the corresponding set of management activities is called as **operations management**

1.3 Components of transformation model

1. Inputs

- Some inputs are used up in the process of creation of goods and services, while others play a part in the creation process but are not used up. To distinguish between these inputs resources, usually classified as

❖ Transformed resources for example material, information

❖ Transforming resource example staffs, land, building, machines, and equipments

2. Out puts

Output is goods and services resulting from the transformation process. In these OM is responsible for minimizing wastes, protecting the health and safety of the employees and ethical behavior in relation to social impact of transformation process.

3. Transformation process

Is any activity or group of activities that takes one or more inputs and transform and add values to them and provides out puts for customers and clients. Transformation process includes

- Change in physical characteristics of materials
- Change in location of materials, information, and customers

  Example Airline service, information exchange and etc.
- Change in ownership of materials or information

- Storage and accommodation of materials or customers
- Change in the process or form of information
- Change in physiological or psychological state of customers

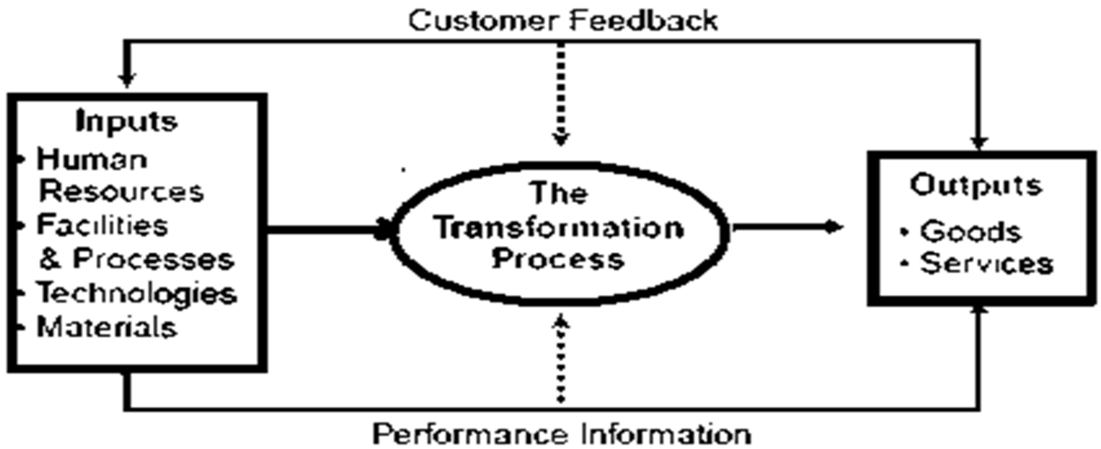

FIGURE 1-2 The transformation process

4. Feed back

Information used to control the operation process by adjusting the inputs and transformation process that are used to achieve desired out comes. It can come from both internal and external sources

- Internal sources : like testing, evaluation, and continuously improving production process
- External source: it includes those who supply raw materials , customers, government and other

5. Boundary of the system

Exercise 1.1

1. Explain what is meant by operations management.
2. Briefly trace the history of operation management. What happed to the development of operations research after 1970s?

My dear students let us now ponder over the role of OM for organizations and discuss difference between manufacturing and service organization.

1.4 The role of OM

The business function that plan, organizes, coordinates and controls the resource needed to produce a company's goods and service. OM involves managing people, equipment, technology, information and many other resources. To transform a company's input into output (finished products) In general, OM is responsible for orchestrating all the resource needed to produce the final product and service. This includes

- Designing the product or service
- Deciding what resources are needed
- Arranging schedules, equipment, and other facilities
- Managing inventory
- Controlling quality
- Designing jobs to make sub products
- Designing work methods

1.5 Manufacturing Operations and Service Operations

An operation is defined in terms of the mission it serves for the organization, technology it employs and the human and managerial processes it involves. Operations in an organization can be categorized into manufacturing operations and service operations. Manufacturing operations is a conversion process that includes manufacturing yields a tangible output: a product, whereas, a conversion process that includes service yields an intangible output: a deed, a performance, an effort.

Distinction between Manufacturing Operations and Service Operations

Following characteristics can be considered for distinguishing manufacturing operations with service operations:

1. Tangible/Intangible nature of output
2. Consumption of output
3. Nature of work (job)
4. Degree of customer contact
5. Customer participation in conversion
6. Measurement of performance.

Manufacturing is characterized by tangible outputs (products), outputs that customers consume overtime, jobs that use less labour and more equipment, little customer contact, no customer participation in the conversion process (in production), and sophisticated methods for measuring production activities and resource consumption as product are made.

Service is characterized by intangible outputs, outputs that customers consumes immediately, jobs that use more labour and less equipment, direct consumer contact, frequent customer participation in the conversion process, and elementary methods for measuring conversion activities and resource consumption. Some services are equipment based namely rail-road services, telephone services and some are people based namely tax consultant services, hair styling

For example, a manufacturer of furniture may also provide shipment of goods and assembly of furniture. On the other hand, a barbershop may sell its own line of hair care products. You might not know that General Motors' greatest return on capital does not come from selling cars but rather from post-sales parts and service. The differences between manufacturing and services are shown in Figure 1.3, which focuses on the dimensions of product tangibility and the degree of customer contact. Pure manufacturing and pure service extremes are shown, as well as the overlap between them.

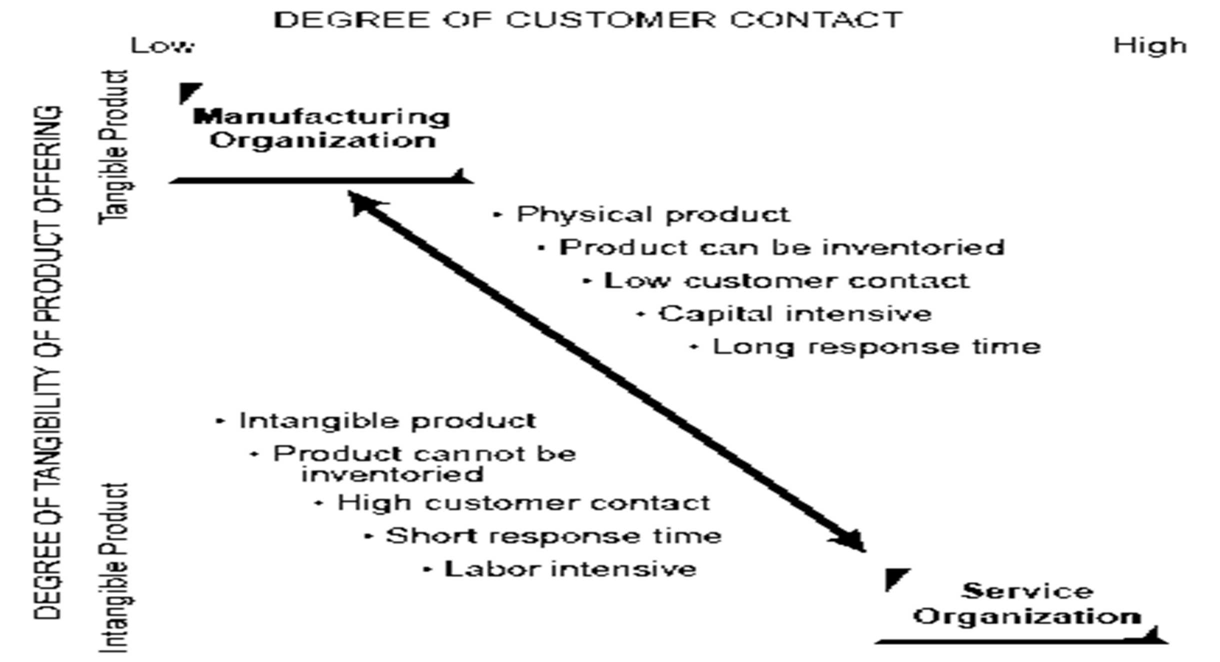

FIGURE 1.3 Characteristics of manufacturing and service organizations

Goods vs. Services

People have long distinguished between businesses that produce goods and businesses that provide services. This distinction between producing goods and providing services seems simple and logical, based on two basic differences:

Goods are tangible and services are intangible. You can touch goods. They are products. They have a physical form. You cannot touch services.

They are activities. They have no physical form. Providing services involves more customer contact than producing goods.

This distinction between goods and services is simple and logical.

However, it's also more and more problematic. The Navy has the adage that if it moves, salutes it, and if it doesn't, paints it. Such a simple notion for distinguishing between products and services no longer exists. Companies that produce goods—manufacturers—often also provide services. Companies that provide services may also produce goods. For example, restaurants are included in the services sector even though they produce meals from raw and processed materials.

Exercise 1.2

1. Explain briefly the difference between manufacturing and service organization?
2. Discuss the role of operations management in an organization

1.6 Operations Decisions

An operation has responsibility for five major decision areas: process, capacity, inventory, work force, and quality.

1. ***Process***: Decisions in this category determine the physical process or facility used to produce the product or service. The decisions include the type of equipment and technology, process flows, layout, and all other aspects of the physical plant or service facility. It is important that the physical process be designed on relation to the long strategic posture of the business.
2. ***Capacity***: Capacity decisions are aimed at providing the right amount of capacity at right place at the right time. Long-range capacity is determined by the size of the physical facility which are built. In the short run, capacity can be augmented by subcontracting, extra shifts, or rental of space. The available capacity must be allocated to specific tasks and jobs in operations by scheduling people, equipment, and facilities.
3. ***Inventory***: Inventory decisions in operations determine what to order, how much to order, and when to order. Inventory control systems are used to manage materials from purchasing

through raw materials, work in process, and finished goods inventories. They manage the flow of materials within the firm.

4. ***Work force***: Work force decisions include selection, hiring, firing, training, supervision, and compensation. Managing the work force in a productive and humane way is a key task for operations today.
5. ***Quality***: Quality is an important operations responsibility which requires total organizational support. Quality decisions must ensure that quality is built into the product in all stages of operations, standard must be set, equipment designed, people trained, and product or service inspected for quality to result.

1.7 Productivity

The creation of goods and service requires changing resources into goods and services. The more efficiently we make this change the more productive we are.

Productivity is the ratio of outputs (goods and services) divided by the inputs (resources, such as labor and capital). Productivity is defined in terms of utilization of resources, like material and labor. In simple terms, productivity is the ratio of output to input. For example, productivity of labor can be measured as units produced per labor hour worked. Productivity is closely linked with quality, technology and profitability.

Productivity can be treated as a multidimensional phenomenon. The modern dynamic concept of productivity looks at productivity as what may be called “productivity flywheel”. The productivity is energized by competition. Competition leads to higher productivity, higher productivity results in better value for customers, and these results in higher share of market for the organization, which results in still keener competition. Productivity thus forms a cycle, relating to design and products to satisfy customer needs, leading to improved quality of life, higher competition *i.e.* need for having still higher goals and higher share of market, and thereby leading to still better designs.

Hence, there is a strong stress on productivity improvement in competitive business environment.

Productivity can be improved by (*a*) controlling inputs, (*b*) improving process so that the same input yields higher output, and (*c*) by improvement of technology. These aspects are discussed in more detail in the following section.

Productivity Improvement Techniques

A. TECHNOLOGY BASED

Computer Aided Design (CAD), Computer Aided Manufacturing (CAM), and Computer Integrated Manufacturing Systems (CIMS): CAD refers to design of products, processes or systems with the help of computers. The impact of CAD on human productivity is significant for the advantages of CAD are:

- Speed of evaluation of alternative designs,
- Minimization of risk of functioning, and
- Error reduction
- CAM is very much useful to design and control the manufacturing. It helps to achieve the effectiveness in production system by line balancing
- Production Planning and Control
- Capacity Requirements Planning (CRP), Manufacturing Resources Planning (MRP II) and Materials Requirement Planning (MRP)
- Automated Inspection.

Computer integrated manufacturing: Computer integrated manufacturing is characterized by automatic line balancing, machine loading (scheduling and sequencing), automatic inventory control and inspection.

- Robotics
- Laser technology
- Modern maintenance techniques
- Energy technology
- Flexible Manufacturing System (FMS)

B. EMPLOYEE BASED

- Financial and non-financial incentives at individual and group level.
- Employee promotion.
- Job design, job enlargement, job enrichment and job rotation.
- Worker participation in decision-making
- Quality Circles (QC), Small Group Activities (SGA)
- Personal development.

C. MATERIAL BASED

- Material planning and control
- Purchasing, logistics
- Material storage and retrieval
- Source selection and procurement of quality material
- Waste elimination.

D. **PROCESS BASED**

- Methods engineering and work simplification
- Job design evaluation, job safety
- Human factors engineering.

E. PRODUCT BASED

- Value analysis and value engineering
- Product diversification
- Standardization and simplification
- Reliability engineering
- Product mix and promotion.

F. TASK BASED

- Management style
- Communication in the organization
- Work culture
- Motivation
- Promotion group activity

Productivity Analysis

For the purposes of studies of productivity for improvement purposes, following types of analysis can be carried out:

1. ***Trend analysis*****:** Studying productivity changes for the firm over a period of time.

2. ***Horizontal analysis*****:** Studying productivity in comparison with other firms of same size and engaged in similar business.

3. ***Vertical analysis*****:** Studying productivity in comparison with other industries and other firms of different sizes in the same industry.

4. ***Budgetary analysis:*** Setting up a norm for productivity for a future period as budget, based on studies as above, and planning strategies to achieve it.

1.8 FACTORS AFFECTING PRODUCTIVITY

Economists site a variety of reasons for changes in productivity. However some of the principle factors influencing productivity rate are:

1. ***Capital/labour ratio*****:** It is a measure of whether enough investment is being made in plant, machinery, and tools to make effective use of labour hours.

2. ***Scarcity of some resources*****:** Resources such as energy, water and number of metals will create productivity problems.

3. ***Work-force changes*****:** Change in work-force effect productivity to a larger extent, because of the labour turnover.

4. ***Innovations and technology*****:** This is the major cause of increasing productivity.

5. ***Regulatory effects*****:** These impose substantial constraints on some firms, which lead to change in productivity.

6. ***Bargaining power*****:** Bargaining power of organized labour to command wage increases excess of output increases has had a detrimental effect on productivity.

7. ***Managerial factors*****:** Managerial factors are the ways an organization benefits from the unique planning and managerial skills of its manager.

8. ***Quality of work life*****:** It is a term that describes the organizational culture, and the extent to which it motivates and satisfies employees

1.9 Productivity Measurement

Productivity can be measured at firm level, at industry level, at national level and at international level. The operations manger's job is to enhance (improve) this ratio of outputs to inputs. Improving productivity means improving efficiency. This improvement can be achieved in two ways:

- A reduction in inputs while output remains constant, or
- An increase in output while inputs remain constant.

$$\text{Productivity} = \frac{\text{Units Produced}}{\text{Input used}}$$

For example, if units produced =1000 and labour hours used is 250, then :

$$\text{Productivity} = \frac{\text{Units produced}}{\text{Labor-hours used}} = \frac{1000}{250} = 4 \text{ units per labor hour}$$

- The use of just one resource input to measure productivity as shown above is known as *single factor productivity*.
- However, a broader view of productivity is *multifactor productivity,* which includes all inputs (e.g., labor, material, energy, capital).
- Multifactor productivity is also known as *total factor productivity*. Multifactor productivity is calculated by combining the input units, as shown below:

$$\text{Productivity} = \frac{\text{Output}}{\text{Labor + Material + Energy + Capital + Miscellaneous}}$$

Example 1

Biruk Textile Company has a staff of 4 each working 8 hours per day (for a payroll cost of $640 /day) and overhead expenses of $400 per day. Collins processes and closes on 8 titles each day. The company recently purchased a computerized title-search system that will allow the processing of 14 titles per day. Although the staff, their work hours, and pay will be the same, the overhead expenses are now $800 per day.

- Labor productivity with the old system $= \frac{\text{8 titles per day}}{\text{32 labor-hours}} =$ 0.25 titles per labor hour

- Labor productivity with the new system $= \frac{\text{14 titles per day}}{\text{32 labor-hours}} =$ 0.4375 titles per labor-hour

- Multifactor productivity with the old system $= \frac{\text{8 titles per day}}{640+400} =$ 0.0077 titles per dollar

- Multifactor productivity with the new system$= \frac{\text{14 titles per day}}{640+800} =$ 0.0097 titles per dollar

❖ Labor productivity has increased from 0.25 to 0.4375. The change is 0.4375÷0.25=1.75 or a 75% increase in labor productivity.

Multifactor productivity has increased from 0.0077 to 0.0097. This change is 0.0097÷0.0077=1.259, or a 25.9% increase in multifactor productivity.

Example 2

A company produces 160 kg of plastic molded parts of acceptable quality by consuming 200 kg of raw materials for a particular period. For the next period, the output is doubled (320 kg) by consuming 420 kg of raw material and for a third period; the output is increased to 400 kg by consuming 400 kg of raw material.

SOLUTION: During the first year, production is 160 kg

- Productivity =Output/Input = 160/200
  = 0.8 or 80%
- For the second year, production is increased by 100%
  Productivity =Output/Input =320/420
  = 0.76 or 76% ↓
- For the third period, production is increased by 150%
  Productivity = Output/Input = 400/400
  = 1.0, *i.e.*, 100%

From the above illustration it is clear that, for second period, though production has doubled, productivity has decreased from 80% to 76% for period third, production is increased by 150% and correspondingly productivity increased from 80% to 100%.

Exercise 1.3

1. Write down major operation decision area?
2. Discuss the importance of operations research in modern management
3. What is productivity? How productivity is improved?

Self-check exercise 1

Part I. Write “true” if the statement is correct and “false” if the statement is incorrect

1. One reason to study operations management is to learn how people organize themselves for productive enterprise.
2. Customer interaction is often high for manufacturing processes, but low for services.
3. Productivity is more difficult to improve in the manufacturing sector.
4. Manufacturing now constitutes the largest economic sector in postindustrial societies.
5. Single factor Productivity is the total value of all inputs to the transformation process divided by the total value of the outputs produced.

Part II. Choose the best answer from the listed alternatives

1. Operations management is applicable
   - A. Mostly to the service sector
   - B. To services exclusively
   - C. Mostly to the manufacturing sector
   - D. To all firms, whether manufacturing and service
   - E. To the manufacturing sector exclusively

2. Which of the following are the primary functions of **all** organizations?
   - A. Operations, marketing, and human resources
   - B. Marketing, human resources, and finance/accounting
   - C. Sales, quality control, and operations
   - D. Marketing, operations, and finance/accounting
   - E. Research and development, finance/accounting, and purchasing

3. Reasons to study Operations Management include
    - A. Studying why people organize themselves for free enterprise
    - B. Knowing how goods and services are consumed
    - C. Understanding what human resource managers do
    - D. Learning about a costly part of the enterprise
    - E. All of the above

4. The person most responsible for popularizing interchangeable parts in manufacturing was
    - A. Frederick Winslow Taylor
    - B. Henry Ford
    - C. Eli Whitney
    - D. Whitney Houston
    - E. Lillian Gilbreth

5. The "Father of Scientific Management" is
    - A. Henry Ford
    - B. Frederick W. Taylor
    - C. W. Edwards Deming
    - D. Frank Gilbreth

6. Which of the following is **not** a typical service attribute?
    - A. Intangible product
    - B. Easy to store
    - C. Customer interaction is high
    - D. Simultaneous production and consumption
    - E. Difficult to resell

7. Gibson Valves produces cast bronze valves on an assembly line. If 1600 valves are produced in an 8-hour shift, the productivity of the line is
    - A. 2 valves/hr
    - B. 40 valves/hr
    - C. 80 valves/hr
    - D. 200 valves/hr
    - E. 1600 valves/hr

8. Gibson Valves produces cast bronze valves on an assembly line, currently producing 1600 valves each 8-hour shift. If the productivity is increased by 10%, it would then be
    - A. 180 valves/hr
    - B. 200 valves/hr

C. 220 valves/hr

D. 880 valves/hr

E. 1760 valves/hr

Part III: Work out questions (show all the necessary steps)

1. A firm cleans chemical tank cars in the Bay St. Louis area. With standard equipment, the firm typically cleaned 70 chemical tank cars per month. They utilized 10 gallons of solvent, and two employees worked 20 days per month, 8 hours a day. The company decided to switch to a larger cleaning machine. Last April, they cleaned 60 tank cars in only 15 days. They utilized 12 gallons of solvent, and the two employees worked 6 hours a day.
   A. What was their productivity with the standard equipment?
   B. What is their productivity with the larger machine?
   C. What is the change in productivity?

2. The following information regarding the output produced and inputs consumed for a particular time period for a particular company is given below:
   - Output – birr 10,000
   - Human input – birr 3,000
   - Material input – birr 2,000
   - Capital input – birr 3,000
   - Energy input – birr 1,000
   - Other misc. input –birr 500 The values are in terms of base year birr value.

Required. Compute various productivity indices.

3. Six hundred patients have visited a dental clinic in one week. There are four dental surgeons employed by the clinic. Assuming equal distribution of work, what is the productivity of an individual dentist per week?

   Required; determine productivity for each dentist

CHAPTER II

OPERATIONS STRATEGY FOR COMPETITIVE ADVANTAGE

2.1 INTRODUCTION

Dear learners Operations capabilities are at the heart of the success of every companies. Although other areas such as marketing and human resource (HR) management are also important, even with the best marketing or HR plans in the world, without operations capabilities an organization will flounder because it cannot deliver on its promises to customers.

Organizations can no longer compete on a single dimension such as low cost, high quality, or delivery, but must provide all of these (and more) simultaneously. Operations managers must put in place a strategy to develop and maintain the operations capabilities to support these competitive objectives, which traditional approaches to strategy do not do. In essence, strategy is about the 'how' of an organization's aims – how it will go from its current state to its intended future position.

The concept of strategy originated in military terminology, where strategy refers to plans devised to outmaneuver the opposition. In business, firms attack where and when other firms are vulnerable.

Chapter Objective

After completing this chapter, you would be able to:

- Know operations strategy;
- To identify difference between different types of Operations Strategies
- Understand how to Achieve Competitive Advantage through Operations

2.2 OPERATIONS STRATEGY FOR COMPETITIVE ADVANTAGE

Each of a firm's strategies should be established in light of (1) the threats and opportunities in the environment and (2) the strengths and weaknesses of the organization. Ultimately, every strategy is an attempt to answer the question, "How do we satisfy a customer?" within these constraints.

Identifying Missions and Strategies

An effective operations management effort must have a *mission* so it knows where it is going and a *strategy* so it knows how to get there.

Mission

Economic success, indeed survival, is the result of identifying missions to satisfy a customer's needs and wants.

Definition: We define the organization's mission as its purpose—what it will contribute to society. Mission statements provide boundaries and focus for organizations and the concept around which the firm can rally. The mission states the rationale for the organization's existence. Developing a good strategy is difficult, but it is much easier if the mission has been well defined. The mission can also be thought of as the *intent* of the strategy—what the strategy is designed to achieve. Once an organization's mission has been decided, each functional area within the firm determines its supporting mission. By "functional area" we mean the major disciplines required by the firm, such as marketing, finance /accounting, and production/operations. Missions for each functional area are developed to support the firm's overall mission. Then within that function lower-level supporting missions are established for the operation management functions.

Figure 2.1 provides such a hierarchy of sample missions.

Sample Company Mission To manufacture and service a growing and profitable worldwide microwave communications business that exceeds our customers' expectations.	
Sample Operations Management Mission To produce products consistent with the company's mission as the worldwide low-cost manufacturer.	
Sample OM Department Mission	To attain the exceptional value that is consistent with our company mission and marketing objectives by close attention to design, procurement, production, and field service opportunities. To lead in research and engineering competencies in all areas of our primary business, designing and producing products and services with

	outstanding quality and inherent customer value. To determine and design or produce the production process and equipment that will be compatible with low-cost product, high quality, and a good quality-of-work life at economical cost.
	To locate, design, and build efficient and economical facilities that will yield high value to the company, its employees, and the community. To provide a good quality-of-work life, with well-designed, safe, rewarding jobs, stable employment, and equitable pay, in exchange for outstanding individual contribution from employees at all levels. To achieve low investment in inventory consistent with high customer service levels and high facility utilization. To achieve high levels of throughput and timely customer delivery through effective scheduling.
Maintenance	To achieve high utilization of facilities and equipment by effective preventive maintenance and prompt repair of facilities and equipment.

Figure 2.1 Sample Mission for a Company, the Operations Function, and Major Departments in an Operations Function

Strategy

With the mission established, strategy and its implementation can begin. Strategy is an organization's action plan to achieve the mission. Each functional area has a strategy for achieving its mission and for helping the organization reach the overall mission.

These strategies exploit opportunities and strengths, neutralize threats, and avoid weaknesses.

Firms achieve missions in three conceptual ways: (1) differentiation, (2) cost leadership, and (3) quick response. This means operations managers are called on to deliver goods and services that are (1) *better*, or at least different, (2) *cheaper*, and (3) more *responsive*. Operations managers translate these strategic concepts into tangible tasks to be accomplished. Any one or combination of these three strategic concepts can generate a system that has a unique advantage over competitors.

Strategies and Tactics

A mission statement provides a general direction for an organization and gives rise to organizational *goals*, which provide substance to the overall mission. For example, one goal of an organization may be to capture a certain percent of market share for a product; another goal may be to achieve a certain level of profitability. Taken together, the goals and the mission establish a destination for the organization.

Strategies are plans for achieving goals. If you think of goals as destinations, then strategies are the road maps for reaching the destinations. Strategies provide *focus* for decision-making. Generally speaking, organizations have overall strategies called *organization strategies,* which relate to the entire organization, and they also have *functional strategies*, which relate to each of the functional areas of the organization. The functional strategies should support the overall strategies of the organization, just as the organizational strategies should support the goals and mission of the organization.

Tactics are the methods and actions used to accomplish strategies. They are more specific in nature than strategies, and they provide guidance and direction for carrying out actual *operations,* which need the most specific and detailed plans and decision-making in an organization. You might think of tactics as the “how to” part of the process (e.g., how to reach the destination, following the strategy road map) and operations as the actual “doing” part of the process. It should be apparent that the overall relationship that exists from the mission down the actual operations is *hierarchical* in nature.

Example- Meron is a high school student in Dessie City. She would like to have a career in business, have a good job, and earn enough income to live comfortably.

A possible scenario for achieving her goals might look something like this:

Mission: Live a good life.

Goal: Successful career, good income.

Strategy: Obtain a university education.

Tactics: Select a university and a major; decide how to finance university.

Operations: Register, buy books, takes courses, study.

Exercise 2.1

4. Write down major reason for devising successful strategy?
5. Discuss the importance of operations strategy in business organization
6. What is strategy? Can you mention example by considering a business organization?

2.3 Operations Strategy

The organization strategy provides the overall direction for the organization. It is broad in scope, covering the entire organization. **Operation strategy** is narrower in scope, deals primarily with the operations aspect of the organization. Operations strategy relates to products, processes, methods, operating resources, quality, cost, lead times, and scheduling. Table 2.1 provides a comparison of an organization's mission, its overall strategy, and its operations strategy, tactics, and operations.

In order for operations strategy to be truly effective, it is important to link it to organization strategy; that is, the two should not be formulated independently. Rather, formulation of organization strategy should take into account the realities of operations' strengths and weaknesses, capitalizing on strengths and dealing with weaknesses. Similarly, operations strategy must be consistent with the overall strategy of the organization, and formulated to support the goals of the organization.

		Management Level	Time Horizon	Scope	Level of Detail	Relates to
The Overall Organization	Mission	Top	Long	Broad	Low	Survival, profitability
	Strategy	Senior	Long	Broad	Low	Growth rate, market share
Production/ Operations	Strategic	Senior	Moderate to long	Broad	Low	Product design, choice of location, choice of technology, new facilities
	Tactical	Middle	Moderate	Moderate	Moderate	Employment levels, output levels, equipment selection, facility layout
	Operational	Low	Short	Narrow	High	Scheduling

						personnel, adjusting output rates, inventory management, purchasing

Table 2.1 Comparison of mission, organization strategy, and operations strategy

Exercise 2.1

1. What is the difference and similarity between operations strategy and business strategy?

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2.4. Strategy Formulation

To formulate an effective strategy, senior management must take into account the *distinctive competencies* of the organization, and they must *scan the environment.* They must determine what competitors are doing, or planning to do, and take that into account. They must critically examine other factors that could have either positive or negative effects. This is sometimes referred to as the SWOT approach (strengths, weaknesses, opportunities, and threats).

In formulating a successful strategy, organizations must take into account both order qualifiers, and order winners. Terry Hill describes **order qualifiers** as those characteristics that potential customers perceive as minimum standards of acceptability to be considered as a potential for purchase. However, that may not be sufficient to get a potential customer to purchase from the organization. **Order winners** are those characteristics of an organization's goods or services that cause them to be perceived as better than the competition.

Distinctive competencies are those special attributes or abilities possessed by an organization that give it a **competitive edge**. In effect, distinctive competencies relate to the ways that organizations compete. These can include price (based on some combination of low costs of resources such as labor and materials, low operating costs, and low production costs); quality (high performance or consistent quality); time (rapid delivery or on-time delivery); flexibility (variety of volume); customer service; and location.

Examples of distinctive competencies

Competency	
Price	Low cost
Quality	High-performance design and /or high quality
	Consistent quality
Time	Rapid delivery
	On-time delivery
Flexibility	Variety
	Volume
Service	Superior customer service
Location	Convenience

The most effective organizations seem to use an approach that develops distinctive competencies based on customer needs as on what the competition is doing. Marketing and operations work closely to match customer needs with operations capabilities. Competitor competencies are important for several reasons. For example, if a competitor is able to supply high-quality products, it may be necessary to meet that high quality as a baseline. However, merely *matching* a competitor is usually not sufficient to gain market share. It may be necessary to exceed the quality level of the competitor or gain an edge by excelling in one or more other dimensions, such as rapid delivery or service after the sale.

Environmental scanning is the considering of events and trends that present threats or opportunities for the organization. Generally these include competitors' activities; changing consumer needs; legal, economic, political, and environmental issues; the potential for new markets; and the like.

1. Dear learners can you mention factors to be considered in formulating successful strategies?

   ____

   ____

   ____

2. By considering different successful business organization try to list down their distinctive competencies

   ____

   ____

   ____

2.5. Achieving Competitive Advantage through Operations

Each of the three strategies (differentiation, cost leadership, and quick response) provides an opportunity for operations managers to obtain competitive advantage. **Competitive advantage** implies the creation of a system that has a unique advantage over competitors. The idea is to create customer value in an efficient and sustainable way. Let us briefly look at how managers achieve competitive advantage via *differentiation*, *low cost*, and *response*.

Competing on Differentiation

Differentiation is concerned with providing *uniqueness*. A firm's opportunities for creating uniqueness are not located within a particular function or activity, but can arise in virtually everything that the firm does. Moreover, because most products include some service and most services include some product, the opportunities for creating this uniqueness are limited only by imagination.

Competing on Cost

One driver of a low-cost strategy is an optimal facility that is effectively utilized. **Low-cost leadership** entails achieving maximum value as defined by your customer. It requires examining each of the different operation management decisions in a relentless effort to drive down costs while meeting customer expectations of value. A low-cost strategy does *not* imply low value or low quality.

Competing on Response

Response is often thought of as *flexible* response, but it also refers to *reliable* and *quick* response. Indeed, we define **response** as including the entire range of values related to timely product development and delivery, as well as reliable scheduling and flexible performance.

Flexible response may be thought of as the ability to match changes in a market place in which design innovations and volumes fluctuate substantially.

In practice, these three concepts- differentiation, low cost, and response-are often translated into six specific strategies:

1. flexibility in design and volume
2. low price
3. delivery
4. quality
5. after-sale service, and
6. a broad product line

Through these six specific strategies, operation management can increase productivity and generate a sustainable competitive advantage. Proper implementation of the operations decisions by operations managers will allow these strategies to be achieved.

2.6 Operations Objectives

Four general operations objectives are possible: cost, quality, delivery, and flexibility. Objectives in operations should be stated in specific quantitative and measurable terms. They are the results that operations is expected to achieve in the short and long run. Examples of objectives for a manufacturing company are:

Examples of objectives for a manufacturing company are:

		Current year	**5 years from now**	**Current world class competitor**
1.	Manufacturing cost as % of sales	55%	48%	50%
2.	Customer satisfaction % satisfied with product	75%	85%	75%

3.	Percentage of scrap and rework	15%	5%	10%
4.	Months to introduce new product	10	6	8

1. Costs are defined to include the costs of production, costs of carrying inventory, and any other costs incurred in using resources. The cost of operation includes the cost of labor, materials, and overhead. These costs are expressed as a percentage of sales or as a unit cost for particular products.
2. Quality means the quality of the product or service as perceived by the customer. Quality is the value of the product, its prestige, and its perceived usefulness. This definition includes not only conformance to specifications, but the design of the product as well. Typical quality measures include customer satisfaction as measured by surveys or consumer tests, the amount of rework or scrap created as part of the production process, and measures of warranty or return of the product. Quality should also be measured relative to the competition and can be an important point of differentiation.
3. Delivery refers to the ability of operations to deliver the product or service when and where consumer needs it. When the product is make to stock, delivery can refer to the percentage of orders filled from inventory and the amount of time (lead time) required to refill stock. In the case of make-to-order products, delivery may refer to the length of time that it takes to deliver the order from start to finish. Delivery is measured by the ability to quickly process and make a product when it is needed (throughput time).
4. Flexibility is either the ability to make new products or the time that it takes to change the volume. If an operation is flexible, new products can be introduced quickly and volume change can be made rapidly. Flexibility can provide a competitive advantage when the firm chooses to compete on the basis of new product innovation or quick response to customer demands. In some cases, however, it may cost more to design and operate and flexible operation. Then the value of flexibility must be weighed against the added cost.

1. Dear learners can you illustrate the four general operations objectives by considering one organization?

____

____

____

Types of Operations Strategies

Operations strategy must be linked to business strategies, to marketing and financial strategies as well. Two business strategies are shown below:

Business strategy	**Low cost Producers’**	**Product innovator**
Market conditions	price sensitive Mature market High volume Standardization	product sensitive emerging market low volume customized products
Operations mission	emphasize low cost	emphasize flexibility
Distinctive competence	low cost through Superior process Technology	fast and reliable new product introduction
Operations policies	superior processes Control location Economy of scale Tight inventory control Low skill work force Highly automated	superior products flexible automation fast reaction to change use of product teams skilled workers low automation
Marketing strategies	mass distribution Repeat sales	selective distribution new market development

	Low cost advertising	product design
		High cost advertising
Financial strategies	high capital needed	low capital needed
	Low risk	high risk
	Low profit margins	high profit margins

Self-check exercise 2

Part I. Write “true” if the statement is correct and “false” if the statement is incorrect

1. Operations strategies are implemented in the same way in all types of organizations.
2. Experience differentiation is an extension of product differentiation, accomplished by using people's five senses to create an experience rather than simply providing a service.
3. An organization's ability to generate unique advantages over competitors is central to a successful strategy implementation.
4. Low-cost leadership is the ability to distinguish the offerings of the organization in any way that the customer perceives as adding value.
5. Strategies change because of an organization's internal strengths and weaknesses change.
6. SWOT analysis identifies those activities that make a difference between having and not having a competitive advantage.
7. For the greatest chance of success, an organization's operations management strategy must support the company's strategy.
8. Critical Success Factors are those relatively few activities that make a difference between having and not having a competitive advantage.

Part II; Choose the best answer from the listed alternatives

1. Which of the following is **true** about business strategies?
   A. An organization should stick with its strategy for the life of the business.
   B. All firms within an industry will adopt the same strategy.
   C. Well defined missions make strategy development much easier.
   D. Strategies are formulated independently of SWOT analysis.
   E. Organizational strategies depend on operations strategies.

2. Which of the following activities takes place once the mission has been developed?

A. The firm develops alternative or back-up missions in case the original mission fails.
B. The functional areas develop their functional area strategies.
C. The functional areas develop their supporting missions.
D. The ten OM decision areas are prioritized.
E. Operational tactics are developed.

3. Which of the following statements about organizational missions is **false**?
   A. They reflect a company's purpose.
   B. They indicate what a company intends to contribute to society.
   C. They are formulated after strategies are known.
   D. They define a company's reason for existence.
   E. They provide guidance for functional area missions.
4. The fundamental purpose of an organization's mission statement is to
   A. create a good human relations climate in the organization
   B. define the organization's purpose in society
   C. define the operational structure of the organization
   D. generate good public relations for the organization
   E. define the functional areas required by the organization
5. Which of the following is **true**?
   A. Corporate mission is shaped by functional strategies.
   B. Corporate strategy is shaped by functional strategies.
   C. Functional strategies are shaped by corporate strategy.
   D. External conditions are shaped by corporate mission.
   E. Functional area missions are merged to become the organizational mission.
6. A firm can effectively use its operations function to yield competitive advantage via all of the following **except**
   A. customization of the product
   B. setting equipment utilization goals below the industry average
   C. speed of delivery
   D. constant innovation of new products
   E. maintain a variety of product options
7. Which of the following is **not** an operations strategy?

A. response
B. low-cost leadership
C. differentiation
D. experience

8. The ability of an organization to produce goods or services that have some uniqueness in their characteristics is
   A. mass production
   B. time-based competition
   C. competing on productivity
   D. competing on flexibility
   E. competing on differentiation
9. Which of the following statements best characterizes delivery **reliability**?
   A. a company that always delivers on the same day of the week
   B. a company that always delivers at the promised time
   C. a company that delivers more frequently than its competitors
   D. a company that delivers faster than its competitors
   E. company that has a computerized delivery scheduling system
10. Which of the following is an example of competing on the basis of differentiation?
   A. a firm manufactures its product with less raw material waste than its competitors
   B. a firm's products are introduced into the market faster than its competitors
   C. a firm's distribution network routinely delivers its product on time
   D. a firm offers more reliable products than its competitors
   E. a firm advertises more than its competitors

CHAPTER THREE

DESIGN OF THE OPERATION SYSTEM

3.1 Product and service design

3.1.1 Introduction

Before products can flow into a market, someone must design and invest in the facilities and organization to produce them. This chapter concerns the planning of the systems needed to produce goods and services.

The word design has many different meanings. To some it means aesthetic design of product, such that the external shape of a car, or the color, texture and shape of the casting can opener. In another sense, design can mean establishing the basic parameters of a system or characteristics of the various units or components. (chase, et al, 2005).

Product or service design is concerned with the functional and aesthetic requirement necessary to meet the demand of market the place and at the same time achieve an acceptable rate of return. Inputs into product or service design decisions can primarily come from marketing, engineering, and production. (Donald, 1985-pp14).

New-product development is a crucial part of business. New products serve to provide growth opportunities and a competitive advantage for the firm. Operations are greatly affected by new product introduction. New-product design greatly affects operations by specifying the products that will be made; it is a prerequisite for production to occur. New products must be defined with not only the market in mind but the production process that will be used to make the product.

Through close cooperation between operations, marketing, and other functions, the product design can be integrated with decisions regarding process, quality, capacity, and inventory. Product design is prerequisite for production, along with a forecast of production volume.

Chapter objective

At the end of this chapter, students will be able to:

- ✓ Explain design of the operation system
- ✓ Discuss Product and service design
- ✓ Discuss Process selection
- ✓ Discuss Strategic Capacity Planning
- ✓ Discuss Facility Location & layout
- ✓ Discuss Job Design and Work Measurement

3.1.2 Reasons for Product or Service Design

Organizations become involved in product or service design for a variety of reasons. An obvious one is to be competitive by offering new products or services. Another one is to make the business grow and increase profits. Furthermore, the best organizations try to develop new products or services as an alternative to downsizing.

Sometimes product or service design is actually redesign. This, too, occurs for a number of reasons such as customer complaints, accidents or injuries, excessive warranty claims, or low demand. This desire to achieve cost reductions in labor or materials can also be a motivating factor.

3.1.3 Objective of products or services design

More generally, products or services design intended to achieve the following objectives

- ➢ To bring new or revised products or services to the market place as fast as possible
- ➢ To design products and service that have customer appeal
- ➢ To increase the level of customer satisfaction
- ➢ To increase quality
- ➢ To reduce cost

3.1.4 Trends in product and service design

Over the last few years, the designing of products and services has increased emphasis on a number of aspects of design. Among them are the following:

1. Increased emphasis on customer satisfaction and increased pressure to be competitive.
2. Increased emphasis on reducing the time needed to introduce a new product or service

3. Greater attention to environmental concerns, including waste minimization, recycling parts, and disposal of worn-out products.
4. Increased emphasis on designing products and services that is user-friendly.
5. Increased effort to use less material for products (e.g., concentrated liquid detergents) and less packaging.

In a competitive environment, getting new or improved products or services to the market ahead of competitors gives an organization a competitive advantage that can lead to increased profits and an increased market share, and create an image of the organization as a leader.

3.1.5 Sources of ideas for new or redesigned products and services

Ideas for new and improved products or services can come from a wide range of sources; both from within the organization and from outside it.

Internal sources for the organization are as follows

1. Employees:- including those who make products or deliver service to customers, sales people, and purchasing agent, can be a rich source of ideas, if they are motivated to offer suggestions.
2. Marketing and research and development departments:- these two departments are the primary source of ideas for product and service design. Marketing people are often sources of ideas based on their studies of markets, buying patterns, and familiarity with demographics.

External sources of product or service design ideas are as follows

1. Customers:- customers may submit suggestion for improvements or new products, or they may be queried through the use of surveys or focus groups. One such approach is a quality function deployment, which seeks to incorporate the "voice of the customer" into product or and service design. Customer complaint can provide valuable insight into areas that need improvement. Similarly, product failures and warranty claims indicate where improvements are needed. One of the strongest motivators for new and improved product or service is competitors' products or service. By studying a competitor's products or services and how the competitors operate (pricing policies, return policies, warranties, location strategies, etc), an organization can glean many ideas. Beyond that, some companies purchase a

competitor's product and then carefully dismantle and inspect it, searching for ways to improve their own product.

This is called **reverse engineering.** For example Ford motor company uses this tactic in developing its highly successful Taurus model. Like searching for best-in- class components

3.1.6 Strategies for New-Product Introduction

There are three fundamentally different ways to introduce new products.

1. **Market pull**- According to this view, the market is the primary basis for determining the products a firm should make, with little regard to existing technology.
   - A firm should make what it can sell.
   - The customer needs are determined, and processes needed to supply the customer. The market will "pull" through the products that are made.
2. **Technology push**- In this view, technology is the primary determinant of the products that the firm should make, with little regard for the market.
   - This approach suggests that "you should sell what you can make". The firm should pursue a technology based advantage by developing superior technologies and products.
   - The products are then pushed into the market, and the marketing's job is to create demand for these superior products.
   - Since the products have superior technology, they will have a natural advantage in the market and the customers will want to buy them.
3. **Inter-functional View-** This view holds that the product should not only fit the market needs but have a technical advantage as well.
   - To accomplish this, all functions (e.g., marketing, engineering, operations, and finance) should cooperate to design the new products needed by the firm.
   - Often this is done by forming cross functional teams that are responsible for development of the new product.
   - This is the most appealing of the three views but also the most difficult to implement.
   - Cross-functional rivalry and friction must be overcome to achieve the degree of cooperation required for inter functional product development to succeed.

Activity 3.1
Dear students answer the following questions before continuing to the next section.

1. State the major objective for product or service design.

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2. What are the major trends in product and service design?

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3. **Can you mention Sources of ideas for new or redesigned products and services?**

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Checklist

Dear learners if you understand the following ideas put a tick (✓) mark in the box, if not please read the section again.

- Product Design -- ☐
- Reverse engineering -- ☐
- Technology push -- ☐
- Inter functional view ------------------------------ ☐

3.1.7 The Design Process

The design process begins with the motivation for design. For a new business or a new product, the motivation may be obvious: to achieve the goals of the organization. For an existing business, in addition to that general motivation, there are more specific factors to consider, such as government regulations, competitive pressures, customer needs, and the appearance of new technologies that have product or process applications.

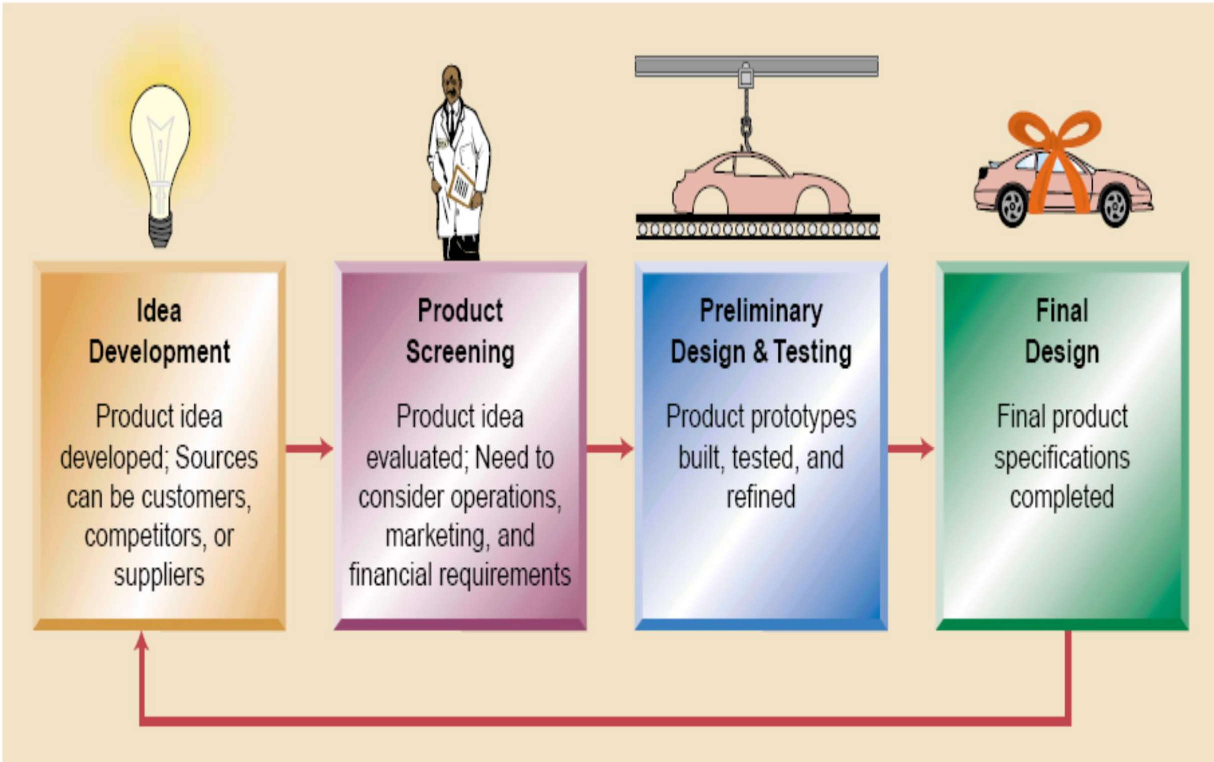
Ultimately, the customer is the driving force for product and service design. Failure to satisfy customers can result in customer complaints, returns, warranty claims, and so on. Loss of market share becomes a potential problem if customer satisfaction is not achieved.

For the design process to occur, a business must have ideas for new or improved designs. These come from a variety of sources, most obviously the customer. Marketing can tap this source of ideas in a number of ways, such as the use of focus groups, surveys, and analyses of buying patterns.

Some organizations have research and development departments that also generate ideas for new or improved products and services. Competitors are another important source of ideas. By studying competitor's products or services, and how the competitor operates (e.g., pricing policies, return policies, warranties), an organization can learn a great deal about achieving design improvements. Beyond that, some companies buy a competitor's newly designed product the moment it appears on the market.

Using a procedure called **reverse engineering**; they carefully dismantle and inspect the product. This may uncover product improvements that can be incorporated in their own product. Sometimes reverse engineering can lead to a product that is superior to the one being examined

Design activity is an iterative process. Thus in designing the products and processes we need to reduce the number of iterations required and increase the speed of designing and development activities of new product. In order to reduce the number of iterations and increase the speed of design and development of products and processes, a team approach is required.



Generally, product design and development as iterative process involves the following steps.

- Generating ideas from both internal and external sources
- Concept development
- Conducting market, financial and technical feasibility
- Developing prototype of the product
- Test marketing
- Final design and full scale production

The team approach of designing products and processes is an interactive process is called **concurrent or simultaneous engineering**. To achieve smooth transmission from product design to production and to decrease product development time and possible errors in the product development process, many companies are using simultaneous development, or concurrent engineering. Concurrent or simultaneous engineering is such an approach (team approach) where product design proceeds at the same time while process design is in progress with continuous iteration. The team approach emphasizes on cross functional integration or concurrent development of products and associated processes. In CE/SE, the team exchanges information that helps to potentially reduce error and speed up the product and processes development design.

Designing products and processes is strategic function in operation management (chase, et al, 2005). The design activity is usually motivated by the fact that production cost, product quality, production efficiency or ease of production, logistics and distribution costs- Physical characteristics of product, inventory investment, product availability- Rate of production, custom duties- rules and regulation, product serviceability- ease of maintenance, flexibility in dealing with unexpected changes in market demand for the product (fluctuating in market demand) are affected by the design of the product and processes. Therefore the design is guided by one or more of the following concepts.

- Design for quality
- Design for manufacturing
- Design for ease of production
- Design for testability
- Design for supply chain management

Design for quality

It is crucial element of product design of quality is its impact on the quality of the final product. Designing products for quality refers to building product quality in to the product design. In this case we need to incorporate the quality dimensions including performance, reliability, feature, serviceability, appearance, durability, safety and customer service.

Design for ease of production

The aim at designing product includes

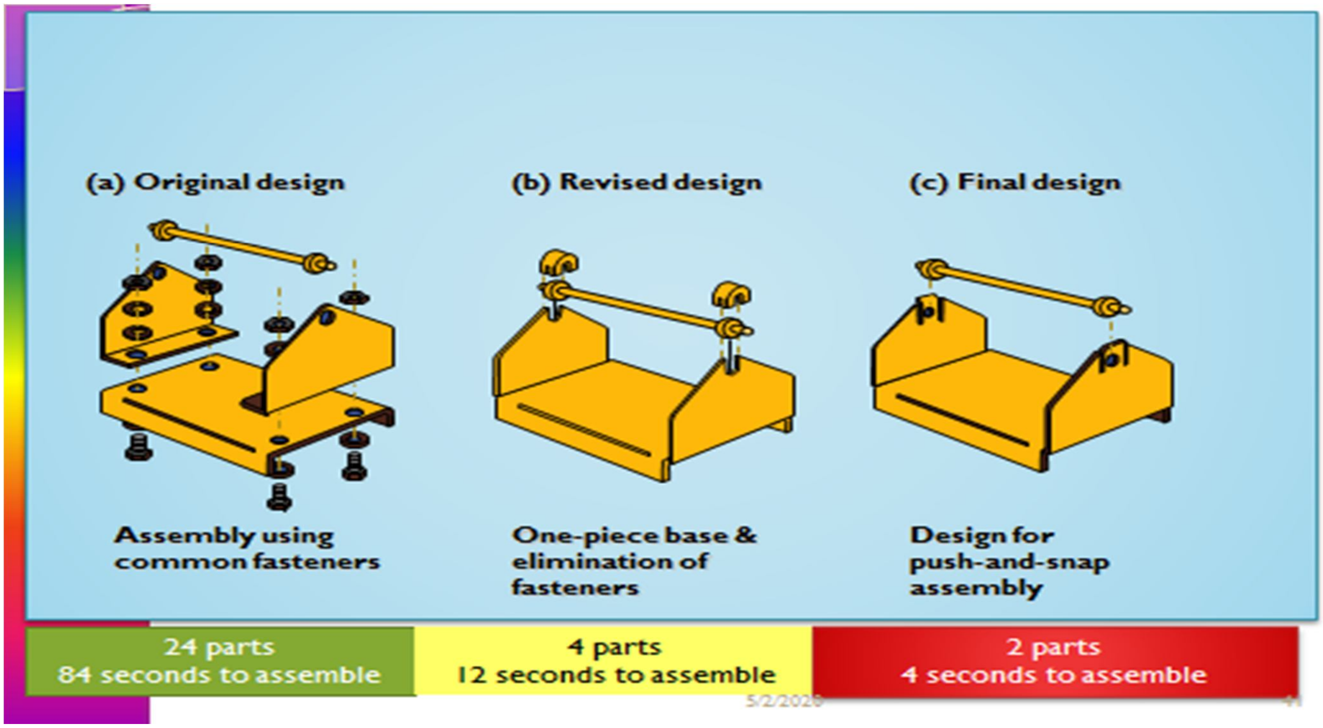
- have fewer parts,
- can be assembled quickly and easily
- can reduce sources of error and improve overall product quality and cost

There are three strategies association to designing for ease production

1. ***Specification***: detailed description of material, part or product including their basic dimensions example physical dimension. It provides production department with precise information about the characteristics of the product to be produced. One form of such specification is to allow both ease of assembly and effective function of the finished product.

2. ***Standardization***: producing uniform products, where there is little or no variety or customization for the customers.
3. ***Simplification***: is related to eliminating unnecessary part which would have the impact of raising the cost of producing the product.

Dear students let's try to support the above idea by practical example



3.1.8 Product Design tools

This section provides an overview of various approaches to product design, including product life cycles, manufacturing design, remanufacturing, robust design, concurrent engineering, computer-aided design, quality function deployment, value analysis (value engineering), Taguchi method, product variety and modular design.

1. **Product Life Cycle**

Many new products go through a product life cycle in terms of demand. In the last stage of a life cycle, some firms adopt a defensive research posture whereby they attempt to prolong the useful life of a product or service by improving its reliability, reducing costs of producing it (and, hence, the price), redesigning it, or changing the packaging.

2. **Manufacturing Design**

The term design for manufacturing **(DFM)** is also used to indicate the designing of products that are compatible with an organization's capabilities. A related concept in manufacturing is design for assembly **(DFA).** A good design must take into account not only how a product will be fabricated, but also how it will be assembled. Design for assembly focuses on reducing the number of parts in an assembly, as well as the assembly methods and sequence that will be employed. Environmental regulations and recycling have given rise to another concern for designers, design for recycling **(DFR).** Here the focus is on designing products to allow for dis-assembly of used products for the purpose of recovering components and materials for reuse.

3. **Remanufacturing**

Remanufacturing refers to removing some of the components of old products and reusing them in new products. This can be done by the original manufacturer, or another company. Among the products that have remanufactured components are automobiles, printers, copiers, cameras, computers, and telephones.

4. **Robust Design**

Some products will perform as designed only within a narrow range of conditions, while other products will perform as designed over a much broader range of conditions. The latter have robust design. The more robust a product, the less likely it will fail due to a change in the environment in which it is used or in which it is performed.

The **Taguchi method** is one of the most popular tools used in robust design. Taguchi's approach is based on three principles:

(i) when the value of a product attribute, such as shape or length, deviates from its target value, the cost to society (consumers and producers) in terms of lower quality increases more than linearly (increases at an increasing rate).

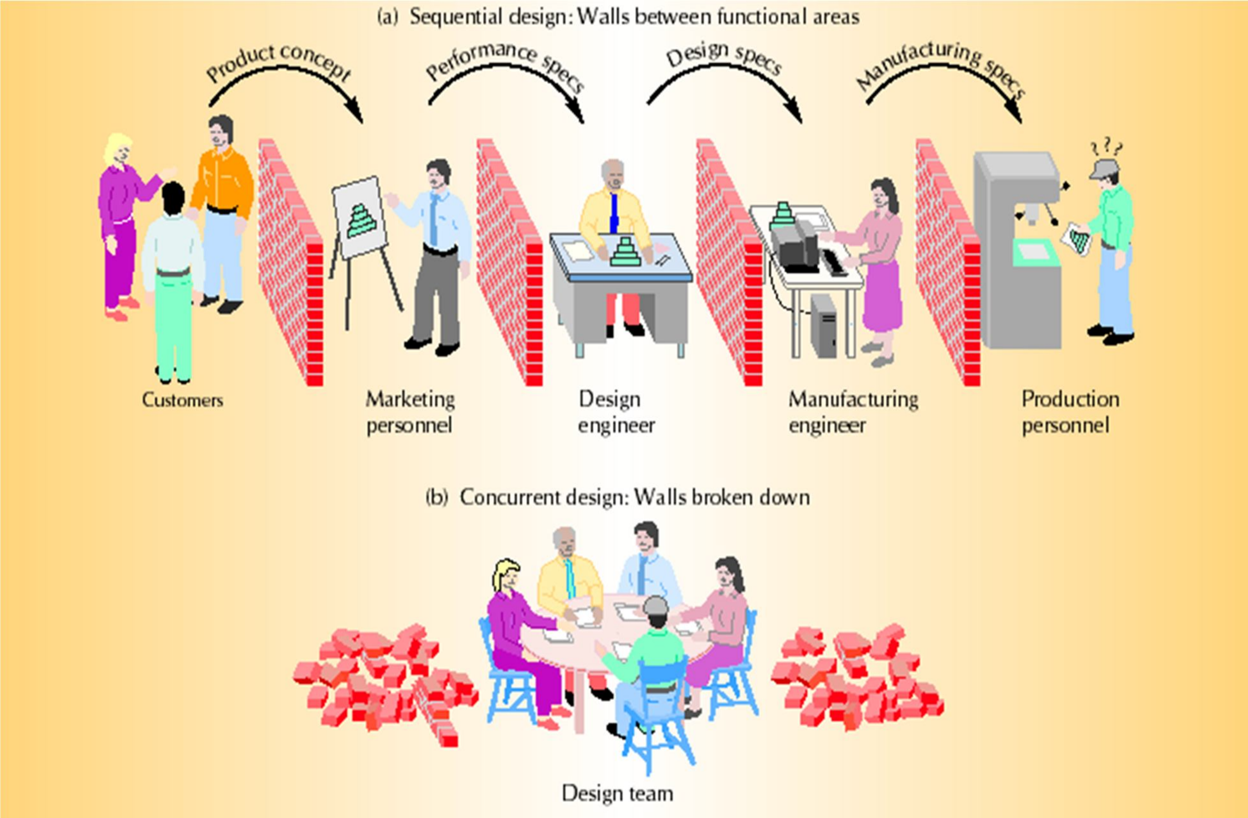
(ii) The design features of the product and the production process together determine the amount of variation in the product attributes.

(iii) Using experimentation, those product and process characteristics that affect product attributes can be determined, and by manipulating these characteristics, products can be designed to reduce the attribute variations that result from normal production variations.

5. Concurrent Engineering

To achieve a smoother transition from product design to production, and to decrease product development time, many companies are using simultaneous development, or concurrent engineering. In its narrowest sense, concurrent engineering means bringing design and manufacturing engineering people together early in the design phase to simultaneously develop the product and the processes for creating the product.

- We include people from Operations, Purchasing, and Marketing. Customers and suppliers are also invited to participate in certain stages of development.
- The purpose is to achieve product designs that reflect customer wants as well as manufacturing capabilities.



Concurrent Engineering : benefits

- Operations personnel contribue early on to avoid trial and errors and adapt the product to our capabilities.
- New Equipment can be ordered more quickly and reduce the time to market.

- Early consideration of the technical feasibility of a particular design or a portion of a design.
- Approach is based on problem résolution as opposed to conflict resolutions.

Potential difficulties:-

- Long-standing existing boundaries between design and manufacturing can be difficult to overcome.
- extra communication and flexibility

6. Computer-Aided Design (CAD)

Computers are increasingly used for product design. Computer-aided design **(CAD)** uses computer graphics for product design. The designer can modify an existing design or create a new one by means of a light pen, keyboard, a joystick, or a similar device. Once the design is entered into the computer, the designer can maneuver it on the screen. The designer can obtain a printed version of the completed design and file it electronically, making it accessible to people in the firm who need this information (e.g., marketing). A major benefit of **CAD** is the increased productivity of designers. No longer is it necessary to laboriously prepare mechanical drawings of products or parts and revise them repeatedly to correct errors or incorporate revisions.

Benefits of CAD/CAM

- Product quality
- CAD provides an opportunity for the designer to investigate more alternatives, potential problems and dangers.
- Shorter design time :- Since time is money, the shorter the design phase, the lower the cost
- Production cost reductions :- Faster implementation of design changes lowers costs
- Database availability
- Consolidating product data so everyone is operating from the same information results in dramatic cost reductions
- New range of capabilities
- CAD/CAM removes substantial detail work, allowing designer to concentrate on the conceptual and imaginative aspects of their task. This is indeed a major benefit of CAD/CAM

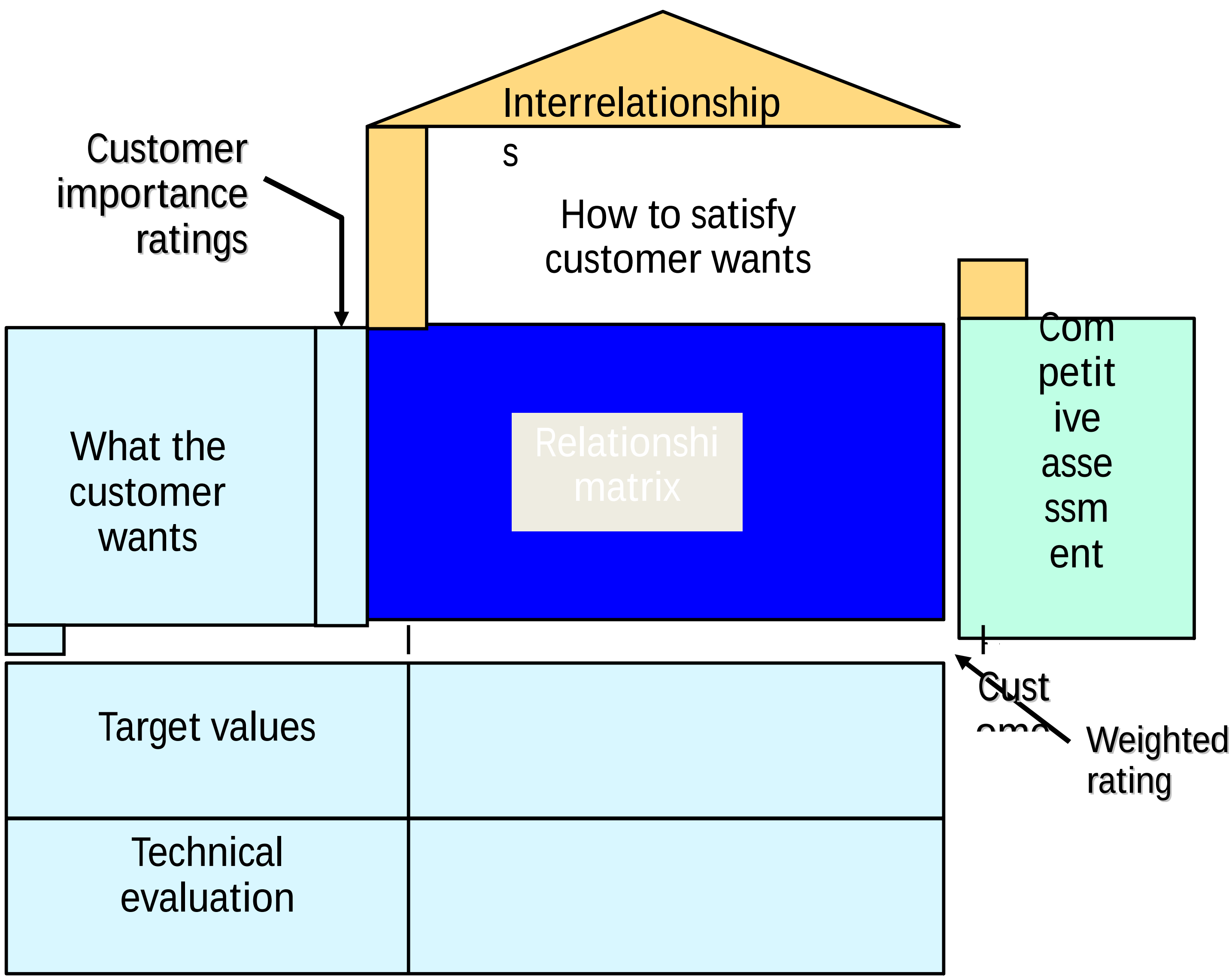
7. **Quality function deployment**

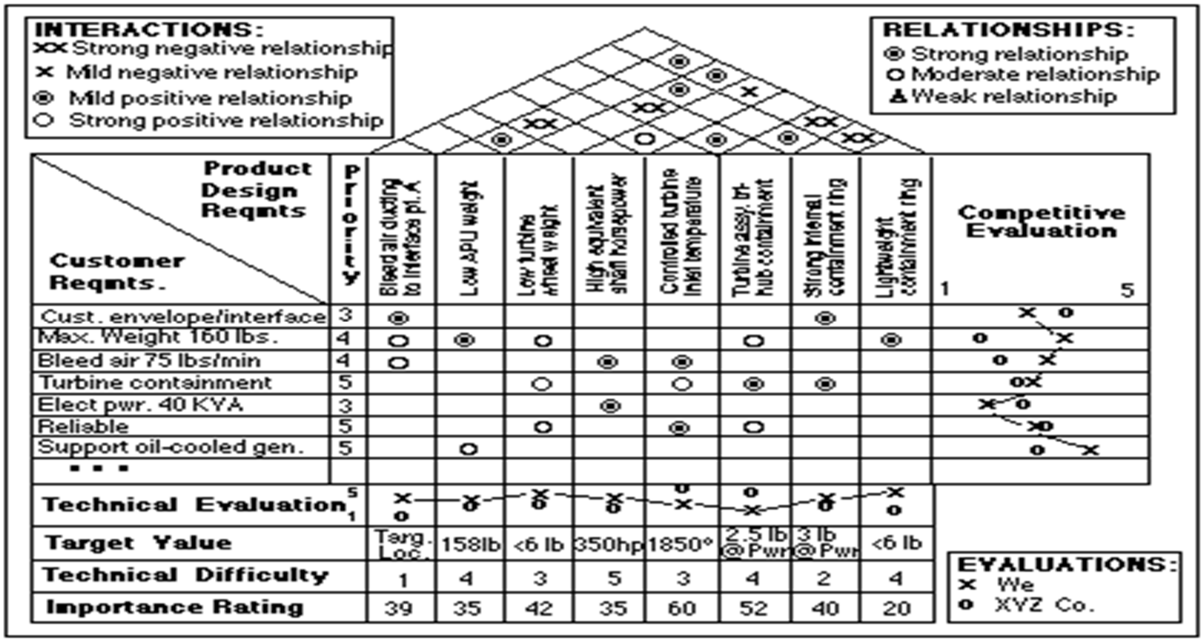
An important aspect of product design is to identify customers' preferences with respect to product features and to convert them into appropriate technical or design attributes. Professor

YojiAkao developed a structured method for doing this called **quality function deployment (QFD)**. The method is based on completing a series of matrices and then combining them into a comprehensive table referred to as the **house of quality**.

Steps of preparing the matrix

- ☑ Identify customer wants
- ☑ Identify how the good/service will satisfy customer wants
- ☑ Relate customer wants to product how's
- ☑ Identify relationships between the firm's how's
- ☑ Develop importance ratings
- ☑ Evaluate competing products
- ☑ Compare performance to desirable technical attributes





8. **Value analysis/value engineering (VA/VE)** is a design methodology developed by Lawrence Miles in the late 1940s that focuses on the function of the product, rather than on its structure or form, and tries to maximize the economic value of a product or component relative to its cost. Three important aspects of value analysis are (i) the use of multidisciplinary teams, (ii) a systematic procedure for evaluating product functionality and value, and (iii) a focus on product simplification.

   The purpose of Value analysis/value engineering (VA/VE) is to simplify product and processes. Its objective is to achieve equivalent or better performance at a lower cost while maintaining all functional and aesthetic requirements defined by the customer.

   VA/VE is the method for improving the product without increasing its cost or reducing cost without reducing the usefulness of the product for the customer. It can result in cost saving or a better product for the customer or both. VA/VE does this by identifying and eliminating product feature which will raise unnecessary cost without adding value to customer.

   Value is defined as the ratio of usefulness to cost. Cost is an absolute term and measure the amount of resources used to produce the product. Usefulness, on the other hand is a relative term describing the functionality that the customer ascribes to the product.

   Although VA and VE are similar in terms of their purpose and objective, technically, VA deals with products already in production processes and used to analyze product specification and requirements as shown in production documents and purchase requests. Typically purchasing department use VA as cost reduction techniques. Performed before the production stage, VE is considered as a cost avoidance method. In practice however, there is a looping back and forth between the two for a given product. This occurs because new materials, processes, and so forth require the application of VA techniques to products that have previously undergone in VE.

Benefits of value analysis/value engineering

- Reduced complexity of products.
- Improved functional aspects of product.
- Improved maintainability of the product.
- Lower costs
- Lower inventories
- Less labor required (simpler flows, easier tasks)
- Higher quality:
- Simple, easy-to-make products means fewer opportunities to make mistakes

9. **Modular Design**

Modular design makes it possible to have relatively high product variety and low component variety at the same time. The basic idea is to develop a series of basic product components, or modules that can be assembled into a large number of different products. To the customer, it appears there are a great number of different products. To operations, there are only a limited number of basic components and processes.

Controlling the number of different components that go into products is of great importance to operations, since this makes it possible to produce more efficiently for large volumes while also allowing standardization of processes and equipment. A large number of product variations greatly increase the complexity and cost of operations.

Modular design offers a fundamental way to change product design thinking. Instead of designing each product separately, the company designs products around standard component modules and standard processes. Common modules should be developed that can serve more than one product line, and unnecessary product frills should be eliminated. This approach will still allow for a great deal of product varieties but the number of unnecessary product variations will be reduced.

The usual way to develop products is to design each one separately without much attention to the other products in the line. Each product is optimized, but the product line as a whole is not. Modular design requires a broader view of product lines, and it may call for changes in individual products to optimize the product line in its entirety.

10. Product Variety

The issue of product variety must be considered from both marketing and an operations point of view. From a marketing point of view, the advantage of a large number of products is the ability to offer customer more choices. Sales may drop if the firm does not offer as many products as its competitors. From an operations point of view, high product variety is seen as leading to higher cost, greater complexity, and more difficulty in specializing equipment and people.

The ideal operations situation is often seen as a few high volume products with stabilized production configurations. Operations managers often prefer less product variety. There is an optimum amount of product variety which results in maximum profits. Both too little and too much product variety will lead to low profits.

Activity 3.2

Answer the following questions before continuing to the next section.

1. Write down steps in product design and development process.

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2. What are the major Fact or concepts that motivate the design activity

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3. List down the three strategies associated to design for ease production

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Checklist

Dear students if you understand the following terms put a tick (✓) mark in the box, otherwise read the section again.

- Robust Design ---
- Value analysis or value engineering ----------------------
- Quality function deployment ------------------------------
- Concurrent engineering ------------------------------------
- Computer Aided Design ------------------------------

3.1.9 Basic principles of designing products for production

Attentions to production, CE, and team design are important in obtaining compatibility between the product and the production process. But this is not enough. Those involved in product design need design principles and tools to guide their thinking and to help them evaluate alternative product designs. The overriding principle of product design is "Make it simple!" Simplicity of design and simplicity of the production process can be promoted by using the following principles:

1. Minimize the number of parts
2. Use common components and processes
3. Use standard components and tools
4. Simplify assembly
5. Use modularity to obtain variety
6. Make product specifications and tolerances reasonable
7. Design products to be robust

In the case of an airplane, as in most manufactured items, a component is typically defined by a drawing, usually referred to as an engineering drawing. An engineering drawing shows the dimensions, tolerances, materials, and finishes of a component. The engineering drawing will be an item on a bill-of-material.

The bill-of-material (BOM) lists the components, their description, and the quantity of each required to make one unit of a product. An engineering drawing shows how to make one item on the bill-of-material.

In the food service industry, bills-of-material manifest themselves in portion control standards.

For e.g., products such as: - chemicals, paints, or petroleum may be defined by formulas or proportions that describe how they are to be made. Motives are defined by scripts, and insurance by legal documents, known as policies.

3.1.10 Service Operations Design

Service is the dominant economic force in the industrialized world today, and growth projections indicate this trend will continue. Yet, service production receives far too little emphasis in operations Management courses and business course in general.

Defining Service

Service is an intangible product, which is produced and consumed simultaneously. Therefore, a service never exists, only the results of the service can be observed. If you get a haircut, the effect is obvious, but the service itself was produced and consumed at the same time.

Simultaneous production and consumption is a critical aspect of service, because it implies that the customer must be in the production system while production takes place. The simultaneity of production and consumption indicate that service cannot be stored or transported; it must be produced at the point of consumption. For operations this means that capacity must be located at or near the customer's location and that the service cannot be produced now and placed into inventory for later consumption.

Service consists of acts and interactions that are social contacts. The interaction between the producer and customer at the time of production is a critical attribute of service. There are professional services such as medicine, law, education and architecture; and capital-intensive services; such as airlines, electric utilities; mass services such as retailing, wholesale, and fast food.

Differences between manufacturing and service

1. Product are generally tangible service are generally intangible consequently, service design often focused on intangible factors (e.g peace of mind, ambiance that does product design)
2. In many instances service are created and delivered at the same time (eg a haircut, a car wash). In such instance there is less latitude in finding and correcting errors before the customer has a chance to discover them. Consequently, training, process design, customer relations are particularly important.

3. Service cannot be inventoried this poses restrictions on flexibility and makes capacity design very important.
4. Services are highly visible to consumers and must be designed with that in mind; this adds an extra dimension to process design, one that usually is not present in product design.
5. Some services have low barriers to entry and exit. This place additional pressure on service design to be innovative and cost effective.
6. Location is often important to service design, with convenience as a major factor. Hence, design of service and choice of location are often closely linked.

3.1.11 Framework for Services

The framework (the service triangle) shown below, assumes there are four elements, which must be considered in producing services: the customer, people, strategy, and the system.

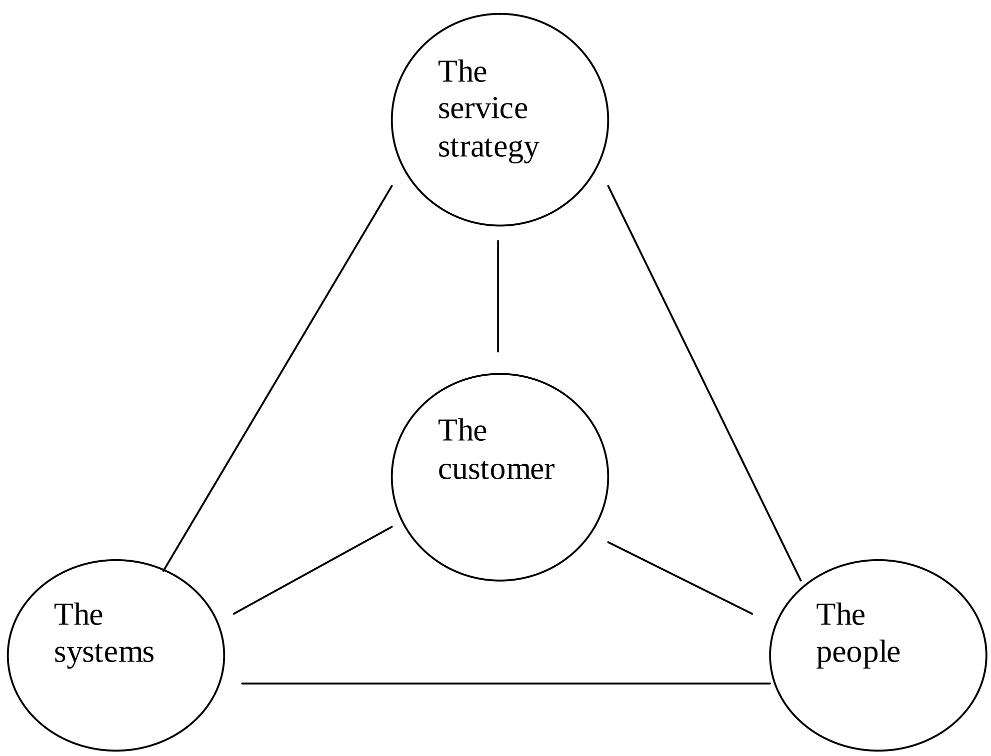


Figure 3.. The service triangle

- The customer is (or should be) the focal point of all decisions and actions of the service organization.
- People are the employees of the service firm who serve the customer.

- The strategy is the vision or philosophy, which is used to guide all aspects of service delivery.
- The service system includes procedures, equipment, and facilities.

The line from the customer to the strategy indicates that the strategy should put the customer first, by meeting the true needs of the customer. Management should ask what goes in the customer's mind.

How does the customer think? What does the customer really want? Also, the company must communicate the service strategy to the customer. What does the company provide that is unique? Why should the customer buy from this company?

The line from customer to system indicates that the system (procedures and equipment) should be designed with the customer in mind.

- crowded seats in airplanes
- forms that cannot be understood, and
- uncomfortable restaurants do not lead to good customer service

The customer-to-people line indicates that everyone should be customer driven, not only the operations people who deliver the service, but all people in the organization. People are the most important element in delivering superior service.

The people-to-system line indicates that people depend on the system to deliver good service. Service systems should be designed to be simple, fast and efficient to operate.

The strategy-to-people line indicates that everyone in the organization should be aware of the strategy. The front-line people who deliver the service are often divorced from the strategy. Management views them as "cog in the wheel" and not in need of knowing service strategy. As a result poor service is delivered.

Phases in services design process

- Conceptualization
- Identify service package component
- Determine performance specification and translate in to design specification
- Translate potential design specification to delivery specification

Design guidelines

A number of simple but highly effective rules are often used to guide the development of service systems. The key rules are the following:

- Have a single, unifying theme, such as convenience or speed. This will help personnel to work together rather than at cross-purposes.
- Make sure the system has the capability to handle any expected variability in service requirements.
- Include design features and checks to ensure that service will be reliable and will provide consistently high quality.
- Design the system to be user-friendly. This is especially true for self-service systems.

Seven characteristics of well – designed service system

- Each element of the service system is consistent with the operating focus of the firm.
- It is use friendly
- It is robust
- It is structured consistent performance by its people and system is easily maintained.
- It provides effective links between the back office and the front office so that nothing falls between the cracks. In football parlance, there should be "no fumbled handoffs."
- It manages the evidence of service quality in such a way that customers see the value of the service provided.
- It is cost effective.

Service–product bundle

Most services come bundled with facilitating goods in a service-goods package. For example when customers go to a restaurant, they receive not only the food but the service, which they hope is fast, courteous, and pleasant.

- The service product bundle consists of three elements:

1. The physical goods (facilitating goods)
2. The sensual service provided (explicit service)
3. The psychological service (implicit service)

Service recovery

Service recovery is an important part of the product design. When there is a service failure, service recovery is the ability to quickly compensate for the failure and restore, if possible, the service required by the customer. For example, when there is a power failure, service recovery is the time it takes for the electric company to restore power. The service recovery must be swift and appropriate in the customer's eyes.

Service guarantees

Many companies are now beginning to offer service guarantees as a way to define service and ensure its satisfactory delivery to the customer. A service guarantee is like its counterpart the product guarantee, except for one thing: the customer cannot return the service if he or she does not like it. For example, if you didn't like your haircut, you have to live with it that way, until it grows out.

The advantage of a service guarantee is it builds customer loyalty and clarifies exactly what the service process must provide.

Cycle of service

The service provided must be considered not only in light of a single service encounter but in terms of the entire cycle of service delivery. Every service is delivered in a cycle of service beginning with the point of initial customer contact and proceeding through steps or stages until the entire service is completed.

Each contact with a service system can be defined as a moment of truth. A moment of truth is any time that the customer comes in contact with the service system during the cycle of service delivery. It is the cumulative effect of all of the moments of truth that defines the service provided. A bad moment of truth can cancel out many positive moments. Even where service recovery is provided, it is better to prevent service failure at each moment of truth than to recover from service failures. As a result, the entire cycle of service should be managed.

Perceived service = f (all previous moments of truth).

Managing the moments of truth to achieve a positive experience is the essence of service process design.

Degree of Customer Contact

With a low customer contact process, it is possible to buffer the customer from the actual process of production. Separating the customer from the service production system allows for more efficiency and greater standardization of processes. Examples of low-contact systems are catalog order processing and automatic bank teller transactions.

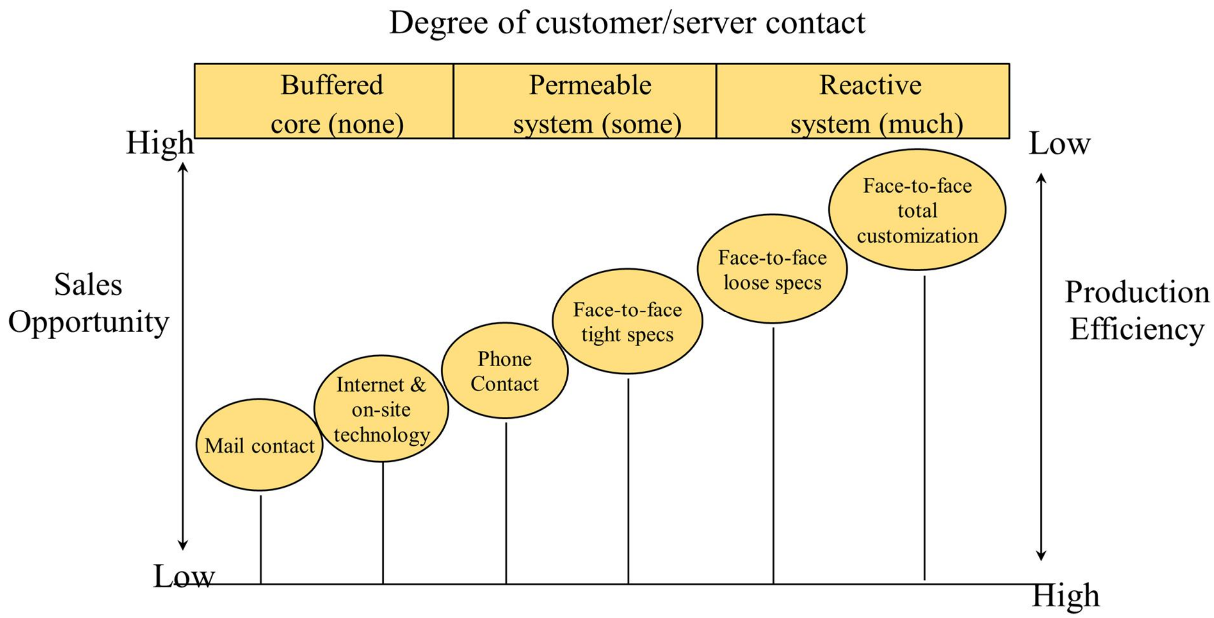
If customer contact is high, the customer can disrupt the production process by demanding certain types of services or special treatment. Therefore, high customer contract can lead to inefficient production process. A customer could require special consideration or more processing time and may impose unique requirements on the service provider like in dentistry and haircut.

High-contact systems have the customer in the system during the production of the service. In these systems, the customer can introduce uncertainty into the process with a resulting loss of efficiency. High-contact systems can lead to a loss of efficiency as follows:

Potential inefficiency =f (degree of customer contact)

The measure of degree of contact is the amount of time that the customer is in the system while the service is being produced. A highly efficient system is one with no customer contact, where the order can be processed away from the customer.

Service-System Design Matrix



Characteristics of high-and low-contact services:

- ✓ Low-contact services are used when face-to-face interaction is not required. High-contact operations are used for changing or uncertain customer demand.
- ✓ Low-contact services require employees with technical skills, efficient processing routines, and standardization of the product and process. High-contact services require employees who are flexible, personable, and willing to work with the costumer (the smile factor).
- ✓ High-contact services generally require higher prices and more customization due to the variable nature of the service required.

3.1.12 Service delivery system design

The design of the service delivery system addresses the question of "how" the service concept is delivered to target customers (Tax and Stuart, 1997). A large number of issues need to be considered to design a service delivery system. Heskett (1987) suggests that design choices revolve around the role of people, technology, facilities, equipment, layout, service processes, and procedures. Similarly, Ramaswamy (1996) suggests that service system design decisions concern the service facilities where the service is provided and the processes through which the service is delivered. Since a service system is characterized by the relationships occurring between people, service processes, and physical elements, these dimensions must be considered jointly to effectively plan and conceive the service delivery system (Tax and Stuart, 1997). Roth and Menor (2003) offer a compelling account of design choices for the service delivery system. They argue that design decisions include aspects of structure, infrastructure, and integration.

Structural choices relate to the physical aspects of the service system such as facilities, layout, and equipment. Infrastructural choices refer to the role of service providers such as job design, policies, and skill set.

Differing Service Designs

There is no one model of successful service design. The design selected should support the company's service concept and provide the features of the service package that the target customers want. Different service designs have proved successful in different environments. In this section we look at three very different service designs that have worked well for the companies that adopted them.

A. Substitute Technology for People

Substituting technology for people is an approach to service design that was advocated some years ago by Theodore Levitt[1]. Levitt argued that one way to reduce the uncertainty of service delivery is to use technology to develop a production-line approach to services.

Substituting technology for people is an approach we have seen over the years in many service industries. For example, almost all gas stations have reduced the number of cashiers and attendants with the advent of credit card usage at self-serve pumps. In addition, many hospitals are using technology to monitor patient heart rate and blood pressure without relying exclusively

[1]Theodore Levitt, "Production Line Approach to Services," *Harvard Business Review* 50, no. 5 (September– October 1972), pp. 41–52.

on nurses. As technologies develop in different service industries, we will continue to see an ever-increasing reliance on its use and an increase in the elimination of workers.

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B. Get the Customer Involved

A different approach to service design was proposed by C. H. Lovelock and R. F. Young.[2] Their idea was to take advantage of the customer's presence during the delivery of the service and have him or her become an active participant. This is different from traditional service designs where the customer passively waits for service employees to deliver the service. Lovelock and Young proposed that since the customers are already there, "get them involved."

This type of approach has a number of advantages. First, it takes a large burden away from the service provider. The delivery of the service is made faster and costs are reduced due to lowered staffing requirements. Second, this approach empowers customers and gives them a greater sense of control in terms of getting what they want. This approach provides a great deal of customer convenience and increases satisfaction. However, as different types of customers have different preferences, many facilities are finding that it is best to offer full-service and self-service options. For example, many breakfast bars still allow a request for eggs cooked and served to order, and most gas stations still offer some full-service pumps.

C. High Customer Attention Approach

A third approach to service design is providing a high level of customer attention. This is in direct contrast to the first two approaches we discussed. The first approach discussed automates the service and makes it more like manufacturing. The second approach requires greater participation and responsibility from the customer. The third approach is different from the first two in that it does not standardize the service and does not get the customer involved.

Rather, it is based on customizing the service needs unique to each customer and having the customer is the passive and pampered recipient of the service. This approach relies on developing a personal relationship with each customer and giving the customer precisely what he or she wants. Whereas the first two approaches to service design result in lowered service costs, this third approach is geared toward customers that are prepared to pay a higher amount for the services they receive. As you can see, different approaches are meant to serve different types of customers. The design chosen need to support the specific service concept of the company.

3.1.13 Service blueprint

The **service blueprint** is a technique used for service innovation. The technique was first described by Lynn Shostack, a bank executive, in the Harvard Business Review in 1984. The blueprint shows processes within the company, divided into different components which are separated by lines

1. **Customer Actions**

This component contains all of the steps that customers take as part of the service delivery
This element is always on top of the service blueprint.

2. **Onstage / Visible Contact Employee Actions**

This element is separated from the customer actions by a 'line of interaction'. These actions are face-to-face actions between employees and customers.

3. **Backstage / Invisible Contact Employee Actions**

The 'line of visibility' separates the Onstage from the Backstage actions. Everything that appears above the line of visibility can be seen by the customers, while everything under the line of visibility is invisible for the customers. A very good example of an action in this element, is a telephone call; this is an action between an employee and a customer, but they don't see each other

4. **Support Processes**

The 'internal line of interaction' separates the contact employees from the support processes. These are all the activities carried out by individuals and units within the company who are not contact employees. These activities need to happen in order for the service to be delivered.

5. **Physical Evidence**

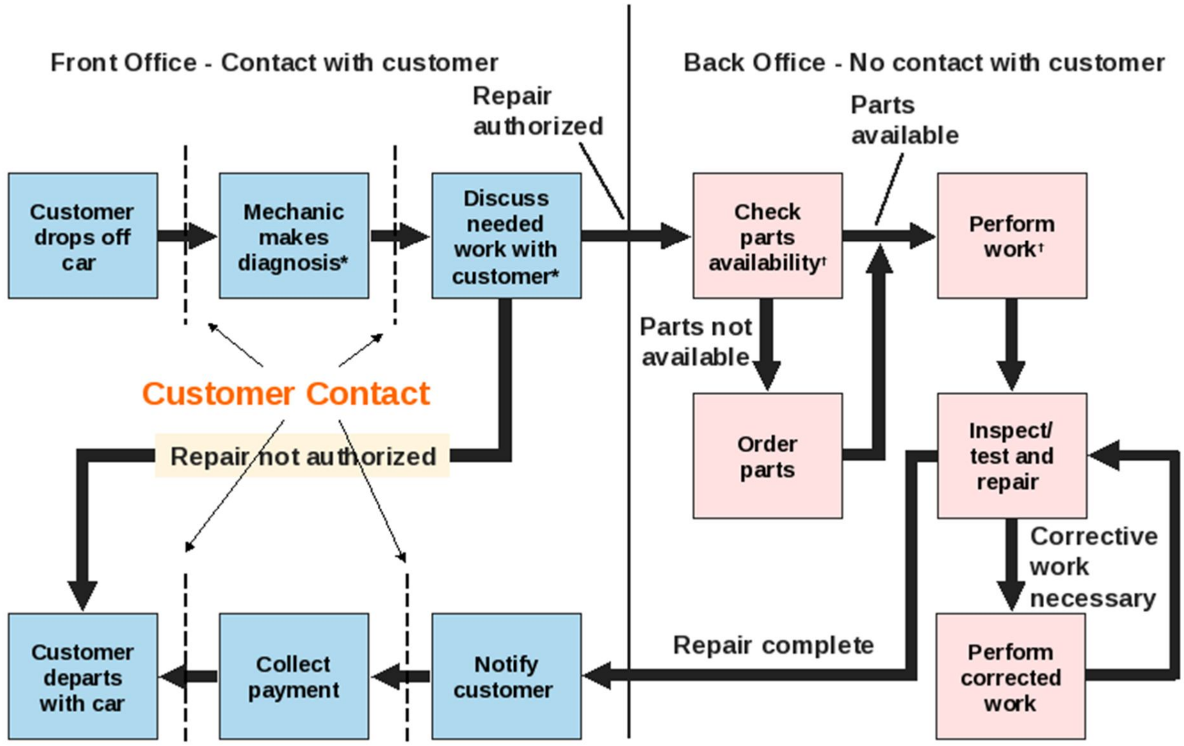
For each customer action, and every moment of truth, the physical evidence that customers come in contact with is described at the very top of the service blueprint. These are all the tangibles that customers are exposed to that can influence their quality perceptions

Building a blueprint

The process of structuring a blueprint involves six steps:

- The identification of the service process, that is supposed to be blueprinted
- The identification of the customer segment or the customers that are supposed to experience the service
- Picturing the service from the customer's perspective
- Picturing the actions of the contact employee (onstage and backstage), and/or technology actions
- Linking the contact activities to the needed support functions
- Adding the evidence of service for every customer action step

Auto repair example of SBP



Activity 3.2

Answer the following questions before continuing to the next section.

1. Write down the three elements of service product bundle.

___

___

___

___

2. What is service and how it differs from manufacturing operation?

___

___

___

3. List down at least three major **characteristics of well-designed service system**

___

___

___

Checklist

Dear students if you understand the following terms put a tick (✓) mark in the box, otherwise read the section again.

- A moment of truth --- ☐
- Service guarantees -- ☐
- Service-goods package --- ☐
- Service blueprint -- ☐
- Service recovery --- ☐

3.2 Process choice design decision

Introduction

Dear students up to know we tried to discuss about product and service design, now let's ponder on another major issue of operations design, i.e. process strategies

Operations managers are responsible for the design, and as in the above case, redesign of processes. Through processes, we operationalize strategies (turn them into reality) and create and deliver the product/ service offerings required. The operations manager's role is vitally important in integrating all the contributors into the design/redesign process.

What is a process?

"Process" is defined as all operations or activities that consume significant resources.

Resources include:

- The utilization of materials,
- Labor,
- Energy, and
- Facility or plant capacity

Major Process Decisions

The five key decisions in process management are:

- Process Choice: Determines how processes are designed relative to the kinds of resources needed, how resources are partitioned between them, and their key characteristics.
- Vertical Integration: The more processes in the supply chain that the more vertically integrated it are. If it doesn't perform some processes itself, it must rely on outsourcing,

- Resource Flexibility: is the ease with which employees and equipment can handle a wide variety of products, output levels, duties, and functions.
- Customer Involvement: refers to the ways in which customers become part of the process and the extent of their participation.
- Capital intensity is the mix of equipment and human skills in a process.

Process Strategies

- It Involves determining how best to produce a product or provide a service
- The ultimate Objective of every process strategies are the following
    - Meet or exceed customer requirements
    - Meet cost & managerial goals

3.2.1. Types of Process Strategies

Virtually every good or service is made by using some variation of one of four process strategies i.e. process focus, repetitive focus, product focus and mass customization. The relations of these four strategies to volume and variety are shown in figure. Although the figure shows only four strategies an innovative operations manager can build process anywhere in the matrix to meet the necessary volume and variety requirements.

Process Focused Repetitive Focus Product Focus

1. Process focus/ Intermittent Operations/JOB SHOP

Seventy- five percent of all global production is devoted to making low-volume, high variety products in place called “job shops”. Such facilities are organized around specific activities of processes. In a factory, these processes might be departments devoted to welding, grinding and painting. In an office, the processes might be accounts payable, sales and payroll. Such facilities are process focused in terms of equipment, layout and supervision. They provide high degree of product flexibility as product move intermittently between processes. Each process is designed to perform a wide variety of activities and handle frequent changes. Consequently, they are also called intermittent processes.

A job shop is a conversion process in which units for different orders follow different sequences through the resource centers grouped by function to satisfy special customer needs for products or services.

Facilities are organized by process; similar processes are together

Low volume, high variety products, Jumbled flow

These facilities have high variable costs with extremely low utilization of facilities, as low as 5%. This is the case for many restaurants, hospitals and machine shops. However, some facilities no do somewhat better through the use of innovative equipment, often with electronic control.

- Advantages
  - Greater product flexibility-allows more customization
  - More general purpose equipment
  - Lower initial capital investment
- Disadvantages
  - More highly trained personnel
  - More difficult production planning & control
  - Low equipment utilization (5% to 25%)
  - high variable cost

2. Repetitive focus

A repetitive process falls between the product and process focuses. Repetitive processes use modules. Modules are parts or components previously prepared often in a continuous process. The repetitive process line is the classic assembly line. Widely used in the assembly of virtually all automobiles and household appliances, it has more structure and consequently less flexibility than a process focused facility.

Facilities often organized by assembly lines

More structured than process focused, less structured than product focused

Enables quasi-customization

Using modules, it enjoys economic advantage of continuous process and custom advantage of low-volume, high variety model.

Fast food firms are an example of a repetitive process using modules. This type of production allows more customizing than a continuous process. Modules (meat, cheese, sauce, tomatoes, and onions) are assembled to get a quasi-custom product, a cheeseburger. In this manner, the firm obtains both the economic advantages of the continuous model (where many modules are prepared) and the custom advantage of the low volume, high variety model.

3. Product focus/Line flow production/Continuous production

High volume, low variety processes are product focused. The facilities are organized around products. They are also called continuous processes, because they have very long, continuous production runs. Products such as glass, paper, light bulbs, beers and tin sheets are made via a continuous process. It is only with standardized and effective quality control that firms have established product focused facilities. An organization that produces the same product day after day can be organized using product focus. Such an organization has an inherent ability to set standards and maintain a given quality, as opposed to an organization that is producing unique products every day.

A flow shop is a conversion process in which successive units of output undergo the same sequence of operations with specialized equipment, usually positioned along a product line.

Product focused facility produces high volume and low-variety. The specialized nature of the facility requires high fixed cost but low variable cost and reward high facility utilization.

Advantages

- Lower variable cost per unit
- Lower but more specialized labor skills
- Easier production planning and control
- Higher equipment utilization (70% to 90%)

- Disadvantages
  - Lower product flexibility
  - More specialized equipment
  - Usually higher capital investment

4. Mass customization:

Our increasingly wealth and sophisticated world demands individualized goods and services. The exploitation of variety of products that operations managers are called on to supply, quality has improved and costs have dropped. Consequently, this wealth of products is available to more people than ever. Operations managers have produced this selection of goods and services through what is known as mass customization. But mass customization is not just about variety, it is about economically making precisely what the customers wants when the customer wants it.

Mass customization is rapid, low cost production of goods and services that fulfill increasingly unique customer desires. Mass customization brings us the variety of products traditionally provided by low volume manufacture (a process focus) at the cost of standardized high volume production. However, producing to achieve mass customization is a challenging requiring enhanced operational capability. The link between sales and production and logistics is much tighter. Operations manager must make imaginative and aggressive use of organizational resources to build agile processes that rapidly and inexpensively produce custom products.

Other specialized types of process strategies

A. Project processes are used to make one-of-a-kind products exactly to customer specifications. These processes are used when there is high customization and low product volume, because each product is different. Examples can be seen in construction, shipbuilding, medical procedures, and creation of artwork, custom tailoring, and interior design. With project processes the customer is usually involved in deciding on the design of the product. The artistic baker you hired to bake a wedding cake to your specifications uses a project process.

B. Batch processes are used to produce small quantities of products in groups or batches based on customer orders or product specifications. They are also known as job shops. The volumes of each product produced are still small and there can still be a high degree of customization. Examples can be seen in bakeries, education, and printing shops. The classes you are taking at the university use a batch process.

C. Line processes are designed to produce a large volume of a standardized product for mass production. They are also known as flow shops, flow lines, or assembly lines. With line processes the product that is produced is made in high volume with little or no customization. Think of a typical assembly line that produces everything from cars, computers, television sets, shoes, candy bars, even food items.

D. Continuous processes operate continually to produce a very high volume of a fully standardized product. Examples include oil refineries, water treatment plants, and certain paint facilities. The products produced by continuous processes are usually in continual rather than discrete units, such as liquid or gas.

They usually have a single input and a limited number of outputs. Also, these facilities are usually highly capital intensive and automated

COMPARISON OF THE TWO MAJOR AND MOST COMMONLY USED PROCESS STRATEGIES

Decision	Intermittent Operations (process focused)	Repetitive Operation (product focused)
Product variety	Great	Small
Degree of standardization	Low	High
Organization of resources	Grouped by function	Line flow to accommodate processing need
Path of products through facility	In a varied pattern, depending on product needs	Line flow
Factor driving production	Customer orders	Forecast of future demands
Critical resource	Labor intensive operations (worker skills important)	Capital intensive operation (equipment, automation, and technology important)
Type of equipment	General purpose	Specialized
Degree of automation	Low	High

Through put time	Longer	Shorter
Work in process inventory	More	Less

3.2.2 Process Performance Metrics

A key factor in the success of every organization is its ability to measure performance. Such feedback on a continuous basis provides management with the data necessary to determine if established goals or standards are being met. As peter Ducker, a well-known management guru, has said, “If you can’t measure it, you can’t manage it.” Without proper measures of performance, managers cannot assess how well their organizations are doing or compare their performance with that of their competitors. Without these performance measures, managers would be like ships’ captains, adrift on the ocean with no land in sight and no compass or other navigational instruments to guide them.

However, with the growing number of performance measures available, managers today must be selective in choosing only those measures that are critical to their firm’s success. Depending on the specific industry or market niche within that industry, some measures of performance are more important to management than others. For example, in a fast food outlet, a key performance indicator is the speed with which food is delivered to the customer. In an upscale restaurant, on the other hand, key performance measures may be the variety of items offered on the menu and the quality of food served.

In today’s information-intense environment, managers, like everyone else, are deluged with reams of reports containing data on all aspects of a company’s performance. It is therefore, essential for management to identify those key indicators that measure those parameters that are critical to the success of their firms.

An important way of ensuring that a process is functioning properly is to regularly measure its performance. Process performance metrics are measurements of different process characteristics that tell us how a process is performing. Just as accountants and finance managers use financial metrics, operations managers use process performance metrics to determine how a process is performing and how it is changing over time. There are many process performance metrics that focus on different aspects of the process. In this section we will look at some common metrics used by operations managers. These are summarized in Table 2-3.

Table 2-3: Process performance matrices

Measure	Definition
Throughput time	Average amount of time product takes to move through the system.
Process velocity $=\frac{throughput time}{value-added time}$	A measure of wasted time in the system
Productivity $=\frac{output}{input}$	A measure of how well a company uses its resources
Utilization $=\frac{time a resource used}{time a resource available}$	The proportion of time as resource is actually used[3]
Efficiency $=\frac{actual output}{standard output}$	Measures performance relative to a standard
Quality	Measured by the defect rate of the products produced[4]
Speed of delivery	Measured using lead time and variability in delivery time
Flexibility	A measure of how readily the company's transformation process can adjust to meet the ever changing demands of its customers [5]

- Capacity utilization where capacity refers to the output of a process in a given time period, It is typically presented in units of output per unit of time.
- Defects include those products that are identified as nonconforming, both internally (prior to shipping the product to the customer) as well as externally (i.e., products whose defects are found by the customer). The topic of process quality measurement and control will be covered in greater detail in section four of the course outline under Quality management.
- Flexibility has three dimensions. The first dimension indicates how quickly a process can convert from producing one product or family of product to another. Another measure of flexibility is its ability to react to changes in volume. Those processes can accommodate

large fluctuations in volume. The third dimension of flexibility is the ability of the process to produce more than one product simultaneously. The dimension of flexibility is especially important in producing customized products

Examples of measuring process performance:

1. If the throughput time for a product is six weeks, and the actual value-added time to complete the product is four hours, then the process velocity of this product is

   Process velocity = $\frac{totalthroughputtime}{value-addedtime}$

   $= \frac{6\ weeks \times 5\ daysperweek \times 8\ hoursperday}{4\ hours} = 60$

   A process velocity 60, in this case, means that it takes 60 times as long to complete the product as it does to do the actual work on the product itself. In other words, process velocity is like golf score- the lower it is the better.

2. XYZ Company is analyzing its operations in an effort to improve performance. The following data have been collected: It takes an average of 4 hours to process and close a title, with value-added time estimated at 30 minutes per title; each title officer is on payroll for 8 hours per day, though working 6 hours per day on average, accounting for lunches and breaks. Industry standard for labor utilization is 80 percent; The Company closes on 8 titles per day, with an industry standard of 10 titles per day for a comparable facility.

   Required: Determine the process velocity, labor utilization, and efficiency for the company. Can you draw any conclusions?

   Solution:

   Process velocity $=\frac{throughputtime}{value-addedt} = \frac{4\ hourspertitle}{0.5\ hourpertitle} = 8$

   Labor utilization = $\frac{6\ hoursperday}{8\ hoursperday}$ = 0.75 or 75%

   Efficiency = $\frac{8\ titlesperday}{10\ titlesperday}$ = .80 or 80%

   A process velocity of eight indicates that the amount of time spent on no value activities is 8 times that of value-added activities. In addition, labor utilization and efficiency are both below standard.

3.2.3 Linking product Design and process selection

Decisions of product design and process selection are directly linked and cannot be made independently of one another. The type of product a company produces defines the type of operation needed. The type of operation needed, in turn, defines many other aspects of the organization. This includes how a company competes in the marketplace (competitive priorities), the type or equipment and its arrangement in the facility, the type of organizational structure, and future types of products that can be produced by the facility. Table 2-4 summarizes some key decisions and how they differ for intermittent and repetitive types of operations. Next we look at each of these decision areas.

Table 2-4: Differences in Key Organizational Decisions for Different Types of operations

Decision	Intermittent operations /process focused	Repetitive operations/product focused
Product design	Early stage of product life cycle	Later stage of product life cycle
Competitive priorities	Delivery, flexibility, and quality	Cost and quality
Facility layout	Resources grouped by function	Resources arranged in a line
Product and service strategy	Make-to-order/ assemble-to-order	Make-to-stock
Vertical integration	Low	High

Activity 3.3

Answer the following questions before continuing to the next section.

1. What are the major key decisions in process management?

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2. What are the major difference between product and process focused process strategies?

____

____

____

3. Briefly explain Mass production process strategy.

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____

Checklist

If you understand the following words or phrases put a tick (✓) mark in the box, otherwise read the section again.

- Process velocity -- ☐
- Project processes -- ☐
- A flow shop -- ☐
- Capital intensity -- ☐
- Through put time -- ☐

3.3 Strategic Capacity Planning

Capacity decisions are one of the key policy decision areas for operations. Like other policy decisions, this involves making trade-offs between investing in productive resources and making the best use of them. On the one hand, transforming resources such as facilities, technology, and people are generally expensive and take time to acquire or create, so the organization wants to use them wisely. On the other, materials, information and effort may be wasted if they are acquired or transformed when there is no demand for them, while sales may be lost if outputs are not available when needed by consumers. Capacity issues are important for all organizations, and at all levels of an organization.

Defining capacity

In operations management, the term *capacity* describes the level of output that the organization can achieve over a specified period of time. Capacity can be defined in several different ways, and some of these are described below.

Capacity refers to an upper limit or ceiling on the load that an operating unit can handle. The operating unit might be a plant, department, machine, store, or worker.

The capacity of an operating unit is an important piece of information for planning purposes: It enables managers to quantify production capability in terms of inputs or outputs, and thereby make other decisions or plans related to those quantities. The basic questions in capacity planning of any sort are the following:

1. What kind of capacity is needed?
2. How much is needed?
3. When is it needed?

The question of what kind of capacity is needed depends on the products and services that management intends to produce or provide. Hence, in a very real sense, capacity planning is governed by those choices.

The most fundamental decisions in any organization concern the products and/or services it will offer. Virtually all other decisions pertaining to capacity, facilities, location, and the like are governed by product and service choices. Thus, a decision to produce high-quality steel will necessitate certain types of processing equipment and certain kinds of labor skills, and it will suggest certain types of arrangement of facilities. It will influence the size and type of building as well as the plant location. Notice how different each of these factors would be if the choice were to operate a family restaurant, and how still different they would be if the choice were to operate a hospital.

3.3.1 Importance of Capacity Decisions

For a number of reasons, capacity decisions are among the most fundamental of all the design decisions that managers must make.

- Capacity decisions have a real impact on the ability of the organization to meet future demands for products and services; capacity essentially limits the rate of output possible. Having capacity to satisfy demand can allow a company to take advantage of tremendous opportunities.
- Capacity decisions affect operating costs. Ideally, capacity and demand requirements will be matched, which will tend to minimize operating costs. In practice, this is not always achieved because actual demand either differs from expected demand or tends to vary

(e.g., cyclically). In such cases, a decision might be made to attempt to balance the costs of over- and under capacity.

- Capacity is usually a major determinant of initial cost. Typically, the greater the capacity of a productive unit, the greater its cost. This does not necessarily imply a one-for-one relationship; larger units tend to cost *proportionately* less than smaller units.
- Capacity decisions often involve long-term commitment of resources and the fact that, once they are implemented, it may be difficult or impossible to modify those decisions without incurring major costs.
- Capacity decisions can affect competitiveness. If a firm has excess capacity, or can quickly add capacity, that fact may serve as a barrier against entry by other firms.

3.3.2 Defining and Measuring Capacity

Capacity often refers to an upper limit on the *rate* of output. Even though this seems simple enough, there are subtle difficulties in actually measuring capacity in certain cases. These difficulties arise because of different interpretations of the term *capacity* and problems with identifying suitable measures for a specific situation.

In selecting a measure of capacity, it is important to choose one that does not require updating. For example, dollar amounts are often a poor measure of capacity (e.g. capacity of $30 million a year) because price changes necessitate continual updating of that measure.

Where only one product or service is involved, the capacity of the productive unit may be expressed in terms of that item. However, when multiple products or services are involved, as is often the case, using a simple measure of capacity based on units of output can be misleading. An appliance manufacturer may produce both refrigerators and freezers. If the output rates for these two products are different, it would not make sense to simply state capacity in units without reference to either refrigerators or freezers. The problem is compounded if the firm has other products.

No single measure of capacity will be appropriate in every situation. Rather, the measure of capacity must be tailored to the situation. The following table provides some examples of commonly used measures of capacity.

Table 3.1: Measures of capacity

Business	Inputs	Outputs
Auto manufacturing	Labor hours, machine hours	Number of cars per shift
Steel mill	Furnace size	Tons of steel per day
Oil refinery	Refinery size	Gallons of fuel per day
Farming	Number of acres, number of cows	Bushels of grain per acre per year, gallons of milk per day
Restaurant	Number of tables, seating capacity	Number of meals served per day
Theater	Number of seats	Number of tickets sold per performance
Retail sales	Square feet of floor space	Revenue generated per day

Up to this point, we have been using a working definition of capacity. Although it is functional, it can be refined into two useful definitions of capacity:

Design capacity: the maximum output that can possibly be attained. Designed capacity of a facility is the planned or engineered rate of output of goods or services under normal or full scale operating conditions. For example, the designed capacity of the cement plant is 100 TPD (Tons per day). Capacity of the sugar factory is 150 tons of sugarcane crushing per day.

The uncertainty of future demand is one of the most perplexing problems faced by new facility planners. Organization does not plan for enough regular capacity to satisfy all their immediate demands.

Design for a minimum demand would result in high utilization of facilities but results in inferior service and dissatisfaction of customers because of inadequate capacity. The design capacity should reflect management's strategy for meeting the demand. The best approach is to plan for some in-between level of capacity.

System/effective capacity: the maximum possible output given a product mix, scheduling difficulties, machine maintenance, quality factors, and so on. System capacity is the maximum output of the specific product or product mix the system of workers and machines is capable of producing as an integrated whole. System capacity is less than design capacity or at the most equal it because of the limitation of product mix, quality specification, and breakdowns. The actual is even less because of many factors affecting the output such as actual demand, downtime due to machine/equipment failure, unauthorized absenteeism. The system capacity is less than design capacity because of long-range uncontrollable factors. The actual output is still reduced because of short-term effects such as breakdown of equipment

These different measures of capacity are useful in defining two measures of system effectiveness: efficiency and utilization. *Efficiency* is the ratio of actual output to effective capacity. *Utilization* is the ratio of actual output to design capacity.

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

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

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

Given the information below, compute the efficiency and the utilization of the vehicle repair department:

Design capacity = 50 trucks per day

Effective capacity = 40 trucks per day

Actual output= 36 trucks per day

$$\text{Efficiency} = \frac{\text{Actual output}}{\text{Effective capacity}} = \frac{\text{36 trucks per day}}{\text{40 trucks per day}} = 90\%$$

$$\text{Utilization} = \frac{\text{Actual output}}{\text{Design capacity}} = \frac{\text{36 trucks per day}}{\text{50 trucks per day}} = 72\%$$

Thus, compared with the effective capacity of 40 units per day, 36 units per day looks pretty good. However, compared with the design capacity of 50 units per day, 36 units per day is much less impressive although probably more meaningful.

Because effective capacity acts as a lid on actual output, the real key to improving capacity utilization is to increase effective capacity by correcting quality problems, maintaining equipment in good operating condition, fully training employees, and fully utilizing bottleneck equipment.

Hence, increasing utilization depends on being able to increase effective capacity, and this requires knowledge of what is constraining effective capacity.

The following section explores some of the main determinants of effective capacity. It is important to recognize that the benefits of high utilization are only realized in instances where there is demand for the output. When demand is not there, focusing exclusively on utilization can be counterproductive, because the excess output not only results in additional variable costs, it also generates the costs of having to carry the output as inventory. Another disadvantage of high utilization is that operating costs may increase because of increasing waiting time due to bottleneck conditions.

3.3.3 Determinants of Effective Capacity

Many decisions about system design have an impact on capacity. The same is true for many operating decisions. This section briefly describes some of these factors,

The main factors relate to the following:

- Facilities
- Products or service
- Processes
- Human considerations
- Operations
- External forces

Facilities Factors; the design of facilities, including size and provision for expansion, is key. Location factors, such as transportation costs, distance to market, labor supply, energy sources, and room for expansion, are also important. Likewise, layout of the work area often determines how smoothly work can be performed, and environmental factors such as heating, lighting, and ventilation also play a significant role in determining whether personnel can perform effectively or whether they must struggle to overcome poor design characteristics.

Product/Service Factors, Product or service design can have a tremendous influence on capacity. For example, when items are similar, the ability of the system to produce those items is generally much greater than when successive items differ. Thus, a restaurant that offers a limited menu can usually prepare and serve meals at a faster rate than a restaurant with an extensive menu. Generally speaking, the more uniform the output, the more opportunities there are for standardization of methods and materials, which leads to greater capacity.

Process Factors, The quantity capability of a process is an obvious determinant of capacity. A more subtle determinant is the influence of output *quality*. For instance, if quality of output does not meet standards, the rate of output will be slowed by the need for inspection and rework activities.

Human Factors, The tasks that make up a job, the variety of activities involved, and the training, skill, and experience required to perform a job all have an impact on the potential and actual output. In addition, employee motivation has a very basic relationship to capacity, as do absenteeism and labor turnover.

Operational Factors, Scheduling problems may occur when an organization has differences in equipment capabilities among alternative pieces of equipment or differences in job requirements. Inventory stocking decisions, late deliveries, acceptability of purchased materials and parts, and quality inspection and control procedures also can have an impact on effective capacity.

External Factors, Product standards, especially minimum quality and performance standards, can restrict management's options for increasing and using capacity. Thus, pollution standards on products and equipment often reduce effective capacity, as does paperwork required by government regulatory agencies by engaging employees in nonproductive activities. A similar effect occurs when a union contract limits the number of hours and type of work an employee may do.

Developing Capacity Alternatives

Aside from the general considerations about the development of alternatives (i.e., conduct a reasonable search for possible alternatives, consider doing nothing, take care not to overlook no quantitative factors), some specific considerations are relevant to developing capacity alternatives. The considerations to be discussed in this section include the following:

1. **Design flexibility into systems.** The long-term nature of many capacity decisions and the risks inherent in long-term forecasts suggest potential benefits from designing flexible systems. For example, provision for future expansion in the original design of a structure frequently can be obtained at a small price compared to what it would cost to remodel an existing structure that did not have such a provision.

2. **Take a "big picture" approach to capacity changes.** A consideration for managers contemplating capacity increases is whether the capacity is for a new product or service, or a

mature one. Mature products or services tend to be more predictable in terms of capacity requirements, and they may have limited life spans. The predictable demand pattern means less risk of choosing an incorrect capacity, but the possible limited life span of the product or service may necessitate finding an alternate use for the additional capacity at the end of the life span. New products tend to carry higher risk because of the uncertainty often associated with predicting the quantity and duration of demand. That makes flexibility appealing to managers.

3. **Prepare to deal with capacity "chunks."** Capacity increases are often acquired in fairly large chunks rather than smooth increments, making it difficult to achieve a match between desired capacity and feasible capacity. For instance, the desired capacity of a certain operation may be 55 units per hour; but suppose that machines used for this operation are able to produce 40 units per hour each. One machine by itself would cause capacity to be 15 units per hour short of what is needed, but two machines would result in an excess capacity of 25 units per hour.

4. **Identify the optimal operating level**. Production units typically have an ideal or optimal level of operation in terms of unit cost of output. At the ideal level, cost per unit is the lowest for that production unit; larger or smaller rates of output will result in a higher unit cost. Figure 4-1 illustrates this concept. Notice how unit costs rise as the rate of output varies from the optimal level.

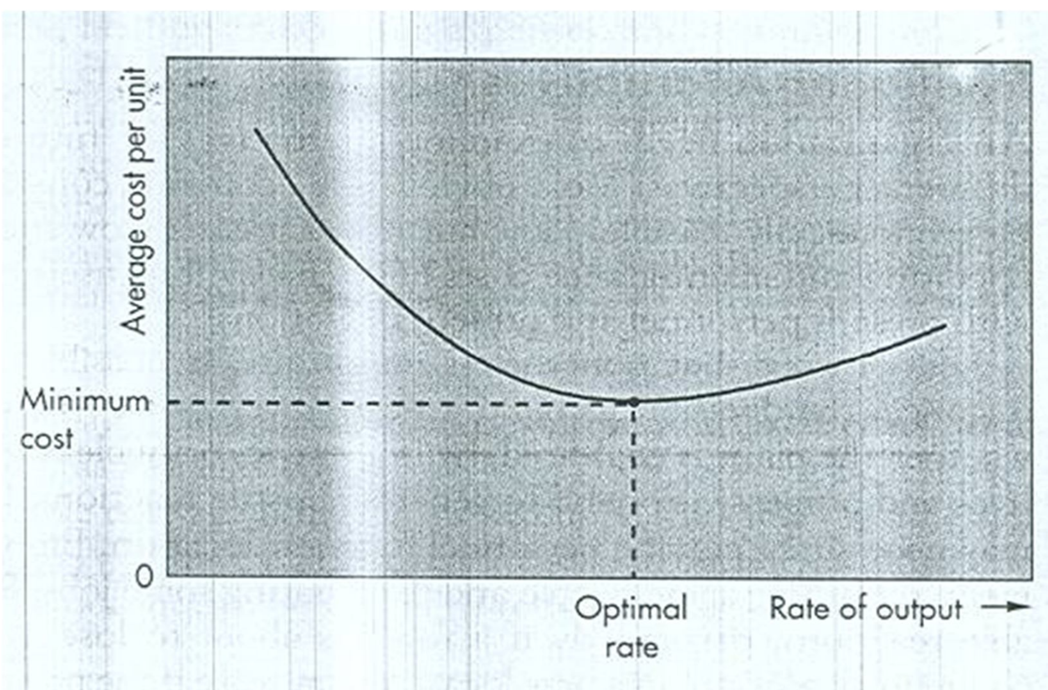


FIGURE -1: *Production units have an optimal rate of output for minimum cost*

The explanation for the shape of the cost curve is that at low levels of output, the costs of facilities and equipment must be absorbed (paid for) by very few units. Hence, the cost per unit is high. As output is increased, there are more units to absorb the "fixed" cost of facilities and equipment, so unit costs decrease. However, beyond a certain point, unit costs will start to rise. To be sure, the fixed costs are spread over even more units, so that does not account for the increase, but other factors now become important: worker fatigue; equipment breakdowns; the loss of flexibility, which leaves less of a margin for error; and, generally, greater difficulty in coordinating operations.

Both optimal operating rate and the amount of the minimum cost tend to be a function of the general capacity of the operating unit. For example, as the general capacity of a plant increases, the optimal output rate increases and the minimum cost for the optimal rate decreases. Thus, larger plants tend to have higher optimal output rates and lower minimum costs than smaller plants. Figure 4-2 illustrates these points.

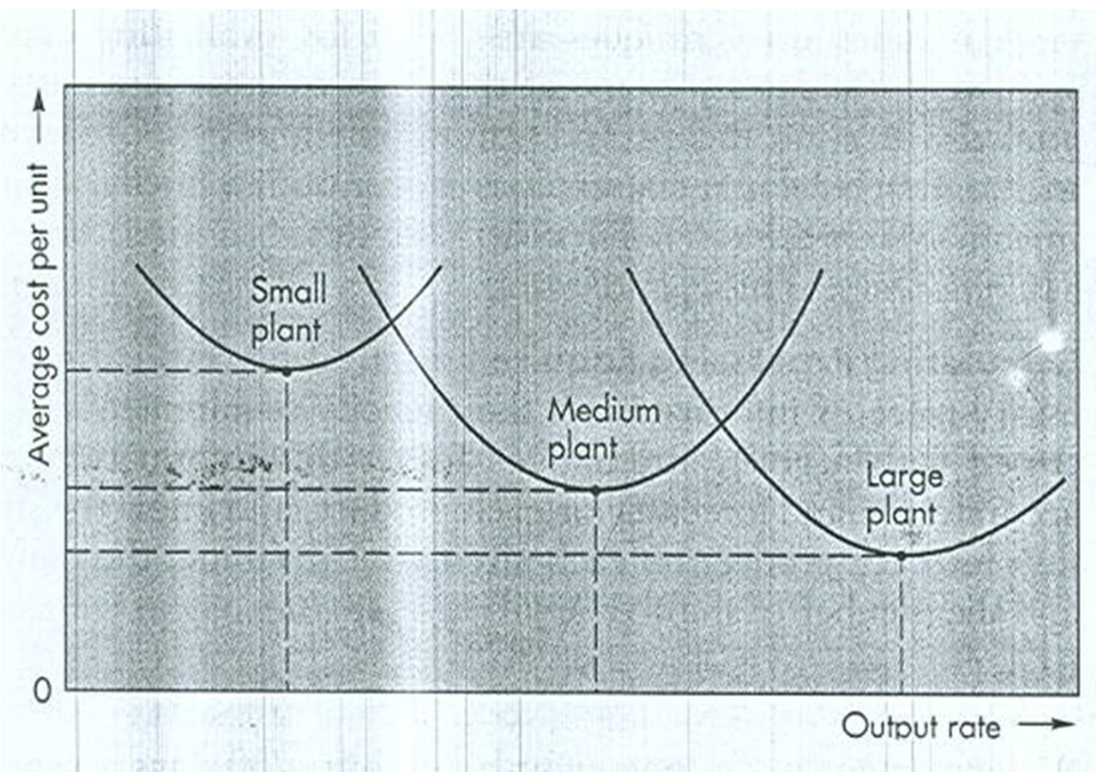


FIGURE 2: *Minimum cost and optimal operating rate are functions of size of a production unit*

Evaluating Alternatives

An organization needs to examine alternatives for future capacity from a number of different perspectives. Most obvious are economic considerations: Will an alternative be economically feasible? How much will it cost? How soon can we have it? What will operating and maintenance costs be? What will its useful life be? Will it be compatible with present personnel and present operations?

A number of techniques are useful for evaluating capacity alternatives from an economic standpoint. Some of the more common are cost-volume analysis, financial analysis, decision theory, and waiting-line analysis.

Calculating Processing Requirements, when evaluating capacity alternatives, a necessary piece of information is the capacity requirements of products that will be processed with a given alternative. To get this information, one must have reasonably accurate demand forecasts for each product, and know the standard processing time per unit for each product on each alternative machine, the number of work days per year, and the number of shifts that will be used.

A department works one eight-hour shift, 250 days a year, and has these figures for usage of a machine that is currently being considered:

Product	**Annual Demand**	**Standard Processing Time per Unit (Hr.)**	**Processing Time Needed (Hr.)**
#1	400	5.0	2,000
#2	300	8.0	2,400
#3	700	2.0	1,400
			5,800

Working one eight-hour shift, 250 days a year provides an annual capacity of 8 X 250 = 2,000 hours per year. We can see that three of these machines would be needed to handle the required volume:

$$\frac{5{,}800 \text{ hours}}{2{,}000 \text{ hours/machine}} = 2.90 \text{ machines}$$

Cost-Volume Analysis, Cost-volume analysis focuses on relationships between cost, revenue, and volume of output. The purpose of cost-volume analysis is to estimate the income of an organization under different operating conditions. It is particularly useful as a tool for comparing capacity alternatives.

Use of the technique requires identification of all costs related to the production of a given product. These costs are then assigned to fixed costs or variable costs. *Fixed costs* tend to remain constant regardless of volume of output. Examples include rental costs, property taxes, equipment costs, heating and cooling expenses, and certain administrative costs. *Variable costs* vary directly with volume of output. The major components of variable costs are generally materials and labor costs. We will assume that variable cost per unit remains the same regardless of volume of output. The following data summarizes the symbols used in the cost-volume formulas.

FC= Fixed cost
VC= Variable cost per unit
TC= Total cost
TR= Total revenue
R= Revenue per unit
Q= Quantity or volume of output
Q_{BEP}= Break-even quantity
P= Profit

The total cost associated with a given volume of output is equal to the sum of the fixed cost and the variable cost per unit time's volume:

TC = FC + VC X Q

The total revenue associated with a given quantity of output, Q, is:

TR = R X Q

The volume at which total cost and total revenue are equal is referred to as the **break-even point (BEP).** When volume is less than the break-even point, there is a loss rather than a profit; when volume is greater than the break-even point, there is a profit. The greater the deviation from this point, the greater the profit or loss. Total profit can be computed using the formula:

P = TR - TC = R X Q - (FC + VC X Q)

Rearranging terms, we have

P = Q(R - VC) – FC

The required volume, Q, needed to generate a specified profit is:

$$Q = \frac{P + FC}{R - VC}$$

A special case of this is the volume of output needed for total revenue to equal total cost. This is the break-even point, computed using the formula:

$$Q_{BEP} = \frac{FC}{R - VC}$$

Example:

The owner of Old-Fashioned Berry Pies, S. Simon, is contemplating adding a new line of pies, which will require leasing new equipment for a monthly payment of $6,000. Variable costs would be $2.00 per pie, and pies would retail for $7.00 each.

a. How many pies must be sold in order to break even?

b. What would the profit (loss) be if 1,000 pies are made and sold in a month?

c. How many pies must be sold to realize a profit of $4,000?

FC = $6,000, VC = $2 per pie, *Rev* = $7 per pie

$$\text{a. } Q_{BEP} = \frac{FC}{Rev - VC} = \frac{\$6{,}000}{\$7 - \$2} = 1{,}200 \text{ pies/month}$$

b. For Q = 1,000, P = Q(R - *VC)* - FC = 1,000($7 - $2) - $6,000 = -$1,000

c. P = $4,000; solve for Q

$$Q = \frac{\$4{,}000 + \$6{,}000}{\$7 - \$2} = 2{,}000 \text{ pies}$$

Activity 3.4

Answer the following questions before continuing to the next section.

1. State clearly the Importance of Capacity Decisions

____

____

____

____

2. No single measure of capacity will be appropriate in every situation. Rather, the measure of capacity must be tailored to the situation. By considering the above statements justify your reason with practical example.

____

____

____

____

Checklist

If you understand the following words or phrases put a tick (✓) mark in the box, otherwise read the section again.

- Effective capacity -- ☐
- *Efficiency* --- ☐
- Capacity --- ☐

3.4 FACILITY LOCATION & LAYOUT

Introduction

Plant location or the facilities location problem is an important strategic level decision making for an organization. One of the key features of a conversion process (manufacturing system) is the efficiency with which the products (services) are transferred to the customers. This fact will include the determination of where to place the plant or facility. The selection of location is a key-decision as large investment is made in building plant and machinery. It is not advisable or not possible to change the location very often. So an improper location of plant may lead to waste of all the investments made in building and machinery, equipment.

Before a location for a plant is selected, long range forecasts should be made anticipating future needs of the company. The plant location should be based on the company's expansion plan and policy, diversification plan for the products, changing market conditions, the changing sources of raw materials and many other factors that influence the choice of the location decision. The purpose of the location study is to find an optimum location one that will result in the greatest advantage to the organization.

Where should a plant or service facility be located? This is a top question on the strategic agendas of contemporary manufacturing and service firms particularly, in this age of global markets and global production. Dramatic changes in trade agreements, both in North America and Europe, have made the world truly a “global village,” allowing companies greater flexibility in their location choices. In practice, however, the question of location is very much linked to two competitive imperatives:

- The need to produce close to the customer due to time-based competition, trade agreements, and shipping costs.
- The need to locate near the appropriate labor pool to take advantage of low wage costs and /or high technical skills.

3.4.1. ISSUES IN FACILITY LOCATION

The problem of facility location is common to new and existing businesses. Criteria that influence manufacturing plant and warehouse location planning are:.

- **Proximity to Customers**: A location close to the customer is important because of the ever-increasing need to be customer-responsive. This enables faster delivery of goods to customers. In addition, it ensures that customers’ needs are incorporated into the products being developed and built. Population characteristics provide a basis for decision making on these criteria.
- **Business Climate:** A favorable business climate can include the presence of similar sized businesses, the presence of companies in the same industry, and, in the case of international locations, and the presence of other foreign companies. Pro-business government legislation and local government intervention to facilitate businesses locating in an area via subsidies, tax abatements, and other support are also factors.
- **Total Costs**: The objective is to select a site with the lowest total cost. This includes regional costs, inbound distribution costs, and outbound distribution costs. Land, construction, labor, taxes, and energy costs comprise the *regional costs*. In addition, there are *hidden costs* that are difficult to measure. These involve (1) excessive moving of preproduction material between

locations before final delivery to the customers and (2) loss of customer responsiveness arising from locating away from the main customer base.

- **Infrastructure:** Adequate road, rail, air, and sea transportation is vital. Energy and telecommunications requirements must also be met. In addition, the local government's willingness to invest in upgrading infrastructure to the levels required may be an incentive to select a specific location.
- **Quality of Labor:** The educational and skill levels to the labor pool must match the company's needs. Even more important are the willingness and ability to learn.
- **Suppliers:** A high-quality and competitive supplier base makes a given location suitable. The proximity of important suppliers' plants also supports lean production methods.
- Other Facilities The location of other plants or distribution centers of the same company may influence a new facility's location in the network. Issues of product mix and capacity are strongly interconnected to the location decision in this context.
- **Free Trade Zones:** A foreign trade zone or a free trade zone is typically a closed facility (under the supervision of the customs department) into which foreign goods can be brought without being subject to the necessary customs requirements. Manufacturers in free trade zones can use imported components in the final product and delay payment of customs duties until the product is shipped into the host country.

- **Political Risk**: The fast-changing geopolitical scenes in numerous nations present exciting, challenging opportunities. But the extended phase of transformation that many countries are undergoing makes the decision to locate in those areas extremely difficult. Political risks in both the country of location and the host country influence location decisions.
- **Government Barriers**: Barriers to enter and locate in many countries are being removed today through legislation. Yet many no legislative and cultural barriers should be considered in location planning.
- **Environmental Regulation**: The environmental regulations that impact a certain industry in a given location should be included in the location decision. Besides measurable cost implications, this influences the relationship with the local community.
- **Host Community:** The host community's interest in having the plant in its midst is a necessary part of the evaluation process. Local educational facilities and the broader issue of quality of life are also important.

- **Competitive Advantage**: An important decision for multinational companies is the nation in which to locate the home base for each distinct business. Porter suggests that a company can have different home base for distinct businesses or segments. Competitive advantage is created at a home base where strategy is set, the core product and process technology are created, and a critical mass of production takes place. So a company should move its home base to a country that stimulates innovation and provides the best environment for global competitiveness. This concept can also be applied to domestic companies seeking to gain sustainable competitive advantage.

3.4.2. THE STRATEGIC IMPORTANCE OF LOCATION

One of the most important strategic decisions companies make is where to locate their operations. The strategic decision often depends on the type of business. For industrial location decisions the strategy is usually minimizing costs, whereas for retail and professional service organizations the strategy focuses on maximizing revenue. Warehouse location strategy, however, may be driven by a combination of cost and speed of delivery. In general, the objective of location strategy is to maximize the benefit of location to the firm.

Companies make location decisions relatively infrequently, usually because demand has outgrown the current plant’s capacity or because of changes in labor productivity, exchange rates, costs or local attitudes. Companies may also relocate their manufacturing or service facility because of shifts in customer demand.

Location options include (1) not moving, but instead expanding an existing facility, (2) maintaining current sites, but adding another facility elsewhere, closing the existing facility and moving to another location.

SELECTING THE LOCATION

Selecting a facility location is becoming much more complex with the globalization of the workplace. Globalization has taken place because of the development of (1) market economics as well as: (2) better international communications; (3) more repaid reliable travel and shipping; (4) ease of capital flow between countries; and (5) high differences in labor costs. Many firms now consider opening new offices, factories, retail stores, or banks outside their own country. Location decisions transcend national borders.

Once a firm decides which country is best for its location, it focuses on a region of the chosen country and a community.

The final step in the location decision process is choosing a specific site within a community. The company must pick the one location that is best suited for shipping and receiving, zoning, utilities, size and cost.

Besides globalization, a number of other factors affect the location decision. Among these are labor productivity, foreign exchange, and changing attitudes toward the industry, unions, employment, zoning, pollution, taxes, and so forth.

3.4.3. METHODS OF EVALUATING LOCATION ALTERNATIVES

Four major methods are used for solving location problems: the factor-rating method, location break-even analysis, center-of gravity method, and the transportation model.

Here we will constrain the three approaches the Factor-rating method and location breakeven analysis and the center-of gravity method.

1. ***THE FACTOR-RATING METHOD***

There are many factors, both qualitative and quantitative, to consider in choosing a location. Some of these factors are more important than others, so managers can use weightings to make the decision process more objective. The rating method is popular because a wide variety of factors from education to recreation to labor skills can be included.

The factor-rating method has six steps:

- Develop a list of relevant factors (Such as those in Table)
- Assign a weight to each factor to reflect its relative importance in the company's objectives.
- Develop a scale for each factor (for example, 1 to 10 or 1 to 100 points)
- Have management score each location for each factor using the scale in step 3.
- Multiply the score by the weights for each factor, and total the score for each location.
- Make a recommendation based on the maximum point score, considering the results of quantitative approaches as well.

Example 1: Selam Parks, has decided to expend its parking services by opening additional park in the regional cities. The rating sheet in Table 3 provides a list of qualitative factors that management has decided are important; their weightings and their rating for two possible sites- Awassa and Dire Dawa are shown

TABLE 3: - WEIGHTS, SCORES, AND SOLUTION

		SCORES			
		(OUT OF 100)		WEIGHTED SCORES	
FACTOR	WEIGHT	AWASSA	DEREDAWA	AWASSA	DEREDAWA
Labor availability and attitude	.25	70	60	(.25)(70) = 17.5	(0.25)x(60)= 15
People-to-car ratio	.50	50	60	(.05)(50) = 2.5	(.05)(60) = 3.0
Per capita income	.10	85	80	(.10)(85) = 8.5	(.10)(80) = 8.0
Tax structure	.39	75	70	(.39)(75) = 29.3	(.39) (70) = 27.3
Education and Health	.21	60	70	(.21)(60) = 12.6	(21))70) = 14.7
				Total = 70.4	68.0

The above Table also indicates use of weights to evaluate alternative site locations. Given the option of 100 points assigned to each factor, the Awassa location is preferable. By changing the points or weights slightly for those factors about which there is some doubt, we can analyze the sensitivity of the decision. For instance, we can see that changing the scores for “labor availability and attitude” by 10 points can change the decision.

When a decision is sensitive to minor changes, further analysis of either the weighting or the points assigned may be appropriate. Alternatively, management may conclude that these intangible factors are not the proper criteria on which to base a location decision. Managers therefore place primary weight on the more quantitative aspects of the decision.

Exercise 1

A certain company is evaluating three locations (Adama, Mekele and Kombolcha) for a new plant. It has weighted and scored the factors as shown below. Using these scores, develop a qualitative factor rating for the three locations.

Relevant Factors		adama		Mekele		Kombolcha	
	AW	S	WS	S	WS	S	WS
Production cost	.33	50		40		35	
Raw mat supply	.25	70		80		75	
Labor availability	.20	55		70		60	
Cost of living	.05	80		70		40	
Environment	.02	60		60		60	
Markets	.15	80		90	____	85	
Total	1.00						

Factor-rating systems are perhaps the most widely used of the general location techniques because they proved a mechanism to combine diverse factors in an easy-to-understand format.

A major problem with simple point-rating schemes is that they do not account for the wide range of costs that may occur within each factor. For example, there may be only a few hundred dollars' difference between the best and worst locations on one factor and several thousands of dollars' difference between the best and the worst on another. The first factor may have the most points available to it but provide little help in making the location decision; the second may have few points available but potentially show a real difference in the value of locations. To deal with this problem it has been suggested that points possible for each factor be derived using a weighting scale based on standard deviations of costs rather than simply total cost amounts. In this way, relative costs can be considered.

2. LOCATIONAL BREAK-EVEN ANALYSIS

Location break-even analysis is the use of cost-volume analysis to make an economic comparison of location alternatives. By identifying fixed and variable cost and graphing them for each location, we can determine which one provides the lowest cost. Locational break-even analysis can be done mathematically or graphically. The graphic approach has the advantage of providing the range of volume which each location is preferable.

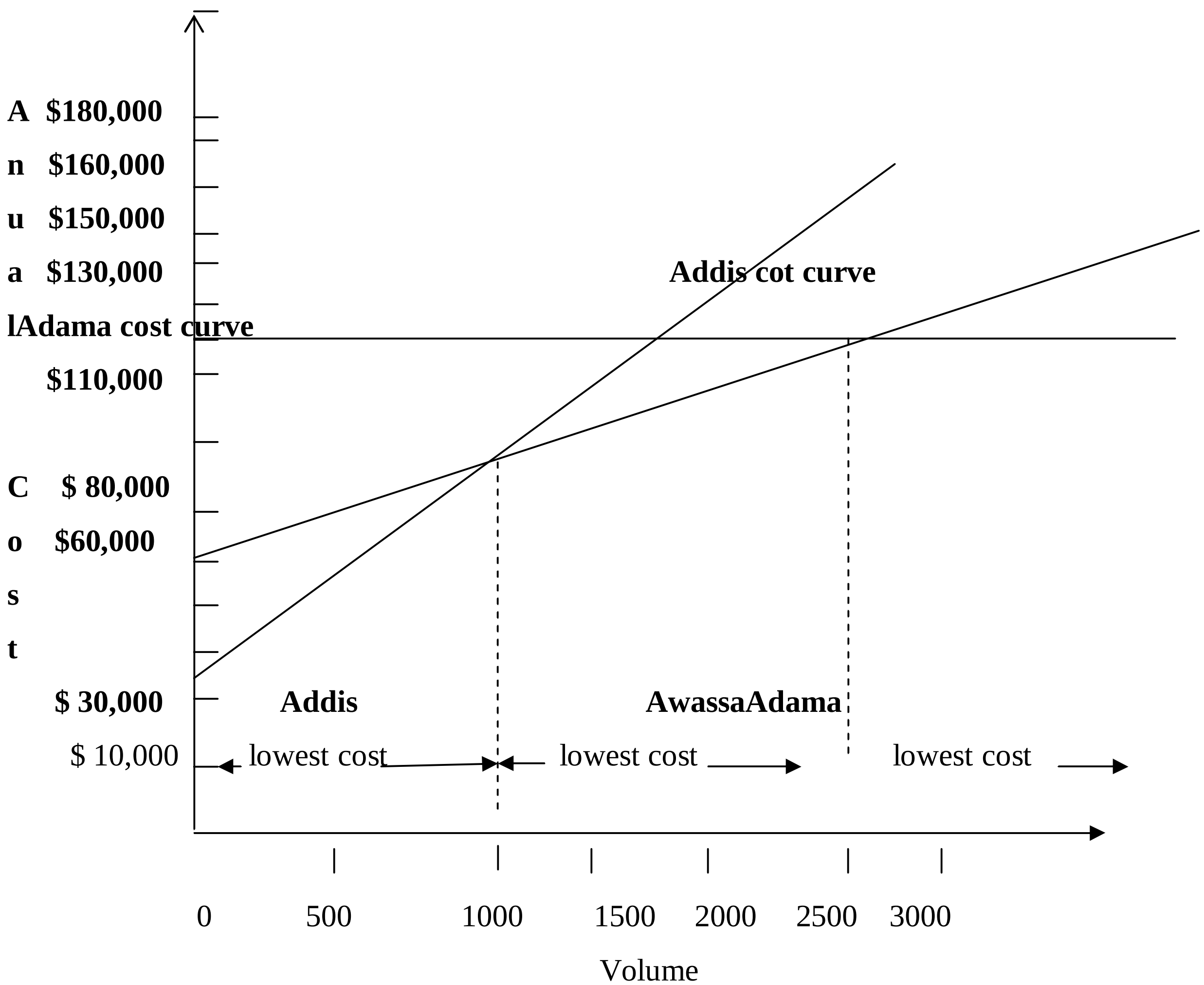
The three steps to location break-even analysis are:

1. Determine the fixed and variable cost for each location
2. Plot the costs for each location, which costs on the vertical axis of the graph and annual volume on the horizontal axis
3. Select the location that has the lowest total cost for the expected production volume. '

Example: 1

A manufacturer of automobile carburetors is considering three locations Addis, Awassa and Adama for a new plant. Cost studies indicate the fixed costs per year at the sites are $30,000. $60,000, and $110,000, respectively; and variable costs are $75 per unit, $45 per unit, and $25 per unit respectively. The expected selling price of the carburetors produced is $120. The company wishes to find the most economical location for an expected volume of zeros units) and the total cost (fixed cost + variable costs) at the expected volume of output. These lines have been plotted in Figure 1

Figure 1: - CROSSOVER CHART FOR LOCATIONAL BREAK-EVEN ANALYSIS



For Addis

Total Cost = #30,000 + $75(2,000) = $180,000

For Awassa

Total cost = $60,000 + $45(2,000) = $150,000

For Adama

Total Cost = $110,000 + $25(2,000) = $160,000

With an expected volume of 2,000 units per year Awassa provides the lowest cost location. The expected profit is:

Total revenue – Total cost = $120(2,000) -$120(2,000) -$150,000 = $90,000 per year

The chart also tells us that for a volume of less than 1,000 Addis would be preferred, and for a volume greater than 2.500, Adama would yield the greatest profit. The crossover points are 1,000 and 2,500.

LINEAR PROGRAMMING

The transportation method of linear programming can be used to test the cost impact of different candidate locations on the entire production-distribution network. Assuming factories in X and Y would be identical in other important respects, the location resulting in the lowest total cost for the network would be selected. This method is easy to use but it does require that at least sub regional locations be identified before a solution can be found.

CENTER OF GRAVITY METHOD

The center of gravity method is a technique for locating single facilities that considers the existing facilities, the distances between them, and the volumes of goods to be shipped. The technique is often used to locate intermediate or distribution warehouses. In its simplest form, this method assumes that inbound and outbound transportation costs are equal, and it does not include special shipping costs for less than full loads.

The center of gravity method begins by placing the existing locations on a coordinate grid system. The choice of coordinate systems is entirely arbitrary. The purpose is to establish relative distances between locations. Using longitude and latitude coordinates might be helpful in international decisions.

Exhibit 1 shows an example of a grid layout.

The ***center of gravity*** is found by calculating the X and Y coordinates that result in the minimal transportation cost. We use the formulas

$$C_x = \frac{\sum d_{ix} V_i}{\sum V_i}$$

$$C_y = \frac{\sum d_{iy} V_i}{\sum V_i}$$ Where

C_x = X coordinate of the center of gravity

C_y = Y coordinate of the center of gravity

d_{ix} = X coordinate of the ith location

d_{iy} = Y coordinate of the ith location

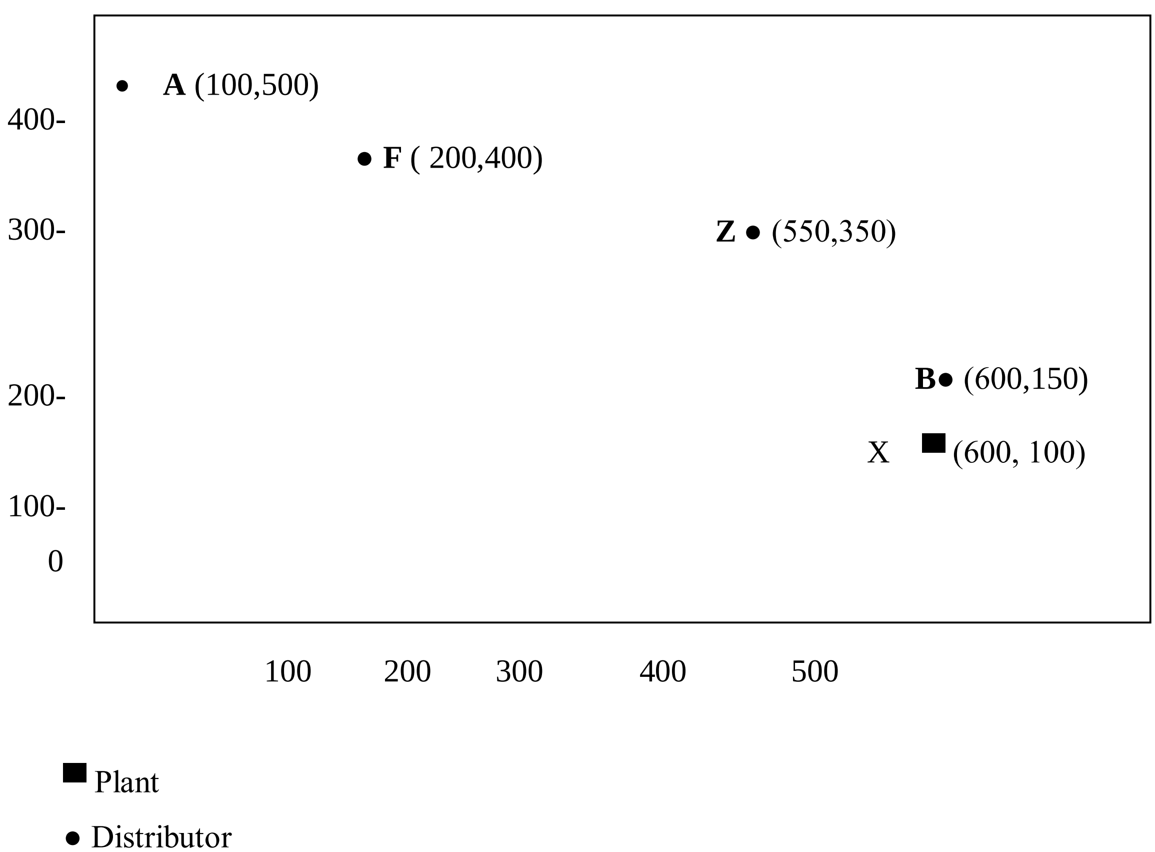
V_i = Volume of goods moved to or from the ith location

Example: NOC Refining Company needs to locate an intermediate holding facility between its refining plant in **X location** and its major distributors. Exhibit 1 shows the coordinate map. The amount of gasoline shipped to or from the plant and distributors appears in Exhibit 2.

In this example, for the X location (the first location) $d_i = 600$ $d_{xy} = 100$, and

$V_i = 1{,}500$.

Exhibit 1: Grid Map for Center of Gravity



Shipping Volumes

Locations	**Gallons of Gasoline per month** ('000,000s)
Long Beach	1,500
Anaheim	250
LaHabra	450
Glendale	350
Thousand Oaks	450

Solution:

Using the information in Exhibits 1 and 2 we can calculate the coordinates of the center of gravity:

$$C_x = \frac{(325x1{,}500)+(400x250)+(450x450)+(350x350)+(25x450)}{1{,}500+250+450+350+450}$$

$$= \frac{923{,}750}{3{,}000} = 307.9$$

$$C_y = \frac{(75x1{,}500)+(150x250)+(350x450)+(400x350)+(450x450)}{1{,}500+250+450+350+450}$$

$$= \frac{650{,}000}{3{,}000} = 216.7$$

This gives management the X and Y coordinates of approximately 308, and 217, respectively and provides an initial starting point to search for a new site.

Exercise 1: The Ministry of health of Ethiopia targeted to serve seven census areas in Addis Ababa. The table given below shows the coordinates for the center of each census area, along with the projected populations, measured in thousands. Customers will travel from the seven census area centers to the new facility when they need health-care. Two locations being considered for the new facility are at (11, 9) and (14, 4), which are the centers of census areas C and F. Details of seven census area centers, coordinate distances along with the population for each center are given below. Find the target area's center of gravity for the Health-care medical facility.

Sl. No.	Census tract	(x, y)	Population (in 000s)
1.	A	(5, 9)	4
2.	B	(5, 5)	10
3.	C	(11, 9)	20
4.	D	(10, 4)	14
5.	E	(16, 10)	20
6.	F	(14, 4)	40
7.	G	(18, 5)	28

3.4.4 LOCATING SERVICE FACILITIES

While the focus in industrial-sector location analysis is on minimizing cost, the focus in the service sector is on maximizing revenue. This is because manufacturing costs tend to vary substantially between locations, but in service firms' location often has more impact on revenue than cost. Therefore, for the service firm a specific location often influences revenue more than it does cost. This means that the location focus for service firms should be on determining the volume of business and revenue.

Table 2: - LOCATION STRATEGIES-SERVICE VERSUS INDUSTRIAL ORGANIZATIONS

SERVICE/RETAIL/PROFESSIONAL	INDUSTRIAL LOCATION
Revenue Focus	**Cost Focus**
Volume/revenue	Tangible costs

Drawing area; purchasing power Competition; advertising/pricing **Physical Quality** Parking/access;security/lighting; appearance/ image Cost determinants Management caliber Operation policies **Techniques**	Transportation cost of raw material Shipment cost of finished goods Energy and utility cost; labor; raw material; taxes, and so on Intangible and future costs Attitude toward union Quality of life Education expenditures by state Quality of state and local government **Techniques**
Regression models to determine importance of various factors Factor-rating method Traffic counts Demographic analysis of drawing area Purchasing power analysis of area Center-of-gravity method **Assumptions**	Transportation method Factor-rating method Locational break-even analysis Crossover charts **Assumptions**
Location is a major determinant of revenue High customer-contact issues are critical Costs are relatively constant for a given area; therefore, the revenue function is critical	Location is a major determent of cost Most major costs can be identified explicitly for each site low customer contact allows focus on the identifiable Cost Intangible Costs Can be evaluated

A common problem encountered by service-providing organizations are deciding how many service outlets to establish within a geographic area, and where. The problem is complicated by the many possible locations and several options in the absolute number of service centers. Thus, attempting to find a good solution, much less an optimal one can be extremely time consuming even for a relatively small problem.

3.4.5. FACILITY LAYOUT DECISIONS

Facility layout decision entails determining the placement of departments, workstations, machines, and stockholding points within a productive facility. Its general objective is to arrange these elements in a way that ensures *a smooth workflow* (in a factory) or a particular traffic pattern (in a service organization). The inputs to the layout decision are:

- Specification of objectives of the system in output and flexibility.
- Estimation of product or service demand on the system.
- Processing requirements in number of operations and amount of flow between departments and work centers.
- Space availability within the facility itself.

All these inputs are, in fact, outputs of process selection and capacity planning. How layouts are developed under various formats (or workflow) structures. Our emphasis is on quantitative techniques used in locating departments within a facility and on workstation arrangements and balance in the important area of assembly lines. Before embarking on this discussion, however, it is useful to note the marks of a good layout listed in Exhibit 1

EXHIBIT 1:

Manufacturing and Back-Office Operations

- Straight-line flow pattern (or adaptation).
- Backtracking kept to a minimum.
- Production time predictable
- Little inter-stage storage of materials
- Open plan floors so everyone can see what's going on
- Bottleneck operations under control.
- Workstations close together.
- Orderly handling and storage of materials.
- No unnecessary re- handling of materials.
- Easily adjustable to changing conditions.

Face-to-Face Services

- Easily understood service flow pattern.
- Adequate waiting facilities.
- Easy communication with customers.
- Customer surveillance easily maintained.
- Clear exit and entry points with adequate checkout capabilities.
- Departments and processes arranged so those customers see only what you want them to see.
- Balance between waiting areas and service areas.
- Minimum walking and material movement.
- Lack of clutter.
- High sales volume per square foot of facility.

3.4.6. STRATEGIC IMPORTANCE OF LAYOUT DECISIONS

Layout is one of the decisions that determine the long-run efficiency of operations. Layout has numerous strategic implications because it establishes a firm competitive priority in regard to capacity, processes, flexibility, and cost, as well as quality work life. An effective layout can help a firm to achieve the following:

- Higher utilization of space, equipment, and people.
- Improve flow of information, materials, or people.
- More convenience to the customer.
- Improved employee morale and safer working conditions.

The objective of layout strategy is to develop economic layout that will assist in these four areas while still meeting the firm's competitive requirements.

3.4.7. TYPES OF LAYOUT

Layout decisions include the best placement of machines (in a production setting), offices and desks (in an office setting), or service centers (in settings such as hospitals or department stores). An effective layout facilitates the flow of materials, people, and information, within and between areas. Management's goal is to arrange (layout) the system so that it operates at peak effectiveness and efficiency. To achieve these layout objectives, a variety of approaches have been developed. Among them are the following:

- Fixed-position layout-addresses the layout requirements of large, bulky projects such as ships and buildings.
- Process-Oriented layout deals with low-volume, high-variety production (also called “job shop” or intermittent production).
- Office layout- positions workers, their equipment, and spaces/offices to provide for movement of information.
- Retail/service layout-allocates shelf space and responds to customer behavior.
- Warehouse layout – addresses trade-offs between space and material handling.
- Product-oriented layout – seeks the best personnel and machine utilization in repetitive or continuous production.

Of these six layout strategies, only a few have undergone extensive mathematical analysis. The layout and design of physical facilities is still as much an art as it is a science. Here we will consider some of the art as well as some of the science for effective and efficient layouts.

1. FIXED-POSITION LAYOUT

A fixed-position layout is one in which the project remains stationary and require workers and equipment to come to one work area. Examples of this of project are a ship, a highway, a bridge, a house, and a burning oil well.

The techniques for addressing the fixed-position layout are not well-developed. Construction sites and shipbuilding sites address this issue on an ad hoc basis. The construction industry usually has a “meeting of the trades” to assign space for various time periods. As you would suspect, this often yields less than an optimum solution, as the discussion may be more political than analytical. Shipyards on the other hand, have loading areas called “platens” adjacent to the ship, which are loaded by a scheduling department.

The fixed-position layout is complicated by three factors:

- Space is limited at virtually all sites
- At different stages in the construction process different materials are needed therefore, different items become critical as the project develops. This adds the dynamics of scheduling to the layout problem.

- The volume of materials needed is dynamic. For example, the rate of use of steel panels for the hull of a ship changes as the project progresses. Because the fixed-position layout is so difficult to solve well at the site, an alternative strategy is to complete as much of the project as possible off site. This approach is used in the shipbuilding industry when standard units, say pipe holding brackets, are assembled in a nearby line process (a product-oriented facility

2. PROCESS-ORIENTED LAYOUT

The process-oriented layout can simultaneously handle a wide variety of products or services. In fact, it is most efficient when making products that have different requirements or when handling customers who have different needs.

A big advantage of process-oriented layout is its flexibility in equipment and labor assignments. The breakdown of one machine, for example, need not halt an entire process; work can be transferred to other machines in the department. Process-oriented layout is also especially good for handling the manufacture of parts in small batches, or job lots, and for the production of a wide variety of parts in different sizes or forms.

The disadvantages of process-oriented layout come from the general-purposes of the equipment. Orders take more time and money to move through the system because of difficult scheduling setups, and material handling. In addition labor skill requirements and work-in-process inventories are higher because of larger imbalances in the production process. High labor skill needs increase the required level of training and experience; high work-in-process increases capital investment.

3. CELLULAR LAYOUT

A special case of process-oriented layout is the work cell, a work cell takes machines that would ordinarily be dispersed in various process departments and arranges them is a small group so that the advantages of product-oriented systems can be brought to bear on a particular batch or family of batches. The work cell is built around the product. The advantages of work cells are.

- Reduced work-in-process inventory because the work cell is set up to provide a balanced flow from machine to machine.
- Less floor space required because less space is needed between the machines to accommodate the work-in-process inventory.

- Reduced raw material and finished goods inventories because less work in process allows more rapid movement of materials through the work cell.
- Reduced direct labor cost because of better flow of material and improved scheduling. The time to move from one piece to another and from one batch within the family to another is substantially reduced.
- Heightened sense of employee participation in the organization and the product because employees accept more responsibility for quality, since quality problems are readily identified with to work cell and the employee.
- Increased utilization of equipment and machinery because of better scheduling and faster material flow.
- Reduced investment in machinery and equipment because good facility utilization reduces the number of machines and the amount of equipment and tooling.

The requirements of cellular production include:

- ✓ Group technology codes or their equivalent
- ✓ A high level of training and flexibility on the part of employees.
- ✓ Either staff support or flexible, imaginative employees to establish the work cells initially.

4. FOCUSED WORK CENTER AND FOCUSED FACTORY

When a firm has identified a large family of like products and the forecast is stable and or adequate volume, a focused work center may be organized. A focused work center moves production from a general-purpose, process-oriented facility to a large work cell. The large work cell may be a part of the present plant, in which case it may be called a focused work center. Or it may be separated and called focused factory. A fast-food restaurant is a focused factory. Burger king, for example, changes the number of personnel and task assignments rather than moving machines and equipment. In this manner, they balance the assembly line to meet changing production demands. In effect, the “layout” changes numerous times each day.

The term-focused factories may also refer to facilities that are focused in was other than by product line or layout. For instance, a facility may be focused in regard to meeting quality, new product introduction, or flexibility requirements. Focused facilities in manufacturing and in services appear to be better able to stay in tune with their customers, to produce quality products, and to operate at higher margins.

5. ***OFFICE LAYOUT***

The criteria for a rational approach to office layouts in terms of workflow are the same as those for manufacturing tangible goods. That is, we can organize around either processes or products. In most organizations, however, there is some middle ground where, for example, the accounts receivable department handles receivables the order department handles incoming orders, and the accounts payable department handles results or purchases and other bills. This middle ground can be thought of as cellular organizations arranged and rearranged as work procedures and volumes change. The frequent rearrangement of offices is witness to the flexibility of this cellular relationship.

As a final comment on the layout of offices, we should note two major trends, First, technology, such as cellular phones, beepers, faxes, the internet, home offices layout laptop computers, and personal digital assistants, allows ever increasing flexibility when information can be moved electronically. Second, virtual companies create dynamic needs for space and services. These two changes require fewer office employees on sit.

6. ***RETAIL STORE LAYOUT***

Retail store layouts are based on the idea that sales vary directly with customer exposure to products. Thus, most retail store operations managers try to export customers to as many products as possible. Studies do show that the greater the rate of exposure the greater the sales and the higher the return on investment. The operations manager can later both with the overall arrangement of the store and the allocation of space within that arrangement to various products.

Five ideas are helpful for determining the overall arrangement of many stores.

- Locate the high-draw items around the periphery of the store. Thus we tend to find dairy products on one side of a supermarket and bread and bakery products on another.
- Use prominent locations for high-impulse and high-margin items such a house wares, beauty aids, and shampoos.
- Distribute what are known in the trade as “power items” – items that may dominate a purchasing trip-to both sides of an aisle, and disperse them to increase the viewing of other items.
- Use end aisle locations because they have a very high exposure rate.

- Convey the image of the store by careful selection in the positioning of the lead-off department; some stores will position the bakery and deli up front to appeal to convenience-oriented customers who want prepared foods.

Once the overall layout of a retail store has been decided, the products need to be and angel for sale. Many considerations go into this arrangement. However the main objective of retail layout is to maximize profitability per square foot of sheet space.

7. WAREHOUSING AND STORAGE LAYOUT

The objective of warehouse layout is to find the optimum trade-off between handling cost and warehouse space. Consequently, management's task is to maximize the utilization of the total "cube" of the warehouse-that is, utilize its full volume while maintaining low material-handling costs. We define material handling cost as all the costs related to the incoming transport, storage, and outgoing transport of the material. These costs include equipment, people, material, supervision, insurance, and spoilage of material within the warehouse. Management minimizes the sum of the resources spent on finding and moving material plus the deterioration and damage to the material itself. The variety of items stored and the number of items "picked" has direct bearing on the optimum layout. A warehouse storing a few items lends itself "picked" has direct bearing on the optimum layout. A warehouse storing a few items lends itself to higher density more than a warehouse storing a variety of items. Modern warehouse management is, in many in stances, an automated procedure utilizing automatic stacking crane, conveyors, and sophisticated controls that manage the flow of materials.

As important component of warehouse layout is the relationship between the receiving/unloading area and the shipping/loading area. The facility design depends on the type of supplies unloaded, what they are unloaded from (trucks, rail cars, barges, and so on), and where they are unloaded. In some companies the receiving and shipping facilities, or docks, as they are called, are even the same area-sometimes they are receiving docks in the morning and shipping docks in the afternoon

8. ***PRODUCT-ORIENTED LAYOUT***

Product-oriented layouts are organized around a product or a family of similar high volume, low-variety products. The assumptions are:

- Volume is adequate for high equipment utilization.
- Product demand is stable enough to justify high investment in specialized equipment.

- Product is standardized or approaching a phase of its life cycle that justifies investment in specialized equipment.
- Supplies of raw material and components are adequate and of uniform quality (adequately standardized) to ensure they will work with the specialized equipment.

One version of a product-oriented layout is a fabrication line; another is an assembly line. The fabrication line builds components, such as automobile tires or metal parts for a refrigerator, on a series of machines. An assembly line puts the fabricated parts together at a series of workstations. That is, the work performed on one machine must balance with the work performed on the next machine in the fabrication line, just as the work done at one workstation by an employee on an assembly line must balance with the work done at the next workstation by the next employee.

Fabrication lines tend to be machine paced and require mechanical and engineering changes to facilitate balancing. Assembly lines, on the other hand, tend to be paced by work tasks assigned to individuals or to workstations. Assembly lines therefore, can be balanced by moving tasks from one individual to another. In this manner, the amount of time required by each individual or station is equalized.

The central problem in product-oriented layout planning is to balance the output at each workstation on the production line so that it is nearly the same, while obtaining the desired amount of output. Management's goal is to create a smooth continuous flow along the assembly line with a minimum of idle time at each person's workstation. A well- balanced assembly line has the advantage of high personnel and facility utilization and equity between employee's workloads. Some union contracts include a requirement that workloads must be nearly equal among those on the same assembly line. The term most often used to describe this process is assembly line balancing. Indeed the objective of the product-oriented layout is to minimize imbalance in the fabrication or assembly line.

The main advantage of product-oriented layout is the low variable cost per unit usually associated with high-volume, standardized products. The product-oriented layout also keeps material handling costs low, reduces work-in-process inventories, and makes training and supervision, easier. These advantages often outweigh the disadvantages of product layout, namely:

- High volume is required because of the large investment needed to set up the process.
- Work stoppage at any one point ties up the whole operation.
- Little flexibility exists when manufacturing a variety of products or production rates.

3.4.8. ASSEMBLY LINE BALANCING

Line-balancing is usually undertaken to minimize imbalance between machines or personnel while meeting a required output from the line. In order to produce at a specified rate, management must know the tools, equipment, and work methods used. Then the time requirements for each assembly task (such as drilling a hole, tightening a nut, or spray-painting a part) must be determined. Management also needs to know the precedence relationship among the activities, that is, the sequence in which various tasks need to be performed.

Steps in assembly line balancing:

The steps in balancing an assembly line are straightforward:

- Specify the sequential relationships among tasks using a precedence diagram. The diagram consists of circles and arrows. Circles represent individual tasks; arrows indicate the order of task performance.
- Determine the required cycle time (C), using the following formula:

$$C = \frac{\text{Production time per day}}{\text{Output per day (in units)}}$$

- Determine the theoretical minimum number of workstations (N_t) required to satisfy the cycle time constraint, using the following formula:

$$Nt = \frac{\text{Sum of task times (T)}}{\text{Cycle time (C)}}$$

- Select a primary rule by which tasks are to be assigned to workstations, and a secondary rule to break ties.
- Assign tasks, one at a time, to the first workstation until the sum of the task times is equal to the cycle time, or no other tasks are feasible because of time or sequence restrictions. Repeat the process for workstation 2, Workstation 3, etc., until all tasks are assigned.
- Evaluate the efficiency of the balance derived using the formula:

$$\text{Efficiency} = \frac{\text{Sum of task times (T)}}{\text{Actual number of workstations } (N_a) \text{ x Cycle time (C)}}$$

- Evaluate the efficiency of the balance derived using the formula:

Example: A certain Model Wagon is to be assembled on a conveyor belt. Five hundred wagons are required per day. Production time per day is 420 minutes, and the assembly steps and times for the wagon are given in workstations, subject to cycle time and precedence constraints.

Solution:

1. Draw a precedence diagram.
2. Cycle time determination. Here we have to convert to seconds since our task times are in seconds.

$$C = \frac{\text{Production time per day}}{\text{Output per day}} = \frac{60\,\text{sec. x } 420\,\text{min}}{500\,\text{wagons}} = \frac{25{,}000}{500} = 50.4$$

3. Theoretical minimum number of workstations required (the actual number may be greater):

$$N_t = \frac{T}{C} = \frac{195\ \text{seconds}}{50.4\ \text{seconds}} = 3.86$$

EXHIBIT 2: Assembly Steps and Times for the wagon

Task	Performance Time (in seconds)	Description	Tasks that Must Precede
A	45	Position rear axle support and hand fasten four Screws to nuts	-
B	11	Insert rear axle	A
C	9	Tighten rear axle support screws to nuts	B
D	50	Position front axle assembly and hand fasten with Four screws to nuts	-
E	15	Tighten front axle assembly screws	D
F	12	Position rear wheel #1 and fasten hub cab	C
G	12	Position rear wheel #2 and fasten hub cab	C
H	12	Position front wheel #1 and fasten hub cap	E
I	12	Position front wheel #2 and fasten hub cap	E
J	8	Position wagon handle shaft on front axle assembly and hand fasten bolt and nut	F,G,H,I
K	9	Tighten bolt and nut	J
	195		

4. Select assignment rules. Research has demonstrated that some rules are better than others for certain problem structures. In general, the strategy is to use a rule assigning tasks that either have many followers or are of long duration since they effectively limit the balance achievable. In this case, we use as our primary rule:

a. Assign tasks in order of the largest number of following tasks. Out secondary rule, to be invoked where ties exist from our primary rule, is

b. Assign tasks in order of longest operating time.

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

5. Make task assignments to form Workstation 1, Workstation 2, and so forth, until all tasks are assigned. The actual assignment is given in Exhibit 4 A and is shown graphically in Exhibit 4 B.
6. Do the efficiency calculation. This is shown in Exhibit 4 C.
7. Evaluate solution. An Efficiency of 77 Percent indicates an imbalance or idle time of 23 percent (1.0 -77) across the entire line. From Exhibit 4- A we can see that there are 57 total seconds of idle time, and the "choice" job is at Workstation 5.

   Is a better balance possible? In this case, yes. Try balancing the line with rule **b** and breaking ties with rule **a**. (This will give you a feasible four-station balance.)

EXHIBIT 4- A: Balance made according to largest number of following tasks rule

	Task	Task Time (in seconds)	Remaining Unassigned Time(in seconds)	Feasible Remaining Tasks	Task with most Followers	Task with Longest operation Time
Section 1	A	45	idle	None		
Section 2	D	50	0.4 idle	None		
	B	11	39.4	C, E	C, E	E
	E	15	24.4	C, H, I	C	
Section 3	C	9	15.4	F, G, H, I	F, G, H, I	F, G, H, I
	F*	12	3.4 idle	None		
	G	12	38.4	H, I	H, I	H, I
Section 4	H*	12	26.4	I		
	I	12	14.4	J		
	J	8	6.4 idle	None		
Section 5	K	9	41.4 idle	None		

*Denotes task arbitrarily selected where there is a tie between longest operation times.

$$\text{Efficiency} = \frac{T}{NC} = \frac{195}{(5)(50.4)} = .77 \; or \; 77\%$$

SPLITING TASKS

Often times the longest required task time forms the shorts cycle time for the production line. This task time is the lower time bound, unless it is possible to split the task into two or more workstations.

Consider the following illustration: Supposing that an assembly line contains the following task times in seconds: 40, 30, 15, 25, 18, and 15. The line runs for $7\frac{1}{2}$ hours per day and demand for output is 750 per day.

The cycle time required to produce 750 per day is 36 seconds ([7 ½ hours x 60 minutes x 60 seconds] / [750].

How do we deal with the task that is 40 seconds long?

There are several ways that we may be able to accommodate the 40-second task in a 36-second cycle. Possibilities are:

- ***Split the task***. Can we split the task so that complete unit is processed in two workstations?
- ***Share the task.*** Can the task somehow be shared so an adjacent work-station does part of the work? This differs from the split task in the first option because the adjacent station acts to assist, not to do some units containing the entire task.
- ***Use a more skilled worker***. Since this task exceeds the cycle time by just 11 percent, a faster worker may be able to meet the 36-second time.
- ***Work overtime***. Predicating at a rate of one every 40 seconds would produce 675 per day, 75 short of the needed 750. The amount of overtime required to do the additional 75 is 50 minutes (75 x 40 seconds/ 60 seconds).
- ***Redesign***. It may be possible to redesign the product to reduce the task time slightly.
- Other possibilities to reduce the task time include equipment upgrading a roaming helper to support the line, a change of materials, and multi skilled workers to operate the line as a team rather than as independent workers.

EXERCISE:

1. An assembly line is to operate 8 hours per day with a desired output of 240 units per day. The following table contains information on this product's task, task time, and precedence relationship.

Task	**Task Time (Seconds)**	**Immediate predecessor**
A	60	-
B	80	A
C	20	A
D	50	A
E	90	B, C

F	30	C, D
G	30	E, F
H	60	G

Required

A. Draw the precedence diagram
B. Determine the cycle time.
C. Balance the line using the longest task time.
D. What is the efficiency of you line balance?

3.5. JOB DESIGN AND WORK MEASUREMENT

3.5.1. JOB DESIGN

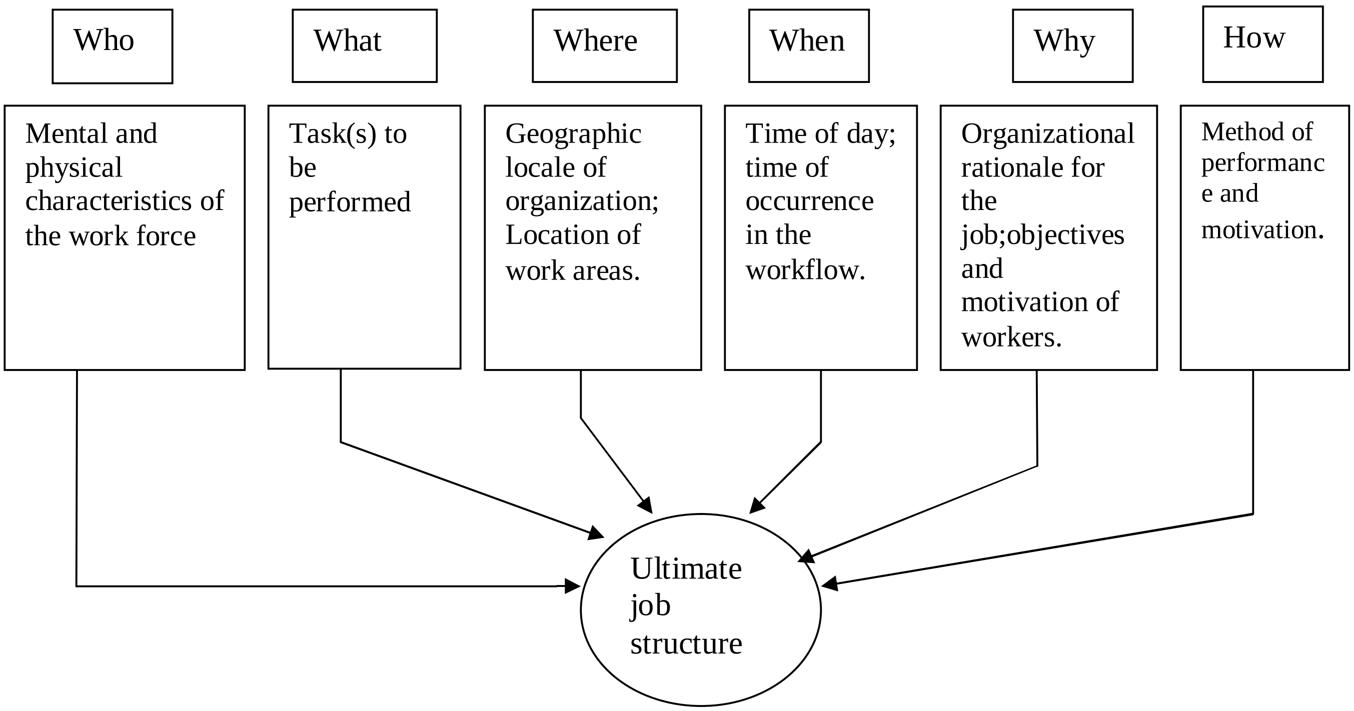
The operations manager's job, by definition deals with managing the human resource that creates the firm's products and services.

The objective in managing personnel is to obtain the highest productivity possible without sacrificing quality, service, or responsiveness. The operations manager uses job design techniques to structure the work so that it will be conducive to both the physical and behavioral needs of the human worker. Work measurement methods are used to determine the most efficient means of performing a given task, as well as to set reasonable standards for performing it.

3.6.1.1 JOB DESIGN DECISIONS

Job design may be defined as the function of specifying the work activities of an individual or group in an organizational setting. Its objective is to develop job structures that meet the requirements of the organization and its technology and that satisfy the job holder's personal and individual requirements.

The decisions involved in job design. Exhibit 1. summarizes the decisions involved.



3.6.1.2 What factors affect job design decisions?

Job design decisions are being affected by the following trends:

- *Quality control as part of the worker's job.* Quality control is linked with the concept of *empowerment.* Empowerment refers to workers being given authority to stop a production line if there is a quality problem, or to give a customer an on –the- spot refund if service was not satisfactory.
- *Cross training workers to perform multi skilled jobs.* As companies engage in downsizing, the remaining workforce is expected to do more and different tasks.
- *Employee involvement and team approaches to designing and organizing work.* This is a central feature in total quality management (TQM) and continuous improvement efforts. In fact it is safe to say that virtually all TQM programs are team based.
- *Informing ordinary workers through telecommunication networks and computers, thereby expanding the nature of their work and their ability to do it.*
- *Automation of heavy manual work.* Examples bound in both services (one –person trash pick up trucks) and manufacturing (robot spray painting on auto lines). These changes are driven by safety regulations as well as economics and personnel reasons.

- *Organizational commitment.* Most important of all, organizational commitment to providing meaningful and rewarding jobs for all employers. For instance, Hewlett Packard's mission statement lists three "people related objectives" :(1). Belief in our people, (2.).Emphasis on working together and sharing rewards (team work and partnership); and (3). a superior working environment which other companies seek but few achieve.

3.6.1.3 BEHAVIORAL CONSIDERATIONS IN JOB DESIGN

Degree of Labor Specialization

Specialization of labor can be seen from two aspects. On one hand, specialization has made possible high speed, low cost production, and from a materialistic standpoint, it has greatly enhanced our standard of living. On the other hand, extreme specialization often has adverse effects on workers, which in turn are passed on to the production systems.

Advantage and disadvantage of specialization

Advantages of specialization

To management	To labor
1. Rapid training of the workforce	1. little or no education required to obtain work
2. Ease in recruiting new workers	2. Ease in learning job
3. High output due to simple and repetitive work	
4. Low wages due to ease of substitutability of labor	
5. Close control over workflow and workloads	

Disadvantages of specialization

To management	To labor
1. Difficulty in controlling quality since no one person has responsibility for entire product.	1. Boredom stemming from repetitive nature of work.
2. Worker dissatisfaction leading to hidden costs arising from turnover, absenteeism, tardiness, to each item. Grievances, and intentional disruption of	2. little gratification from work itself because of small contribution
3. Reduced likelihood of improving the process Because of worker's limited perspective. workplace,	3. little or no control over the leading to frustration

4. Limited flexibility to change the production process and fatigue (in assembly-line to produce new or improved products. Situations) 4. Little opportunity to progress to a better job since significant learning is rarely possible on fractionated work.

3.6.1.4 APPROACHES TO JOB DESIGN WITHIN THE CONTEXT OF BEHAVIORAL CONSIDERATIONS

To improve the quality of jobs, leading organizations try different approaches to job design. Two popular contemporary approaches are job enrichment and socio-technical systems.

▫ **Job Enrichment**

Job enlargement generally entails adjusting a specialized job to make it more interesting to the job holder. A job is said to be enlarged *horizontally* if the worker performs a great number or variety of tasks, and it is said to be enlarged vertically if the worker is involved in planning, organizing and inspecting his work. Horizontal enlargement is intended to counteract oversimplification and to permit the worker to perform a 'whole unit of work'. Vertical enlargement (traditionally termed job enrichment) attempts to broaden workers' influence in the transformation process by giving them certain managerial powers over their own activities. Today, common practice is to apply both horizontal and vertical enlargement to a given job and refer to the total approach as **job enrichment**.

The organizational benefits of job enrichment occur both in quality and productivity. Quality in particular improves dramatically because when individuals are responsible for their work output, they take ownership of it and simply do a better job. Also because they have a broader understanding of the work process, they are more likely to catch errors and make corrections than if the job is narrowly focused.

▫ **Socio-technical Systems**

The socio-technical systems approach is consistent with the job enrichment philosophy but focuses more on the interaction between technology and workgroup. This approach attempts to develop jobs that adjust the needs of the production process technology to the needs of the worker and work group. The term was developed from studies of weaving mills in India and of coal mines in England in the early 1950s. These studies revealed that work groups could effectively handle many production problems better than management if they were permitted to make their own decisions on scheduling, work allocation among members, bonus sharing, and so forth. This was particularly true when there were variations in the production process requiring quick reactions by the group or when one shift's overlapped with other shifts work.

Since those pioneering studies, the socio technical approach has been applied in many countries. The term is used under the heading of "***autonomous work groups",***" ***Japanese style work groups", or employee involvement (EI) teams.***

The benefits of teams are similar to those of individual job enrichment: they provide higher quality and greater productivity (they often set higher production goals than management), do their own support work and equipment maintenance, and have increased chances to make meaningful improvements. One major conclusion from these applications is that the individual or work group requires a logically integrated patter of work activities that incorporates the following job design principles:

- **Task Variety:** an attempt must be made to provide an optimal variety of tasks within each job. Too much variety can be inefficient for training and frustrating for the employee. Too little can lead to boredom and fatigue. The optimal level is one that allows the employee to take a rest from a high level of attention or effort while working on another task or, conversely, to stretch after periods of routine activity.
- **Skill variety:** research suggests that employees derive satisfaction form using a number of skill levels.
- **Feedback:** there should be some means for informing employees quickly when they have achieved their targets. The feedback aids the learning process. Ideally, employees should have some responsibility for setting their own standards of quantity and quality.
- **Task identity:** sets of tasks should be separated from other sets of tasks by some clear boundary. Whenever possible, a group or individual employee should have responsibility for a set of tasks that is clearly defined, visible, and meaningful.
- **Task autonomy:** employees should be able to exercise some control over their work.

3.6.1.5 PHYSICAL CONSIDERATIONS IN JOB DESIGN

Beyond the behavioral components of job design, another aspect warrants consideration: the physical side. Indeed, while motivation and work group structure strongly influence job performance, they may be of secondary importance if the job is too demanding form a physical (human factors) standpoint.

- **Work physiology:** is an approach to incorporating the physical coats of moderate to heavy work in job design. Work physiology sets work rest –cycles according to the energy expended in the various parts of the job. For example, if a job entails caloric expenditure above five calories per minute, the required rest period must equal or exceed the time spent working. Obviously, the harder the work, the more frequent and longer the rest periods.
- **Ergonomics:** The Operation manger is interested in building a good interface between human and machine. Studies of this interface are known as **ergonomics.** Ergonomics means the "study of work" (Ergo is from the Greek Word for Work). It is used to describe the study of the physical arrangement of the work space together with the tools used to perform a task. In applying ergonomics, we strive to fit the work to the body rather than forcing the body to conform to the work.
- ***Work environment:*** the physical environment in which employees work affects their performance, safety, and quality of work life. Illumination, noise and vibration, temperature, humidity, and air quality are work environment factors under the control of the organization and the operations manager.

3.5.2 LABOR STANDARDS AND WORK MEASUREMENT

Effective management of people requires knowledge of labor standards. Labor standards are the amount of time required to perform a job or part of a job. Every firm has standards, although they may vary from those established via informal methods to those established by professionals. Labor standards are necessary to determine the following:

- Labor content of items produced (the labor cost).
- Staffing needs of organizations (how many people it will take to make the required production).
- Cost and time estimates prior to production (to assist in a variety of decisions from developing cost estimates for customers to the make-or-buy decision)
- Crew size and work balance (who does what on a group activity or assembly line).
- Production expected (both manager and worker should know what constitutes a fair day's work).
- Basis of wage-incentive plans (what provides a reasonable incentive).

- Efficiency of employees and supervision (a standard is necessary against which to determine efficiency).

Work measurement techniques.

The fundamental purpose of work measurement is to set time standards for a job.

Properly set labor standards represent the amount of time it should take an average employee to perform specific job activities under normal working condition. Labor standards may be set in four ways:

- Historical experience
- Time studies
- Predetermined time standards
- Work sampling

The following sections cover each of these techniques.

- **HISTORICAL EXPERIENCE**

Labor standards can be estimated based on historical experience, that this, how many labor-hours were required to do a task the last time it was performed. Historical standards have the distinct advantage of being relatively easy and inexpensive to obtain. They are usually available from employee time cards or production records. But they are not objective. And we do not know their accuracy. Do they present a reasonable work pace or a poor work pace? Are unusual occurrences included? Because these variables are unknown, their use is not recommended. Instead, we will stress the three work-measurement methods that are preferred to set labor standards.

- **TIME STUDIES**

The classical stopwatch study, or time study, originally proposed by Frederick W. Taylor in 1981, is still the most widely used time-study method. A time study involves timing a sample of a worker's performance and using it to set a standard. A trained and experienced person can establish a standard by following these eight steps:

- ☑ Define the task to be studied (after methods analysis has been conducted).
- ☑ Break down the task into precise elements (parts of a task that often take no more than a few seconds).
- ☑ Decide how many times to measure the task (the number of cycles or samples needed).
- ☑ Time and record the elemental times and ratings of performance.

- ☑ Compute the average actual cycle time. The average actual cycle time is the arithmetic mean of the times for each element measured, adjusted for unusual influences for each element:
- ☑ Average actual cycle time = Sum of the time recorded to perform each element
  - o Number of cycles observed
- ☑ Compute the normal time for each element. This measure is a "Performance rating" for the particular worker pace observed.

Normal time = (Average actual cycle time) x (Rating factor)

The performance rating adjusts the observed time to what a normal worker could expect to accomplish. For example, a normal worker should be able to walk three miles per hour. He or she should also be able to deal a deck of 52 cards into four equal piles in 30 seconds. There are numerous videos specifying work pace on which professionals agree; and activity benchmarks have been established by the society for the advancement of management.

However, performance rating is still something of an art.

1. Sum of normal times for each element to develop at total normal time for the task.
2. Compute the standard time. This adjustment to the total normal time provides for allowances such as personal needs, unavoidable work delays, and worker fatigue:

Standard time =Total normal time

1- Allowance factor

Personal time allowances are often established in the range of 4% to 7% of total time, depending upon nearness to restrooms, water fountains, and other facilities. Delay standards are often set as a result of the actual studies of the delay that occurs. Fatigue standards are based on our growing knowledge of human energy expenditure under various physical and environmental conditions.

EXAMPLE 1.

The time study of a work operation yielded an average actual cycle time of 4.0 minutes. The analyst rated the observed worker at 85%. This means the worker performed at 85% or normal when the study was made. The firm uses a 13% allowance factor. We want to compute the standard time.

SOLUTION;

Average actual time = 4.0 min

Normal time = (Average actual cycle time) x (Rating factor)

= (4.0) (.85)

= 3.4 minutes

Standard time = $\frac{\text{Normal time}}{1 - \text{allowance factor}}$

$= \frac{34}{1-.13} = \frac{3.4}{.87}$

= 3.9 minutes

Let us now look at an example in which we are given a series of actual stop watch times for each element.

EXAMPLE 2

Management Science Associates promotes its management development seminars by mailing thousands of individually typed letters to various firms. A time study has been done on the task of preparing letters for mailing. On the basis of the observations below, Management Science Associates wants to develop a time standard for the task. The firm's personal, delay, and fatigue allowance factor is 15%

JOB ELEMENT	CYCLE OBSERVED (IN MINUTES)					PERFORMANCE Rating
	1	2	3	4	5	
Type letter	8	10	9	21*	11	120%
Type envelope address	2	3	2	1	3	105%
Stuff, stamp, seal, And sort envelopes	2	1	5*	2	1	110%

The procedure after the data have been collected is as follows:

1. Delete all unusual or nonrecurring observations, such as those marked with an asterisk (*), (they might be due to personal interruption, a conference with the boss, or a mistake of an unusual nature; these are not part of the job).
2. Compute the average cycle time for each job element:

Average time for A = $\frac{8+10+9+11}{4}$

= 9.5 minutes

Average time for B $= \frac{2+3+2+1+3}{5}$

= 2.2 minutes

Average time for C $= \frac{2+1+2+1}{4}$

= 1.5 minuets

3. Compute the normal time for each job element:

Normal time for A = (Average actual time) x (Rating)

= (9.5) (1.2)

= 11.4 minuets

Normal time for B = (2.2) (1.05)

= 2.31 minuets

Normal time for C = (1.51) (1.10)

= 1.65 minutes

Normal times are computed for each element because the rating factor may vary for each element, which it did in this case.

4. Add the normal times for each element to find the total normal time (the normal time for the whole job):

Total normal time = 11.40 + 2.31 + 1.65

= 15.36 minutes

5. Compute the standard time for the job:

Standard time $= \frac{\text{Total normal time}}{\text{1-allowance factor}} = \frac{15.36}{1-.15}$

= 18.07 minutes

Thus, 18.07 minutes is the time standard for this job.

Time studies provide accuracy in setting labor standards, but they have two disadvantages. First, they require a trained staff of analysts. Second, labor standards cannot be set before the task is actually performed. This leads us to two alternative work measurement techniques.

- **WORK SAMPLING**

Work sampling method of developing labor or production standards, was developed by an Englishman, L. Tippet, in the 1930s. The method involves random observations to record the activity that the worker is performing. Work sampling is used in:

1. Ratio delay studies. These estimate the percentage of time employees spend in unavoidable delays. The results are used to investigate work methods, to estimate activity costs, and to set allowances in labor standards.
2. Setting labor standards. For setting standard task times, the observer must be experienced enough to rate the worker's performance.
3. Measuring worker performance. Sampling can develop a performance index for workers for periodic evaluations.

The work sampling procedure can be summarized in seven steps:

- Take a preliminary sample to obtain an estimate of the parameter value (such as percent of time a worker is busy).
- Compute the sample size required.
- Prepare a schedule for observing the worker at appropriate times. The concept of random numbers is used to provide for random observation.
- Observe and record worker activities; rate the worker's performance.
- Record the number of units produced. During the applicable portion of the study.
- Compute the normal time per part.
- Compute the standard time per part.

Time study is a sampling process, and the question of sampling error in the average actual cycle time naturally arises. Error, according to statistics, varies in verily with sample size. In order to determine just how many cycles should be timed. Consideration of the variability of each element on the study is necessary.

To determine an adequate sample size, three items must be considered:

1. How accurate we want to be (that is, is $\pm$ 5% of actual close enough?).
2. The desired level of confidence (that is, the Z value; is 95% adequate or is 99% required?)

TABLE 1

DESIRED CONFIDENCE (percent)	Z VALUE (standard deviation required for desired level of confidence)
90.0	1.65
95.0	1.96
95.4	2.00
99.0	2.58
99.7	3.00

3. How much variation exists within the job elements (that is, if the variation is large, a large sample will be required).

The formula for finding the appropriate sample size given these three variables is

$$n = \left[\frac{ZS}{Hx}\right]^2$$

Where

H = Accuracy level desired in percent of the job element, expressed as a decimal (5% = .05)

z. = Number of standard deviations required for desired level of confidence (90% confidence 1.65; see Table 1 for the more common z values)

S= standard deviation of the initial sample

X=Mean of the initials sample.

Example 3,

A certain company asked you to check labor standard prepared by a recently terminated analyst. Your first task is to determine the correct sample size. Your accuracy is to be within 5% and your confidence level is 95%. The standard deviation of the sample is 1.0 and the mean is 3.00

SOLUTION:

H=.05

Z=1.96

X=3.00

S=1.0

$$n = \left[\frac{ZS}{Hx}\right]^2$$

$$n = \frac{(1.96\ x1.0)^2}{(.05x3)^2}$$

=170.74=171.

Therefore, you recommend a sample size of 171.

Let's now look at two variations of example 3. First if h, the desired accuracy is expressed an absolute amount of error (say one minute of error is acceptable) then substitute e, for hx, and the appropriate formula is:

$$n = \left[\frac{zs}{e}\right]^2$$

Where e=absolute amount of acceptable error

Secondly, for those cases when **s,** the standard deviation of the sample, is not provided, it must be computed. The formula for doing so is:

$$S = \sqrt{\sum\left(\frac{x_i - x}{n-1}\right)^2}$$

Where

n=number of observations

Xi=value of each observations

X=mean of each observations

PREDETERMINED TIME STANDARDS

A third way to set production standards is to use predetermined time standards. Predetermined time standards divide manual work into small basic elements before established times (based on very large samples of workers). To estimate the time for a particular task, the time factors for each basic element of the task are added together. For any given firm to develop a comprehensive system of predetermined time standards would be prohibitively expensive. Consequently, a number of systems are commercially available.

Predetermined time standards have several advantages relative to direct time studies. First, they may be established in a laboratory environment, which will not upset production activities (which time studies tend to do). Second, the standard can be set before a task is done and can be used for planning. In addition, no performance ratings are necessary-and the method is widely accepted by unions as a fair means of setting standards. Predetermined time standards are particularly effective in firms that do substantial numbers of studies where the tasks are similar. Some firms use both time studies and predetermined time standards to ensure accurate labor standards.

Self-check exercise 3

Part I. Write “true” if the statement is correct and “false” if the statement is incorrect

1. Quality function deployment refers to first, determining what will satisfy the customer, and second, translating the customers’ desires into a target design.
2. Robust design is a method that ensures that small variation in production or assembly does not adversely affect the product
3. The factor-rating method can consider both tangible and intangible costs.
4. The moment-of-truth is the crucial moment between the service provider and the customer that exemplifies, enhances, or detracts from the customer's expectation.
5. The graphic approach to location break-even analysis displays the range of volume over which each location is preferable.
6. Service blueprinting is a process analysis technique that focuses on the customer and the provider's interaction with the customer.
7. A firm's process strategy is its approach to transforming resources into goods and services.
8. Capacity decisions are based on technological concerns, not demand forecasts.
9. Effective capacity is the maximum theoretical output of a system in a given period under ideal conditions.
10. The layout approach that addresses trade-offs between space and material handling is called the fixed position layout.
11. The dominant problem associated with the fixed-position layout is that workers are fixed in position, and cannot be reassigned.
12. Job rotation is an example of job enlargement.
13. Psychological factors have little relevance in the design of assembly line jobs since they involve physical products and production technology.

Part II; Choose the best answer from the listed alternatives

1. The behavioral approach to job design that involves giving the worker a larger portion of the total task is
   A. job enlargement
   B. job enrichment
   C. job enhancement
   D. job rotation
   E. job involvement

2. The difference between **job enrichment** and **job enlargement** is that
   A. enlarged jobs involve vertical expansion, while enriched jobs involve horizontal expansion
   B. enriched jobs enable an employee to do a number of boring jobs instead of just one
   C. job enlargement is more psychologically satisfying than job enrichment
   D. job enrichment is suitable for all employees, whereas job enlargement is not
   E. enriched jobs involve vertical expansion, while enlarged jobs involve horizontal expansion
3. **Labor standards** are defined as the
   A. preset activities required to perform a job
   B. amount of space required by a specific crew to perform the job
   C. standard set of procedures to perform the job
   D. standard labor agreements
   E. amount of time required to perform a job or part of a job
4. "A special arrangement of machinery and equipment to focus on production of a single product or group of related products" describes what layout type?
   A. fixed-position layout
   B. intermittent production
   C. focused factory
   D. work cell
5. The major problem addressed by the process-oriented layout strategy is
   A. the movement of material to the limited storage areas around the site
   B. requiring frequent contact close to one another
   C. the provision of low-cost storage with low-cost material handling
   D. minimizing difficulties caused by material flow varying with each product
   E. balancing product flow from one work station to the next
6. If demand exceeds capacity, an organization can use which of the following to adjust demand to an existing facility?
   A. aggressive marketing
   B. lower prices
   C. build a facility of the correct size
   D. add a complementary product
   E. reduce lead times

7. An organization's process strategy
   A. will have long-run impact on efficiency and flexibility of production
   B. is the same as its transformation strategy
   C. must meet various constraints, including cost
   D. is concerned with how resources are transformed into goods and services
   E. All of the above are true.
8. Which of the following transformations generally has the highest equipment utilization?
   A. process-focused process
   B. repetitive process
   C. product-focused process
   D. specialized process
   E. modular process
9. Which of the following phrases best describes *process focus*?
   A. low volume, high variety
   B. finished goods are usually made to a forecast and stored
   C. operators are modestly skilled
   D. high fixed costs, low variable costs
   E. raw material inventories are high relative to the value of the product
10. In location planning, environmental regulations, cost and availability of utilities, and taxes are
   A. global factors
   B. country factors
   C. regional/community factors
   D. site-related factors
   E. none of the above
11. Evaluating location alternatives by comparing their composite (weighted-average) scores involves
   A. factor rating analysis
   B. cost-volume analysis
   C. transportation model analysis
   D. linear regression analysis
   E. crossover analysis
12. Which of the following is **true** regarding computer-aided design?
   A. It is too expensive to use in most manufacturing and design settings.
   B. It is an old technology, no longer in significant use.
   C. It is the use of computers to interactively design products and prepare engineering documentation.
   D. All of the above are true.

13. Which of these is **not** a benefit of CAD/CAM?

A. shorter design time
B. images substitute for the real product
C. production cost reductions
D. new range of capabilities
E. database availability

14. Modern ATM machines are an automated example of a service design that

A. reduces customer interaction
B. modularizes the service
C. delays service customization
D. has no moment of truth
E. has insufficient quality function deployment

Part three: Write a short answer

1. What is quality function deployment (QFD)?
2. Discuss the advisability of using modular assemblies in manufacturing. (What are the advantages and disadvantages?) To what extent can these arguments be utilized in service products?
3. What is the fundamental distinction between design capacity and effective capacity? Provide a brief example
4. Name the four basic process strategies; describe them in a complete sentence or two each.

Part four: work out question

1. XYZ is considering two different locations for a new retail outlet. They have identified the four factors listed in the following table as the basis for evaluation, and have assigned weights as shown on the left. The manager has rated each location on each factor, on a 100-point basis, as shown on the right.

Factor	Factor Description	Weight
1	Average community income	.40
2	Community growth potential	.25
3	Availability of public transportation	.15
4	Labor cost	.20

Dessie	Kombolcha
80	40
70	80
60	85
90	75

Required

A. Select the best location using factor rating method

2. A firm is considering two location alternatives. At location A, fixed costs would be $4,000,000 per year, and variable costs 0.30 per unit. At alternative B, fixed costs would be $3,600,000 per year, with variable costs of $0.35 per unit. If demand is expected to be 10 million units, which plant offers the lowest total cost?

3. Cyclone Appliances has developed a new European-style convection oven that will be made on an assembly line. The schedule requires 80 ovens in an 8-hour day. The assembly includes seven tasks. The table below indicates the performance time and the sequence requirements for each task.

Task	Performance Time (minutes)	Task must follow Task listed below
A	1	
B	2	A
C	3	B
D	2	B
E	4	C, D
F	1	E
G	2	F

Required

A. What is the cycle time for this assembly operation?
B. What is the minimum number of workstations?
C. Draw the precedence diagram.

4. The local convenience store makes personal pan pizzas. Currently, their oven can produce 50 pizzas per hour. It has a fixed cost of $2,000, and a variable cost of $0.25 per pizza. The owner is considering a bigger oven that can make 75 pizzas per hour. It has a fixed cost of $3,000, but a variable cost of $0.20 per pizza.

a. At what quantity do the two ovens have equal costs?

4. A telecommunications firm is planning to lay fiber optic cable from several community college distance learning sites to a central studio, in such a way that the miles of cable are minimized. Some locations require more than one set of cables (these are the loads). Where the studio should be located to accomplish the objective?

College	**Map Coordinate (x, y)**	**Load**
A	(2,10)	3
B	(6,8)	2
C	(4,9)	4
D	(9,5)	1
E	(8,1)	3
F	(3,2)	2
G	(2,6)	1

CHAPTER FOUR

OPERATION PLANNING AND CONTROL

Dear students in this section we will to discuss about operation scheduling and production planning in manufacturing organization.

Chapter objective

At the end of this chapter students will be able to:

- ✓ Explain operations planning & control
- ✓ Discuss Aggregate production planning
- ✓ Discuss Operations Scheduling

4.1 AGGREGATE PRODUCTION PLANNING

It involves translating annual and quarterly business plans into broad labor and output plans for the intermediate term (6 to 18 months). Its objective is to minimize the cost of resources required to meet demand over that period.

An overview of operations planning activities

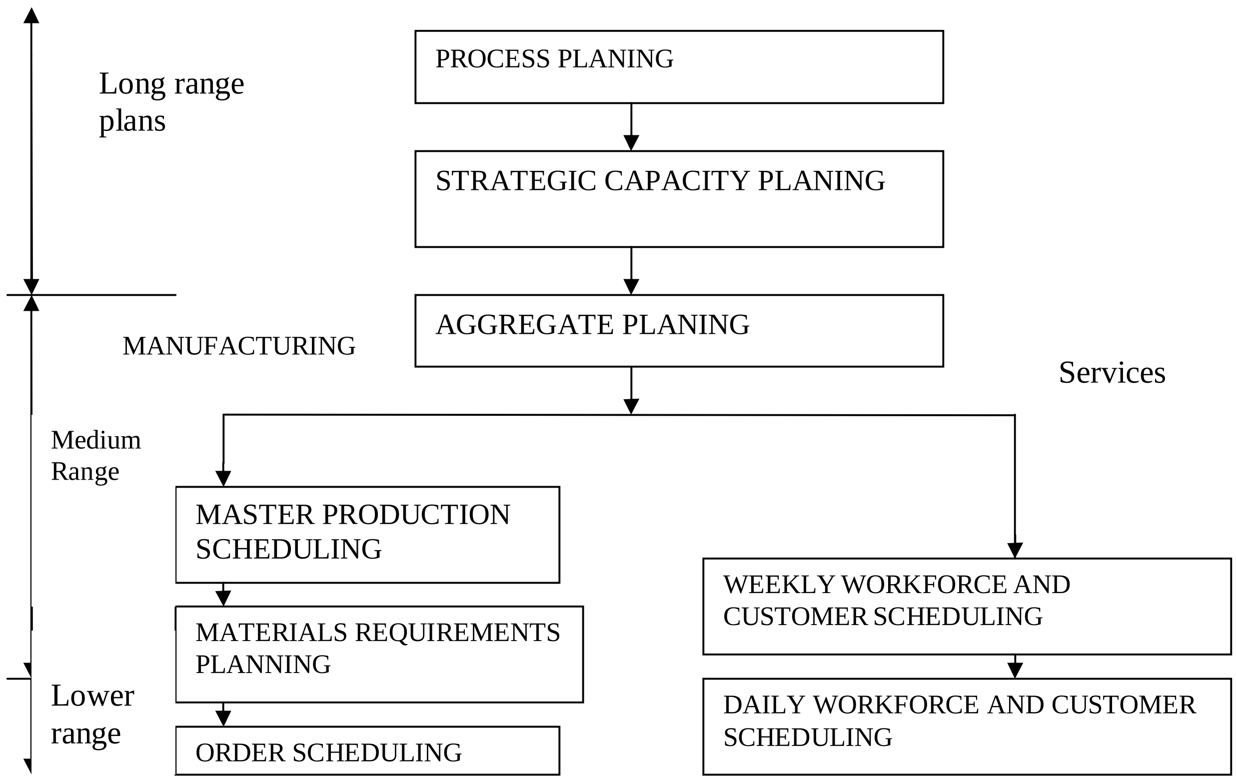
Based on time dimension: the time dimension is shown as long, intermediate, and short range

- **Long range planning:** is generally done annually, focusing on a horizon greater than one year.
- **Intermediate range planning:** usually covers a period from 6 to 18 months, with time increments that are monthly or sometimes quarterly.
- **Short range planning:** covers a period from one day or less to six months, with time increment usually weekly.

Process planning: deals with determining the specific technologies and procedures required to produce a product or service.

Strategic capacity planning: deals with determining the long- term capabilities (e.g. size and scope) of the production system.

Fig.1: an Overview of Operations planning Activities



- **Master production schedules (Mps):** generates the amounts and dates of specific items required for each order. **Rough –cut capacity planning** is then used to verify that production and warehouse facilities, equipment, and labor are available and that key vendors have allocated sufficient capacity to provide materials when needed.
- **Material requirements planning (MRP):** takes the end product requirements from the MPS and breaks them down into their component parts and subassemblies to create a materials plan. This plan specifies when production and purchase orders must be placed for each part and subassembly to complete the products on schedule.
- **Order scheduling:** specifies the daily or weekly order scheduling of jobs to specific machines, production lines, or work centers.

Aggregate production planning:

Aggregate production planning is concerned with setting production rates by product group or other broad categories for the intermediate term (6 to 18 months).

Aggregate plans precede the master schedule

The main purpose of the aggregate plan is to specify the optimal combination of production rate, the work force level, and inventory on hand.

Production rate: refers to the number of units completed per unit of time (such as per hour or per day).

Workforce level: is the number of workers needed for production.

Inventory on hand: is the balance of unused inventory carried over form the previous period.

Here is a formal statement of the aggregate planning problem:

Given the demand forecast **Ft** for each period **t** in the planning horizon that extends over **T** periods, determine the production level **Pt**, inventory level **It,** and workforce level **Wt**fro periods t= 1,2,…,T that minimizes the relevant costs over the planning horizon.

The production planning environment:

The internal and external factors that constitute the production planning environment include:

Internal factors:

- Activities required for production
- Inventory levels
- Current workforce
- Currently completed activities

External factors:

- Competitors behavior
- Raw materials availability
- Market demand
- Economic conditions
- External capacity(e.g. subcontractors)

4.2. Production planning strategies

There are essentially three production planning strategies. These strategies involve trade- offs among the **work force size**, **work hours**, **inventory**, and **backlogs.**

1. **Chase strategy:** Match the **production rate** to **order rate** by hiring and laying off employees as the order rate varies. The success of this strategy depends on having a pool of easily trained applicants to draw on as order volumes increase. The problem in this case is

the impact on motivation. When order backlogs are low, employees may feel compelled to slow down out of the fear of being laid off as soon as existing orders are completed.

2. **Level strategy.** Maintain a stable workforce working at a constant output rate. Shortages and surpluses are absorbed by fluctuating inventory levels, order backlogs, and lost sales. Employees benefit from stable work hours at the costs of potentially decreased customer service levels and increased inventory costs. Another concern is the possibility of inventoried products becoming obsolete. **Stable workforce –variable work hours.** Vary the output by varying the number of hours worked through flexible work schedules or overtime. By varying the number of work hours, you can match production quantities to orders. This strategy provides workforce continuity and avoids many of the emotional and tangible costs of hiring firing associated with the chase strategy. When just one of these variables is used to absorb demand fluctuations, it is termed **a pure strategy** two or more used in combination is **a mixed strategy.**
3. **Mixed strategy or combination strategy:** Mixed strategies are more widely applied in industry. In addition to the above strategies, managers may also choose to subcontract some portion of production. This strategy is similar to the chase strategy, but hiring and laying off are translated into subcontracting, and not subcontracting. Some level of subcontracting can be desirable to accommodate demand fluctuations. However, unless the relationship with the suppliers is particularly strong, a manufacturer can lose control over schedule and quality. For this reason extensive subcontracting, may be viewed as a high-risk strategy.

Relevant costs to aggregate production planning: there are four costs relevant to aggregate production planning. These costs relate to the production cost itself as well as the cost to hold inventory and have unfilled orders.

- **Basic production costs:** the fixed and variable costs incurred in producing a given product type in a given time period. It includes direct and indirect labor costs and regular as well as overtime compensation.
- **Costs associated with changes in the production rate:** costs involved in hiring, training, and laying off personnel.
- **Inventory holding costs:** A major component is the cost of capital tied up in inventory. Other components are storing, insurance, taxes, spoilage, and obsolescence.

- **Backordering costs.** Usually these costs are very hard to measure and include costs of expending, loss of customer goodwill, and loss of sales revenues resulting from backordering.

Aggregate planning techniques:

Two methods are commonly used to develop aggregate plans:

1. **A cut and try approach**: involves costing out various productions planning alternatives and selecting the one that is best. Spreadsheets incorporated with sophisticated linear programming and simulations are used to facilitate the decision process.
2. **Graphic methods.**

ILLUSTRATION ON AGGREGATE PLANNING

CASE: To illustrate the general principles in aggregate plan with a shorter horizon, suppose we wish to set up a production plan for the ABC company. for the next six months. We are given the following information.

Demand and working days	Jan.	Feb.	Mar.	April	May	June	Totals
Demand forecast	1,800	1500	1100	900	1100	1600	8,000
Number of working days	22	19	21	21	22	20	125

Costs

Materials	$100.00/unit
Inventory holding cost	$1.5/unit/month
Marginal cost of stock out	$ 5.00/unit/month
Marginal cost of subcontracting	$20.00/unit ($120 subcontracting cost Less $100 material savings)
Hiring and training cost	$200.00/worker
Layoff cost	$250.00/worker
Labour hrs required	$ 5/unit
Straight line cost (first eight hrs each day)	$4.00/hour

Overtime cost (time and half) $6.00/hour

Inventory

Beginning inventory	400 units
Safety stock	25% of month demand

Beginning inventory at the end of the first period is 400 units. Because the demand forecast is imperfect, the company has determined that a safety stock (buffer inventory) should be established to reduce the likelihood of stock outs. For this example, we assume the safety stock should be one –quarter of the demand forecast.

Before investigating alternative production plans, it is often useful to convert demand forecasts into production requirements, which take into account the safety stock estimates. Note that these requirements implicitly assume that the safety stock is never actually used, so that the ending inventory each month equals the safety stock for that month. For example, the January safety stock of 450(25% of January demand of 1800) the inventory at the end of January. The production requirement for January is demand plus safety stock minus beginning inventory (1800+ 450-400= 1,850).

Developing Aggregate production planning Requirements:

	Jan.	Feb.	Mar.	Ap.	Ma	Jun
Beginning Inventory	400	450	375	275	225	275
Demand forecast	1800	1500	1100	900	1100	1600
Safety stock (.25 x Demand forecast)	450	375	275	225	275	400
Production requirement (Demand Forecast + Safety stock –Ending inv.)	1850	1425	1000	850	1150	1750
Ending inventory : (Beginning Inv.+ production Requirement -demand forecast)	450	375	275	225	275	400

Now, we must formulate alternative production plans for the co. with the objective of finding the one with the lowest total cost:

Plan 1: Produce to exact monthly production requirements using a regular eight hour day by varying the workforce size

- Expected cots: hiring, layoff, straight time.

In solving all problem, we can exclude the material costs. We could have included this $100 cost in all our calculations, but if we assume that a $100 cost is common to each demanded unit, then, we need only to concern ourselves with the marginal costs. Because the subcontracting cost is $120, our true cost for subcontracting is just $20 because we save the materials. Note that many costs are expressed in a different form than typically found in the accounting records of a firm. Therefore, do not expect to obtain all these cots directly from such records, but obtain them directly form management personnel, who can help interpret the data.

The next is to calculate the cost of each plan.

Strategy	Variables	Rows needed		Calculations
Chase (Produce exactly what's needed In each time period.)	• Vary work force size (hire & lay off) • No inventory holding or shortage • Constant production rate	Plan	Production requirement	(# units demanded + safety stock) – beginning inventory
			Hours required	Production requirement * # hours needed to produce one unit
			# days in period	(given)
			Hours per worker	# hours per day * # days in the period
			# workers needed	Hours required / hours per worker per period
			# hired	Max {workers needed – previous period workforce, 0}
			# laid off	Max {previous period workforce - workers needed, 0}
		Costs	*Regular time cost*	*Hours required * regular time labor rate*
			Hiring cost	*# hired * hiring cost*
			Layoff cost	*# laid off * layoff cost*
			Total cost	*Regular time + hiring + layoff costs*
Level (Produce at a constant rate)	• Constant work force size • Constant production rate • Inventory will vary (excesses & shortage)	Plan	Production requirement	(# units demanded + safety stock) – beginning inventory
			# days in period	(given)
			Hours per worker	# hours per day * # days in the period
			# workers used	Given or calculated as # workers needed to produce average requirement
			# units produced	(Hours per worker * # workers used) / # hours needed to produce one unit
			Beginning inventory	(given)
			Ending inventory	Beginning inventory + # units produced - production requirement
		Costs	*Initial w/f adjustment*	*Hiring or layoff cost, if needed to get # workers used*
			Regular time labor cost	*# workers used * hours per worker * regular time labor rate*
			Inventory carrying cost	*Max {ending inventory, 0} * carrying cost per unit per period*
			Backorder cost	*Min {ending inventory, 0} * backorder cost per unit per period*
			Total cost	*Initial hiring/layoff + regular time + inventory carrying + backorder costs*
Stable work force – vary production rate (Produce at a constant rate, using overtime as needed)	• Constant work force size (lower than level strategy) • Work overtime when needed • No inventory holding or shortage	Plan	Production requirement	(# units demanded + safety stock) – beginning inventory
			Hours required	Production requirement * # hours needed to produce one unit
			# days in period	(given)
			Hours per worker	# hours per day * # days in the period
			# workers used	Given or calculated as # workers needed to produce lowest requirement
			Regular time hours used	Hours per worker * # workers used
			Overtime hours used	Max {hours required – regular time hours used, 0}
		Costs	*Regular time cost*	*Regular time hours used * regular time labor rate*
			Overtime cost	*Overtime hours used * overtime labor rate*
			Initial w/f adjustment	*Hiring or layoff cost, if needed to get # workers used*
			Total cost	*Initial hiring/layoff + regular time + overtime costs*
Mixed or hybrid	More than one variable used	Combine rows from other strategies, as needed		(Although the rows needed will depend on the strategy, each needed row will be computed as described in other strategies)

Plan 1: Exact production; Vary workforce

	Jan.	Feb.	Mar.	Apr	May	June	Total
• Production requirements(1)	1,850	1,425	1,000	850	1,150	1,725	
• Production hrs. required (2) [(1) X 5hr.per unit]	9250	7125	5000	4250	5750	8625	
• Working days per month (3)	22	19	21	21	22	20	
• Hrs. Per month per worker **(4)**: [(3) X 8hr/day]	176	152	168	168	176	160	
• Workers required **(5)**: [(2)/ (4)]	53	47	30	25	33	54	
• New workers hired (assuming opening workforce equal to first month's requirement of 53 workers) **(6)**	0	0	0	0	8	21	
• Hiring cost **(7): [**(6) X$200]	$0	$0	$0	$0	$1600	$4200	$5800
• Workers laid off **(8)**	0	6	17	5	0	0	
• Layoff cost **(9)** [workers laid off x $250)	0	$1500	$4250	$1250	$ 0	$0	$7000
Straight time –cost: (10) [(2) x $4]	$37000	$28500	$ 20,000	$ 17000	$23,000	$34500	$160,000
				Total cost			$172,800

Plan 2: Produce to meet expected average demand over the next six months by maintaining a constant workforce

This constant number of workers = Total production requirement (**p_t**) X Time required for Each unit / the total time that one person works over the Horizon

[(8,000unitsx5 hours per unit)/(125 days x8 hours per day) =40 workers]

Inventory is allowed to accumulate, with shortages filled from next month's production by back ordering. Notice that in this plan use our safety stock in January, February, March and June to meet expected demand

Production Plan 2: Constant Workforce; Vary Inventory and Stock out

	January	February	March	April	May	June	Total
Beginning inventory	400	8	-276	-32	412	720	
Working days per month	22	19	21	21	22	20	
Production hours available (working days per month x8 hr./Day x40 workers*)	7.040	6,080	6,720	6,720	7,040	6,400	
Actual production (Production hours available/5 hr./unit)	1,408	1,216	1,344	1.344	1,408	1,280	
Demand forecast (from Exhibit 14.4	1,800	1,500	1,100	900	1,100	1,600	
Ending inventory (Beginning inventory + Actual production-Demand forecast)	8	-276	-32	412	720	400	
Shortage cost (Units short x $5)	$0	$1.380	$160	$0	$0	$0	$1,540
Safety stock (from Exhibit 14.4)	450	375	275	225	275	400	
Units excess (Ending inventory – safety stock) only if positive amount	0	0	0	187	445	0	
Inventory cost (Units excess x $1.50)	$0	$0	$0	$281	$668	$0	$948
Straight time cost (Production hours available x $4)	$28.160	$24,320	$26,880	$26,880	$28.160	$25,600	$160,000
Total cost $162,488							

Plan 3 Produce to meet the minimum expected demand (April) using a constant workforce on regular time. Subcontract to meet additional requirements.

- The number of workers is calculated by locating the minimum monthly production requirement and determining how many workers would be needed for that month [(850 units x 5 hours per unit) /(21 days x 8 hours per day)=25 workers]and subcontracting any monthly difference between requirements and production.

	January	February	March	April	May	June	Total
Production requirement	1,850	1,425	1,000	850	1,150	1,725	
Working days per month	22	19	21	22	22	20	
Production hours available (working day x 8 hrs./day x 25 workers)*	4,400	3,800	4200	4200	4,400	4,000	
Actual production (production hours available/ 5 hr. per unit)	880	760	840	880	880	800	

Units subcontract (Production requirement –Actual production)	970	665	160	10	270	925	
Subcontracting cost (Units subcontracted x $20)	$19,400	$13,300	$3,200	$200	$5,400	$18,500	$60,000 **$100,000**
Straight time cost (Production hours available x $4)	$17,600	$15,200	$16,800	$16,800	$17,600	$16,000 Total cost	$160,000

- Minimum production requirement in this example, April is minimum of 850 units. Number of workers required for April is (850 x 5) /(21 x 8) = 2
    - **Plan 4**. Produce to meet expected demand for all but the first two months using a constant workforce on a regular time. Use overtime to meet additional output requirements. The number of workers is more difficult to compute for this plan, but the goal is to finish June with an ending inventory as close as possible to the June safety stock. By trial and error it can be shown that a constant work force of 38 workers is the closest approximation.

	January	February	March	April	May	June	Total
Beginning inventory	400	0	0	177	$54	792	
Working days per month	22	19	21	21	22	20	
Production hours available (Working days x 8 hr./day x 38 workers)*	6,688	5,776	6,384	6,384	6,688	6,080	
Regular shift production (Production hour's available/5 hrs. per unit)	1,338	1,155	1,277	1,277	1,338	1,216	
Demand forecast	1,800	1,500	1,100	900	1,100	1,600	
Units available before overtime(Beginning inventory + Regular shift production – Demand forecast). This number has been rounded to nearest integer.	-62	-345	177	554	792	408	
Units overtime	62	345	0	0	0	0	
Overtime cost (Units Overtime x 5hr/ unit x $6/hr.)	$1,860	$10,350	$0	$0	$0	$0	$12,210
Safety stock	450	375	275	225	275	400	
Units excess (Units available before overtime-safety stock) only if positive amount	0	0	0	329	517	8	
Inventory cost (Unit excessive x 1.50)	$0	$0	$0	$494	$776	$12	$1,281
Straight time cost (Production hours available	$26,752	$23,104	$25,536	25,536	$26,752	$24,320	$152,000

x $4)							
						Total cost	$165,491

- Workers determined by trial-and-error. See text for explanation.

Comparison of cost between different types aggregate plans

Cost	Plan1:Exact production; Vary Workforce	Plan2: Constant Workforce; Vary Inventory and Stockout	Plan 3: constant Low Workforce; Subcontract	Plan4: Constant Workforce; Overtime
Hiring	$ 5,800	$ 0	$ 0	$ 0
Layoff	7,000	0	0	0
Excess	0	948	0	1,281
inventory	0	1,540	0	0
Shortage	0	0	60,000	0
Subcontract	0	0	0	12,210
Overtime	160,000	160,000	100,000	152,000
Straight time	$172,800	$162,488	$160,000	$165,491

Eagle Fabrication has the following aggregate demand requirements and other data for the upcoming four quarters.

Demand	**quarter 1**	**quarter 2**	**quarter 3**	**quarter 4**	**Totals**
Demand forecast	1600	1400	1500	1800	6000
Number of working days	64	63	65	64	256

Costs

Materials $100.00/unit

Inventory holding cost	$3/unit/month
Marginal cost of stock out	$ 10/unit/month
Marginal cost of subcontracting	$30.00/unit ($150 subcontracting cost Less $120 material savings)
Hiring and training cost	$500.00/worker
Layoff cost	$750.00/worker
Labour hrs required	$8/unit
Straight line cost (first eight hrs each day)	$10.00 birr/hour
Overtime cost (time and half)	$12.00 birr/hour

Inventory

Beginning inventory	600 units
Safety stock	30% of monthly demand

Required: Which of the following production plans is better?

A. Plan A: Produce to exact monthly production requirements using a regular eight hour day by varying the workforce size
B. Plan B: Produce to meet expected average demand over the next six months by maintaining a constant workforce
C. Plan C: Produce to meet the minimum expected demand (quarter 2) using a constant workforce on regular time. Subcontract to meet additional requirements

4.3 OPERATIONS SCHEDULING

Detailed day-to- day planning of operations is called scheduling. Scheduling decisions allocate available capacity or resources (equipment, labor and space) jobs, activities, tasks or customers over time. Since scheduling is an allocation decision, it uses the resources made available by facilities decisions and aggregate planning. Therefore, scheduling is the last and most constrained decision in the hierarchy of capacity planning decisions.

In practice, scheduling results in a time phased plan, or schedule, of activities. The schedule indicates what is to be done, when, by whom, and with what equipment. Scheduling should be differentiated from aggregate planning. Aggregate planning seeks to determine the resources needed, while scheduling allocates the resources made available through aggregate planning in the best manner to meet operations objectives.

Scheduling deals with questions such as

- Which work centers will do which job?
- When should an operation / job be started? When should it end?
- On which equipment should it be done, and by whom?
- What is the sequence in which jobs/ operations need to be handled in facility or on equipment?

4.3.1 Why scheduling is necessary?

Scheduling operational tactical plans by defining at the shop-floor level of production activity exactly what each worker has to do to complete the operations management transformation process. Scheduling provides the detailed instructions necessary to convert the production objectives of the MPS into-day to day directives for workers who perform different tasks.

Scheduling is a necessary operations management activity that helps the organization minimize inefficiency and maximize customer service. In scheduling, an organization allocates its production capacity to meet timely customer demand requirements. If too much capacity is scheduled, idle workers and idle facilities will result in costly waste of time causing poor service to customers and possibly a loss of business to the organization. An organization that schedules the exact amount of capacity at the right time to meet customer demand will optimize its resources.

Scheduling is also a tactical means of achieving a competitive advantage. Some organizations have built flexibility into their scheduling systems to accommodate rapid changes in customer demand. By designing operations management production scheduling systems to be highly flexible, companies are better able to shift production activity to more profitable or sales generating new markets as external demand shifts.

4.3.2 Basics of scheduling

Schedules should be easy to use, easy to understand, to carry out, and flexible enough to accommodate necessary demand requirement changes.

The primary objective of short range scheduling in any type of production operation include

- Minimizing waste and inefficiency of human, technology and system resources
- Maximizing customer service

The objectives are universal to any type of operation.

4.3.3 Scheduling methods

Many different methods are used to develop a schedule in job operation. The selection of the methods depends on the volume of orders and nature of the operation. Most of the scheduling methods can be categorized as being forward scheduling, backward scheduling, or some combination of both.

- **Forward scheduling.** In forward scheduling actual production activities begin when a job

Order is received. Materials and production capacity are immediately allocated to satisfy the job order on its arrival. Forward scheduling refers to the situation in which the system takes an order and then schedules each operation that must be completed forward in time.

Forward scheduling is used in fabrication operations in which custom products are the norm and product demand is unknown until announced by the customer. Scheduling operating rooms, doctors, nurses, and equipment for surgery in hospitals is one example of forward scheduling in a service operation.

- **Backward scheduling.** In backward scheduling, production activities are scheduled by their due dates, i.e., starting in reverse order with the due dates for job orders, production activity is scheduled backward from the finished product to the procurement of materials. Backward scheduling starts from some date in the future (a due date) and schedules the required operations in reverse sequence. The backward schedule tells when an order must be started in order to be done by specific date. An MRP system is an example of an infinite, backward scheduling system for materials.

Backward scheduling is ideal for manufacturing organizations that use MRP systems in service operations in which demand for services is known ahead of time. When a customer special orders an automobile from a manufacturer or a motion picture service organization produces a film, backward scheduling is necessary to complete these products.

A combination of both forward and backward scheduling

Scheduling Activities

Regardless of the method, scheduling requires the use of routing information, job loading, job sequencing, and dispatching.

1. **Routing sheets:** to help management prepare a schedule, routing sheets or routing files must exist on each product. Routing sheets (hard copy) or routing files (electronic copy for computer based operations) are a set of detailed information that explains how a product is to be produced in manufacturing or prepared in service operations. Routing information can include a list of operations that must be performed by workstation or employee, the sequence of operations necessary to complete a product, information on tooling, operator skill requirements, standard set up times for machines and runs, and even testing requirements. Routing is based on a product's production requirements and largely dictated by plant layout considerations.

2. Job loading: once the jobs are routed, management must load them into the operation. Loading is the scheduling process by which the jobs are assigned to individual work centers or workstations.

The loading process can be based on capacity restrictions –that's, managers simply load jobs into a work center upon its standard capacity. In operations in which capacity limitations are not critical, loading is based on assigning jobs to minimize costs by reducing idle time, inventory, and so on.

Based on how capacity is considered in determining the schedule, scheduling systems can use either infinite loading or finite loading.

- **Infinite loading** occurs when work is assigned to a work center simply based on what is needed overtime. No consideration is given directly to whether there is not sufficient capacity at the resources required to complete the work, nor is the actual sequence of the work is done by each work in the work center is considered.
- **Finite loading** a finite loading approach actually schedules in each detail each resourceusing the setup and run-up time required for each job.
- **Job sequencing:** Loading also involves the sequencing of jobs (i.e., an initial ordering of jobs to achieve a specific objective for the production facility as a whole).
- **Dispatching** is the final act of releasing job orders to workers for completion. A job order is dispatched in accordance with a planned sequence, or the act of dispatching determines a job's sequence in the production process. In both manufacturing and service operations, **dispatching rules** or **priority rules** are used to schedule production activity.

Common dispatching or priority rules include the following:

1. First -come, first –served. Jobs arriving at a work station or service center are processed as soon as they arrive in the order of their arrival. This rule is used in operations in which fairness may be a factor in customer service, such as waiting for a service in post office or for an amusement park ride.

2. Earliest due date. The job arriving at a work station or service center with the earliest due date is dispatched first, the next earliest second, and so on. This rule is used in job –type operations in which substantial back logs can be justified by the customer service being provided.

3. Longest processing time. The job arriving at a workstation or service center that requires the longest amount of processing time is dispatched first, the job requiring second longest amount of time, second and so on. This rule based on the logic that jobs that take longer will be of more value to the organization and therefore, should be completed first to maximize sales, profit, and service to important customers. A tool manufacturer for, example, can make more profit by processing a $1000 tool order than a single tool order from a customer.

4. Shortest processing time. The job arriving at a workstation or service center that requires the least amount of processing time is dispatched first, the job requiring second longest amount of time, second and so on. This rule is based on the concept that maximizing the flow of completed jobs will reduce costs (such as those associated with inventory and idle capacity) and thereby maximize profits.

The following standard measures of schedule performance are used to evaluate priority rules:

1. Meeting due dates of customers or downstream operations.
2. minimizing the flow time (the time a job spends in the process)
3. minimizing work in process inventory
4. Minimizing idle time of machines or workers.

Scheduling in manufacturing operations differs in many ways from scheduling in service operations. The greater material requirements necessary to complete manufactured products as well as product complexity are sources of some of these differences.

■ **Priority rules and Scheduling techniques**

Scheduling methods include Gantt Charts, job sequencing rules, lot-sizing rules, JIT scheduling principles, queuing analysis, simulation analysis, critical- ratio method, optimized production technology, input-output control, and expert systems. We will focus only on some of these methods for our purpose:

- **Gantt Charts** are simple bar graphs that can be used to schedule any type of operation. Two basic types of Gantt Charts are work load charts and scheduling charts. A work load chart is usually used to predict work load levels for equipment, work stations or departments.

  A Gantt scheduling chart is used to track the progress of jobs as they pass through various departments in an organization.

- **Job sequencing rules:** in all types of operations, scheduling jobs is a critical scheduling activity. Operations sequencing is a scheduling activity that is necessary to minimize the total time it takes to process a batch of job orders, improve the efficiency of an operation, and minimize the processing costs of a fixed number of jobs over a given period of time.

  When jobs go through only a single stage of production, they are scheduled one after another. If jobs go through two or more stages of production (for example, two or more departments), we run the risk of idle time occurring in some of the later stages or departments.

  Johnson's job sequencing rules can be used when we have a set of known jobs (and timing requirements for each job) that must each go through a two- stage production process.

Ten priority rules for job sequencing

■ FCFS (first come, first served).

■ SOT/SPT (shortest operating/Processing time)

■ Due date –Earliest due date first

■ Start date – Due date minus normal lead time

■ STR (slack time remaining): time remaining before the due date – the processing time remaining. Orders with the shortest STR are run first.

■ STR /OP (Slack time remaining per operation), Orders with shortest STR/OP is calculated as follows:

$$\textbf{STR/OP} = \frac{\textbf{Time remaining before the due date – Remaining processing time}}{\textbf{Number of remaining operations}}$$

■ CR (Critical Ratio): This is calculated as the difference between the due date and the current date divided by the number of work days remaining. Orders with the smallest CR are run first.

CR= <u>due date – processing time</u>

Make span time

■ QR (Queue ratio): This is calculated the slack time remaining in the schedule divided by the planned remaining queue time. Orders with smallest QR are run first.

■ LCFS (Last come, First served). This rule occurs frequently by default. As orders arrive they are placed on the top of the slack; the operator usually picks up the order on top to run first.

■ Random order or whim: The supervisors or the operators usually select whichever job they feel like running.

- **Scheduling n Jobs on one Machine (n job one –machine problem: n/1)**

Consider the following example:

Five customers submitted their orders at the beginning of the week. Specific scheduling data are as follows:

Job (in order of arrival)	Processing Time days	Due Date (Days hence)
A	3	5
B	4	6
C	2	7
D	6	9
E	1	2

All orders require the use of only color copy machines available. The firm must determine the processing sequence for the five orders. The evaluation criterion is minimum flow time. Suppose that the firm decides to use the **FCFS** rule in an attempt to become fair to its customer

SOLUTION: USING FCFS RULE: the FCFS rule results in the following flow times:

FCFS SCHEDULE

Job sequence	Processing Time (days)	Due Date (Days hence)	Flow time (days)
A	3	5	0+3 = 3
B	4	6	3+ 4 = 7
C	2	7	7 + 2 = 9

D	6	9	9 + 6 = 15
E	1	2	15 + 1=16

Total Flow Time = 3+7+9+ 15+ 16 = 50 days

Mean flow time = 50 days = 10 days

5

Comparing the due date of each job with its flow time, we observe that only job A will be on time. Jobs B, C, D, and E will be late by 1, 2, 6, and 14 days respectively. On average, a job will be late by (0 + 1+ 2+ 6+ 14)/ 5 = 4.6 days.

SOLUTION: FIND THE SOLUTIONS USING RULES: SOT, Due DATE, LCFS, RANDOM, AND STR.

SOT SCHEDULE:

Job sequence	Processing Time (days)	Due Date (Days hence)	Flow time (days)
E	1	2	0+1 = 1
C	2	7	1+2 = 3
A	3	5	3+3 = 6
B	4	6	6+4 =10
D	6	9	10+6= 16

Total flow time = 1+3+6+10+16= 36 days

Mean flow time = 36 = 7.2 days. SOT results in a lower average flow time than the FCFS rule.

5

In addition jobs E and C will be ready before the due date; job A is late by only one day. On the average a job will be late by (0+ 0+ 1+4+7)/5 = 2.4 days.

DD DATE schedule:

Job sequence	Processing Time (days)	Due Date (Days hence)	Flow time (days)
E	1	2	0+1 = 1
A	3	5	1+3 = 4
B	4	6	4+4 = 8
C	2	7	8+2 =10
D	6	9	10+6=16

Total completion time = 1+4+8+10+16= 39 days

Mean flow time = 7.8 days

In this case jobs B, C, and D will be late. On the average a job will be late by (0+ 0+2+3+7)/5= 2.4 days.

Solutions: LCFS, RANDOM, and STR RULES:

LCFS schedule

Job sequence	Processing Time (days)	Due Date (Days hence)	Flow time (days)
E	1	2	0+1 = 1
D	6	9	1+ 6 = 7
C	2	7	7+2 = 9
B	4	6	9+4 = 13
A	3	5	13+3=16

Total completion time = 1+7+9+13+16= 46 days

Mean flow time = 9.2 days

Average lateness = 4.0 days

RANDOM **schedule**

Job sequence	**Processing Time (days)**	**Due Date (Days hence)**	**Flow time (days)**
D	6	9	0+6 = 6
C	2	7	6+ 2 = 8
A	3	5	8+3 = 11
E	1	2	11+1 =12
B	4	6	12+4=16

Total completion time = 6+8+11+12+16= 53 days

Mean flow time = 10.6 days

Average lateness = 5.4 days

STR. Schedule

Job sequence	**Processing Time (days)**	**Due Date (Days hence)**	**Flow time (days)**
E	1	2	0+1 = 1
A	3	5	1+ 3 = 4
B	4	6	4+4 = 8
D	6	9	8+6 =14
C	2	7	14+2=16

Total completion time = 1+4+8+14+16= 43 days

Mean flow time = 8.6 days

Average lateness = 3.2 days

COMPARISON OF PRIORITY RULES:

RULE	TOTAL COMPLETION TIME (DAYS)	AVERAGE COMPLETION TIME (DAYS)	AVERAGE LATENESS (DAYS)
FCFS	**50**	**10**	**4.6**
SOT	**36**	**7.2**	**2.4**
DDATE	**39**	**7.8**	**2.4**
LCFS	**46**	**9.2**	**4.0**
RANDOM	**53**	**10.6**	**5.4**
STR	**43**	**8.6**	**3.2**

Obviously, here SOT is better than the rest of the rules.

Exercise 1

Mesfin industrial engineering has engaged in assembling different model cars. Assume five customers submitted their orders for different model of cars: the first customer order model type A, the seconded model type B, the third model type C, the fourth for model type D and the fifth order model type E. Further assume that all order requires the use of only one machine which forces the company to decide on the processing sequence for the five orders.

Job (in order of arrival)	processing time (in weeks	due date
Model A	3	5
Model B	4	6
Model C	2	7
Model D	6	9
Model E	1	2

Required

A. Determine schedule for MIE using FCFS, SPT, EDD, CR and LCFS
B. Select the best scheduling technique and make your recommendation

☑ **Scheduling n Jobs on Two Machines (n/2 Flow)**

Johnson's rule or method

The objective of this approach is to minimize the flow time from the beginning of the first job until the finish of the last. Johnson's rule consists of the following steps:

1. List the operation time for each job on both machines.
2. Select the shortest operation time.
3. If the shortest time is for the first machine, do the job first; if it is for the second machine, do the job last.
4. Repeat steps 2 and 3 for each remaining until the job scheduling is complete.

NB: If a job has the same processing time at each work center, it makes no differences whether we place it forward the beginning or the end of the sequence so we can assign arbitrarily.

EXAMPLE 2. n jobs on two machines. Scheduling four jobs through two machines

Solution. step 1: list operation times.

Job	**operation time on machine 1**	**operation time on machine 2**
A	3	2
B	6	8
C	5	6
D	7	4

Step 2 and 3: select the shortest operation time and assign. Job A is shortest on machine 2 and is assigned first and performed last. (Once assigned job A is no longer available to be scheduled)

Step 4. Repeat steps 2 and 3 until completion of schedule. Select the shortest operation time among the remaining jobs. Job D is second shortest on machine 2, so it is performed second to last. (Remember Job A is last). Now jobs A and D are not available any more for scheduling. Job C is the shortest on machine one among the remaining jobs. Job C is performed first. Now job B is left with the shortest operation time on machine 1. Thus according to step 3 it is performed first among the remaining, or second overall. (Job C was already scheduled first).

In summary, the solution sequence is: C –B- D - A and the flow time is 25 days, which is a minimum. Total idle time and mean idle time is also minimized.

Optimal scheduling of jobs using Johnson's rule

MACHINE 1	**Job C**	**Job B**	**Job D**	**Job A**	**Idle but available for other work**
MACHINE 2	**Idle**	**Job C**	**Job B**	**Job D**	**Job A**

0 5 11 19 23 25

Cumulative time in days

Scheduling a set number of Jobs on the same number of machines

Some job shops have enough of the right kinds of machines to start all jobs at the same time. Here the problem is not which job to do first, but rather which particular assignment of individual jobs to individual machines will result in the best overall schedule. In such cases, we can use the assignment method.

The a**ssignment method:** is a special case of the transportation method of linear programming. It can be applied to situations where there are **n supply sources** and **n demand uses** (e.g., five jobs on five machines) and the objective is to minimize or maximize some measures of effectiveness. This technique is convenient in applications involving allocation of jobs to work centers, people to jobs, and so on. The assignment method is appropriate in solving problems that have the following characteristics:

1. There are n **things** to be distributed to **n destinations**
2. Each thing must be assigned to and only one destination.
3. Only one criterion can be used (minimum cost, maximum profit, or minimum completion time, for example).

Example .3: assignment method. Suppose that a scheduler has five jobs that can be performed on any of five machines (n=5). The cost of completing each job –machine combination is shown below. The scheduler wants to devise a minimum- cost assignment.(there are 5!, or 120 possible assignments).

Machine

	A	B	C	D	E
Job					
I	$5	$6	$4	$8	$3
II	6	4	9	8	5
III	4	3	2	5	4
IV	7	2	4	5	3
V	3	6	4	5	5

Solution: this problem may be solved by assignment method, which consists of **four steps**:

1. Subtract the smallest number in each row from it self and all other numbers in that row. (There will then be at least one zero in each row).
2. Subtract the smallest number in each column from all other numbers in that column. (There will then be at least one zero in each column).
3. Determine if the minimum number of lines required to cover each zero is equal to n. If so, an optimal solution has been found, because job machines assignments must be made at the zero entries. And this test proves that this is possible. If the minimum number of lines required to cover each zero is less than n, then go to step 4.
4. Draw the least possible number of lines through all zeros. Subtract the smallest number not covered by the lines from itself and all other uncovered numbers, and add it to the number at each intersection of lines. Repeat step 3.

Step 1: Row Reduction –the smallest number is deducted from each row.

Machine

Job	A	B	C	D	E
I	2	3	1	5	0
II	2	0	5	4	1
III	2	1	0	3	2
IV	5	0	2	3	1
V	0	3	1	2	2

Step 2: column Reduction –the smallest number is deducted from each column.

Machine

Job	A	B	C	D	E
I	2	3	1	3	0
II	2	0	5	2	1
III	2	1	0	1	2
IV	5	0	2	1	1
V	0	3	1	0	2

Step 3: apply line test- the number to lines to cover all zeros is 4; because 5 is required, go to step 4.

Machine

Job	A	B	C	D	E
I	2	3	1	3	0
II	2	0	5	2	1
III	2	1	0	1	2
IV	5	0	2	1	1
V	0	3	1	0	2

Step 4: subtract smallest uncovered number and add to intersection of lines – using lines drawn in step 3, smallest uncovered number is 1.

Machine

Job	A	B	C	D	E
I	1	3	0	2	0
II	1	0	4	1	1
III	2	2	0	1	3
IV	4	0	1	0	1
V	0	4	1	0	3

Optimum solution _by line test:

Machine

Job	A	B	C	D	E
I	1	3	0	2	0
II	1	0	4	1	1
III	2	2	0	1	3
IV	4	0	1	0	1
V	0	4	1	0	3

Optimum assignments and their costs:

Job I	to Machine E	$3
Job II	to Machine B	4
Job III	to Machine C	2
Job IV	to Machine D	5
Job V	to Machine A	3
	Total cost	$17

Exercise 2

A wood carpentry has received orders from its customers for chair, table, shelf, door, and board. The owner has organized two job centers one for assembly and one for finishing. Every product has to pass through the two work centers in the sequence. The following is the time (per hour) required to complete the jobs in each work center

Job order	assembly (in hours)	finishing (in hours)
Chair(C)	4	2
Table(T)	3	8
Shelf(S)	4	1
Door(D)	6	3
Board(B)	5	9

Required

A. Determine and optimal schedule using Johnson rule

Self-check exercise 4

Part I. Write “true” if the statement is correct and “false” if the statement is incorrect

1. The only objective of aggregate planning is to minimize the cost of matching capacity to demand over the planning period.
2. The strategies of aggregate planning are broadly divided into demand options and capacity options
3. In aggregate planning, the amount of overtime and the size of the work force are both adjustable elements of capacity.
4. Mixed strategies in aggregate planning utilize inventory, work force, and production rate changes over the planning horizon.
5. Earliest due date is a shop floor dispatching (sequencing) rule that relates the time available to complete a job to the amount of work left to be completed.
6. In forward scheduling, jobs are scheduled as late as possible within the time allowed by the customer due dates.
7. The benefits of effective scheduling include lower cost, faster delivery, and dependable delivery.

Part II; Choose the best answer from the listed alternatives

1. Aggregate planning is capacity planning for
   A. the long range
   B. the intermediate range
   C. the short range
   D. typically one to three months

2. Planning tasks associated with loading, sequencing, expediting, and dispatching typically fall under
   A. short-range plans
   B. intermediate-range plans
   C. long-range plans
   D. mission-related planning
   E. strategic planning

3. Which of the following statements about aggregate planning is **true**?

A. Advertising/promotion is a way of manipulating product or service supply.
B. Work station loading and job assignments are examples of aggregate planning.
C. Overtime/idle time is a way of manipulating product or service demand.
D. Aggregate planning uses the adjustable part of capacity to meet production requirements.
E. All of the above are true.

4. Dependence on an external source of supply is found in which of the following aggregate planning strategies?
   A. varying production rates through overtime or idle time
   B. subcontracting
   C. using part-time workers
   D. back ordering during high demand periods
   E. hiring and laying off

5. Which choice best describes **level aggregate planning**?
   A. Daily production is variable from period to period.
   B. Subcontracting, hiring, and firing manipulate supply.
   C. Price points are calculated to match demand to capacity.
   D. Inventory goes up or down to buffer the difference between demand and production.
   E. Seasonal demand fluctuations are matched without hirings or layoffs.

6. In level scheduling, what is kept uniform from month to month?
   A. product mix
   B. inventory levels
   C. production/workforce levels
   D. demand levels
   E. sub-contracting levels

7. Which of the following is **not** an effectiveness criterion for scheduling?
   1. minimizing customer waiting time
   2. minimizing completion time
   3. minimizing WIP inventory
   4. maximizing utilization

5. maximizing flow time

8. The short-term scheduling activity called **loading**
   A. assigns dates to specific jobs or operations steps
   B. specifies the order in which jobs should be done at each center
   C. assigns jobs to work centers
   D. assigns workers to jobs
   E. assigns workers to machines
9. A scheduling technique used to achieve optimum, one-to-one matching of tasks and resources is
   A. the assignment method
   B. Johnson's rule
   C. the CDS algorithm
   D. the appointment method
   E. the reservation method
10. The production database containing information about each of the components that a firm produces or purchases is the
   A. routing file
   B. work center master file
   C. control file
   D. item master file
   E. none of the above

Part three: Write a short answer

1. What are the major Objectives of scheduling?
2. What is the major difference between operations scheduling and aggregate production plan?
3. Compare and contrast the chase versus level strategy options.
4. What makes short-term scheduling of strategic importance?

Part four: work out question

1. Kombolcha textile industry is preparing its aggregate plan for the second half of the year. The table below contains monthly demand estimates and working days per month.

Month	Expected Demand	Production Days
July	1800	20
August	2100	23
September	1750	21
October	1250	21
November	1200	20
December	1350	21

Costs

Materials	$150.00/unit
Inventory holding cost	$5/unit/month
Marginal cost of stock out	$20/unit/month
Marginal cost of subcontracting	$15.00/unit ($165 subcontracting cost Less $150 material savings)
Hiring and training cost	$250.00/worker
Layoff cost	$450.00/worker
Labour hrs required	$6hrs/unit
Straight line cost (first eight hrs each day)	$12.00 birr/hour
Overtime cost (time and half)	$8.00 birr/hour

Inventory

Beginning inventory	1200 units
Safety stock	30% of monthly demand

Required: Which of the following production plans is better?

A. Plan A: Produce to exact monthly production requirements using a regular eight hour day by varying the workforce size

B. Plan B: Produce to meet expected average demand over the next six months by maintaining a constant workforce

C. Plan C: Produce to meet the minimum expected demand (quarter 2) using a constant workforce on regular time. Subcontract to meet additional requirements

2. Five jobs are waiting for processing through two work centers. Their processing time (in minutes) at each work center is contained in the table below. Each job requires work center Alpha before work center Beta. According to Johnson's rule, which job should be scheduled first?

Job	Alpha	Beta
R	20	10
S	25	35
T	50	20
U	15	35
V	55	75

3. A practitioner of family medicine begins her day with five patients needing urgent care. She does a very brief assessment of what each patient appears to need and estimates the time required of each. None of the cases is life-threatening, and so she determines to take the five in the order that they arrived at the clinic. The data for these patients, in the order they arrived, is Patient A, 30 minutes; Patient B, 40 minutes; Patient C; 10 minutes; Patient D, 50 minutes; and Patient E, 15 minutes.

Required

- If it is now 8:00 a.m., at what time will the doctor be finished with all five of these emergencies? Using FCFS, SPT, LPT, CR, AND LCFS
- How much time will the five patients have collectively spent waiting? FCFS, SPT, LPT, CR, AND LCFS
- Which one is the best scheduling technique for the doctor?

4. Jack's Refrigeration Repair is under contract to repair, recondition, and/or refurbish commercial and industrial icemakers from restaurants, seafood processors, and similar organizations. Jack currently has five jobs to be scheduled, shown in the order in which they arrived.

Job	Processing Time (hours)	Due (hours)
V	20	50
W	10	35
X	50	90

Y	15	35
Z	55	75

A. Complete the following table. (Show your supporting calculations below).

B. Which dispatching rule has the best score for flow time?

C. Which dispatching rule has the best score for work-in-process (jobs in the system)?

D. Which dispatching rule has the best score for lateness?

Dispatching Rule	Job Sequence	Average Flow Time	Average Number of Jobs	Average Lateness
FCFS				
SPT				
EDD				
CR				

5. The president of a consulting firm wants to minimize the total number of hours it will take to complete four projects for a new client. Accordingly, she has estimated the time it should take for each of her top consultants Abdi, Zekariyas, Fasika, and Habte to complete any of the four projects, as follows:

Project (hours) Consultant	A	B	C	D
Abdi	13	16	11	18
Zekariyas	13	15	10	12
Fasika	15	11	20	15
Habte	17	17	12	22

A. What is the optimal assignment of consultants to projects? (Use the assignment method; **SHOW YOUR WORK!**)

B. For the optimal schedule, what is the total number of hours it will take these consultants to complete these projects?

CHAPTER FIVE

QUALITY MANAGEMENT AND CONTROL

Introduction

Dear students in discussing the performance objectives and competitive priorities of operations (mentioned in Chapter 2), quality is often described as getting things done 'right first time, every time'. In past chapters we have discussed the physical aspects of the transformation process by which goods and services are created and delivered. In this chapter we take a closer look at why quality is important, and how 'right first time' can be achieved.

In any business organization, profit is the ultimate goal. To achieve this, there are several approaches. Profit may be maximized by cutting costs for the same selling price per unit. If it is a monopolistic business, without giving much of importance to the cost reduction programs, the price may be fixed suitably to earn sufficient profit. But, to survive in a competitive business environment, goods and services produced by a firm should have the minimum required quality.

Extra quality means extra cost. So, the level of quality should be decided in relation to other factors such that the product is well absorbed in the market. In all these cases, to have repeated sales and thereby increased sales revenue, basic quality is considered to be one of the supportive factors. Quality has proved more difficult to define than other operations concepts. Quality is a measure of how closely a good or service conforms to specified standard.

Quality is a key competitive battleground for all organizations that provide a product or service to customers or clients. Managing quality is one of operations management's most important responsibilities.

Chapter Objective

At the end of this unit students will be able to:

- Explain quality management and control
- Describe the role of quality management in any organization
- Compare Meaning and nature of quality, Overview of TQM
- Discuss Quality Specification, Continuous Improvement, Statistical Quality Control, Process Control Charts

5.1 Meaning and nature of quality

Once the facilities, machines, energy, money, materials, and manpower have been combined in the transformation process, the output becomes products and services. Since the quality of the product and services is of vital importance to the firm's service to customers, careful attention must be given to inspection and quality control. Quality is an important dimension of operations management. It is not enough to produce goods and services in the right quantity and at the right time; it is important to ensure that goods services produced are of the right quality.

Quality is one of the four key objectives of operations, along with **cost, flexibility, and delivery.** While quality management is cross functional in nature and involves the entire organization, an operation has special responsibility to produce a quality product for the customer. This requires the cooperation of the entire organization and careful attention to management and control of quality.

Quality definitions

Quality can be defined as the ability of a product or service to meet or exceed customers' expectation.

Quality can be defined in a number of different ways according to transcendent, product based, user based, manufacturing based or value based approaches.

Transcendent view: according to this view quality is synonymous with" innate excellence"

This approach claims that quality cannot be defined precisely. It is a simple unanalyzable property we learn to recognize only through experience.

Product based view: views quality as a precise and measurable variable. Differences in quality reflect differences in the quantity of some ingredient or attributes possessed by a product. High quality ice cream has high butterfat content, for instance. This approach lends a vertical and horizontal dimension to quality because goods can be ranked according to the amount of the desired attribute they possess. This approach, however, has limitations as well. A one-to –one correspondence between product attribute and quality does not always exist.

User based approach: In this approach, the goods and services that best satisfy individual consumer's different wants or needs are regarded as having the highest quality. This view of quality has is idiosyncratic and persona. It is highly subjective and focuses on issues of "fitness for use" by the individual consumer. For example, a student using a microcomputer for the first time might evaluate the quality of the computer substantially differently than would an experienced user who better understands user friendliness.

Manufacturing based: manufacturing definitions of quality focus on producers of goods and services and are primarily concerned with engineering and manufacturing practices. Virtually all manufacturing –based definitions identify quality as conformance to requirements. Once design or specifications have been established, any deviation implies a reduction in quality.

Value based approach: defines quality in terms of cots and prices. Any quality product is therefore one that provides performance or conformance at an acceptable price or cost. An inexpensive product is expected to be of lower quality than similar, more expensive product.

But many scholars further define quality as follows:

Juran (1986) defined quality as fitness for use. He stated that only customers can determine the quality of a product or service and therefore fitness for use is a utility value concept which varies from one customer to another. Example micro computers may satisfy the primary school students' use but not higher education PHD students. Deming has also supported the definition of Juran by stating quality as a fitness for purpose.

Garvin (1988) suggested that multi dimensions are required to elicit the most fundamental meaning of quality like performance, Aesthetics, conformance, safety, reliability, Durability, perceived quality and service after sale. Garvin has also defined quality from the flowing five perspectives;

- Transcendent definition: excellence
- Product-based definition: quantities of product attributes
- User-based definition: fitness for intended use
- Value-based definition: quality vs. price
- Manufacturing-based definition: conformance to specifications

Crosby (1979) described the meaning of quality in a way he called it the five absolutes of quality i.e.

- Quality is a conformance to requirements
- There is no such thing as a quality problem.
- There is no such thing as the economies of quality; it is always cheaper to do the job right the first time.
- The only performance standard is zero defects.
- The only performance measurements are the cost of quality.

Check point

Dear students do you know what will happen if a company failed to produce a quality product or service? If so please try to mention some of them

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5.2 Cost of Quality

Failure to produce quality product may result in one of the following four costs incurred;

Internal failure costs; discovered during the production process due to: defective materials used, incorrect machine setting, carelessness, improper or faulty handling etc. with in the manufacturing site. And this may result in consequences like →production time loss, scrap, rework, employee injury, schedule disruption and etc.

External failure costs; discovered or recognized after the products are delivered to the customers. And this will incur costs like

- Warranty work
- Handling of complaints
- Liability /litigation
- Loss of customer good will

Appraisal costs; costs incurred to uncover defective products or to assure that products are defective free. Some examples include inspectors' payment (fee), test equipment, field testing cost etc.

Prevention costs; these are related to the attempts to prevent the occurrence of defects. These include:- planning, Administration, working with vendors training on quality and the like costs.

How much important quality is?

- Medical defects or errors kill 142000 persons every year according to NATIONAL ACADEMY OF SCIENCES report on 2019 GC. Even greater than
- Approximately 1.35 million people die each year as a result of road traffic crashes.
- Road traffic crashes cost most countries 3% of their gross domestic product.

- 93% of the world's fatalities on the roads occur in low- and middle-income countries, even though these countries have approximately 60% of the world's vehicles.
- Road traffic injuries are the leading cause of death for children and young adults aged 5-29 years.

5.3 Fundamental Factors Affecting Quality

The nine fundamental factors **(9 M's)**, which are affecting the quality of products and services, are: markets, money, management, men, motivation, materials, machines and mechanization. Modern information methods and mounting product requirements.

- **Market:** Because of technology advancement, we could see many new products to satisfy customer wants. At the same time, the customer wants are also changing dynamically. So, it is the role of companies to identify needs and then meet it with existing technologies or by developing new technologies.
- **Money:** The increased global competition necessitates huge outlays for new equipment and process. This should be rewarded by improved productivity. This is possible by minimizing quality costs associated with the maintenance and improvements of quality level.
- **Management:** Because of the increased complex structure of business organization, the quality related responsibilities lie with persons at different levels in the organization.
- **Men:** The rapid growth in technical knowledge leads to development of human resource with different specialization. This necessitates some groups like, system engineering group to integrate the idea of full specialization.
- **Motivation:** If we fix the responsibility of achieving quality with each individual in the organization with proper motivation techniques, there will not be any problem in producing the designed quality products.
- **Materials:** Selection of proper materials to meet the desired tolerance limit is also an important consideration. Quality attributes like, surface finish, strength, diameter etc., can be obtained by proper selection of material.
- **Machines and mechanization:** In order to have quality products which will lead to higher productivity of any organization, we need to use advanced machines and mechanize various operations.

- **Modern information methods:** The modern information methods help in storing and retrieving needed data for manufacturing, marketing and servicing.
- **Mounting product requirements:** Product diversification to meet customers taste leads to intricacy in design, manufacturing and quality standards. Hence, companies should plan adequate system to tackle all these requirements

5.4 Dimensions of Quality

It may be obvious that from a customer perspective, quality does not pertain to a single aspect of a product or service but to a number of different dimensions among which the primary ones are:
Producers should continuously strive to improve quality, i.e., doing a better job of meeting customer needs by reducing variability in all processes and by introducing new products when needed.
Continuous improvement is a never ending process and is driven by knowledge and problem solving.
Producers should continuously strive to improve quality, i.e., doing a better job of meeting customer needs by reducing variability in all processes and by introducing new products when needed. Continuous improvement is a never ending process and is driven by knowledge and problem solving.
Whether the product is a good or service, the following dimensions of quality may be defined:

- Quality of design
- Quality of conformance
- The" abilities"- reliability and maintainability.
- Field service

☑ **Quality of design**

Quality of design is determined before the product is produced. This determination is usually the primary responsibility of cross –functional product design team, including members from marketing, engineering operations, and other functions.
Quality design is determined by market research, design concept, and specifications.

☑ **Quality of conformance**

Quality of conformance means producing a product to meet the specifications. when the product conforms to specifications, it is considered by operations as a quality product regardless of the quality of the design specifications. For example, an inexpensive pair of shoes will have a high quality if they are made according to specifications, and they will have low quality if they do not meet specifications. Quality of design and quality of conformance thus represent two different uses of the term "quality".

- ☑ **The" abilities"- availability, reliability and maintainability:** another aspect of quality involves the so called abilities: availability, reliability and maintainability. Each of these terms has a time dimension and thus extends the meaning of quality beyond the beginning or starting quality level. The addition of time to the definition of quality is, of course, necessary to reflect continued satisfaction by the customer.
- ☑ **Availability** defines the continuity of service to the customer. A product is available if it is in an operational state and not down for repairs or maintenance. Availability can be measured quantitatively as follows:

$$\text{Availability} = \frac{\text{Uptime}}{\text{Uptime} + \text{Down time}}$$

- ☑ **Reliability** refers to the length of time that a product can be used before it fails. Formally speaking, reliability is the probability that a product will function for a specified period of time without failure. The reliability of a light bulb for 1000 hours might, for example, be 80%. In this case if many light bulbs are tested for 1000 hours, 80 percent of them will remain lighted the entire lime and 20% will fail within the 1000 hrs. The reliability of a product is also related mean time between failure (MTBF), which is just the average time the product functions from one failure to the next. The longer the MTBF, the more reliable the product is.
- ☑ **Maintainability:** refers to the restoration of a product or service once it has failed. All customers consider maintenance or repairs as a nuisance. Thus, a high degree of maintainability is desired so that a product can be restored to use quickly. For example, Caterpillar Company supports excellent maintainability by supplying spare parts anywhere in the world within 48 hours. Maintainability can be measured by the mean time to repair (MTTR) the product. Availability, then, is a combination of reliability and maintainability. If a product is high in both reliability and maintainability, it will also be high in availability.

The above relationship can be restated in terms of MTBF and MTTR:

$$\text{Availability} = \frac{\text{MTBF}}{\text{MTBF} + \text{MTTR}}$$

For example, if a product has an MTBF of 8 hrs and MTTR of 2 hrs each time it fails, then its availability will be 80%.

- ☑ **Performance:** Main characteristics of a product as service. Here the product is expected to perform all the expected functions from it.
- ☑ **Aesthetics;** (artistic nature of the product) Appearance, feel, test, smell etc of a product A hard ware of a computer being attractive, small space occupation, color etc.
- ☑ **Special features;** what special extra character a product owes. Example modern and up dated soft wares included in a computer that are extra to the originally required functions
- ☑ **Safety;** free from risk of injury or harm. The computers above need not be releasing harmful lights to the customer eye.
- ☑ Eg. Gion Gas in its introduction phase.
- ☑ **Perceived quality;** indirect evaluation of quality. A computer awarded for its processing speed.
- ☑ **Field Service:** the last dimension of quality represents warranty and repair or replacement of the product after it has been sold. Field service is also called customer service, sales service, or just service. Field service is intangible, since it related to such variables as promptness, competence, and integrity. The customer expects that any problem will be corrected quickly, in satisfactory manner, and with a high degree of honesty and courtesy.

Activity 5.1

Answer the following questions before continuing to the next section.

1. Name the four costs of quality. Which one is hardest to evaluate? Explain.

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2. Write down the Key dimensions of Quality?

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3. Compare and contrast the definition given by **Juran (1986) and Garvin (1988) and write down their major difference**.

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Checklist

If you understand the following words or phrases put a tick (✓) mark in the box, otherwise read the section again.

- **User based approach** -- ☐
- **Manufacturing based** approach -- ☐
- **A value based** approach -- ☐
- **Transcendent view** --- ☐

5.5 Total Quality Management (TQM)

Quality management is a primary factor in the survival and success of all organizations.

Quality management, which includes ensuring proper quality for a company's output, is important not only for its survival in the market, but also to expand its market or when it wants to ensure into new product line and various other marketing ventures.

Total Quality Management (TQM) is a management concept that focuses the collective efforts of all managers and employees on satisfying customer expectations by continually improving operations management processes and products. TQM is a philosophical strategy for manufacturing and service excellence that includes, but goes beyond, the concepts and methods of total quality control. Focuses on a commitment by management to have a continuous, company-wide, excellence in all aspects of products and services that are important to the customer, it encompasses entire organization, from supplier to customer.

Management commitment to TQM principles and methods & long term Quality plans for the Organization

- Focus on customers
- Quality at all levels of the work force.
- Continuous improvement of the production or business process.
- Treating suppliers as partners
- Establish performance measures for the processes.

Why Total Quality Management is necessary?

- Improved flexibility and/ or improved productivity
- Reduce operating costs
- Reduce product/service price and or/ improved product service quality

- Competitive advantage
- Increased product or service sales
- Increase sales

5.6 Quality planning, control and improvement

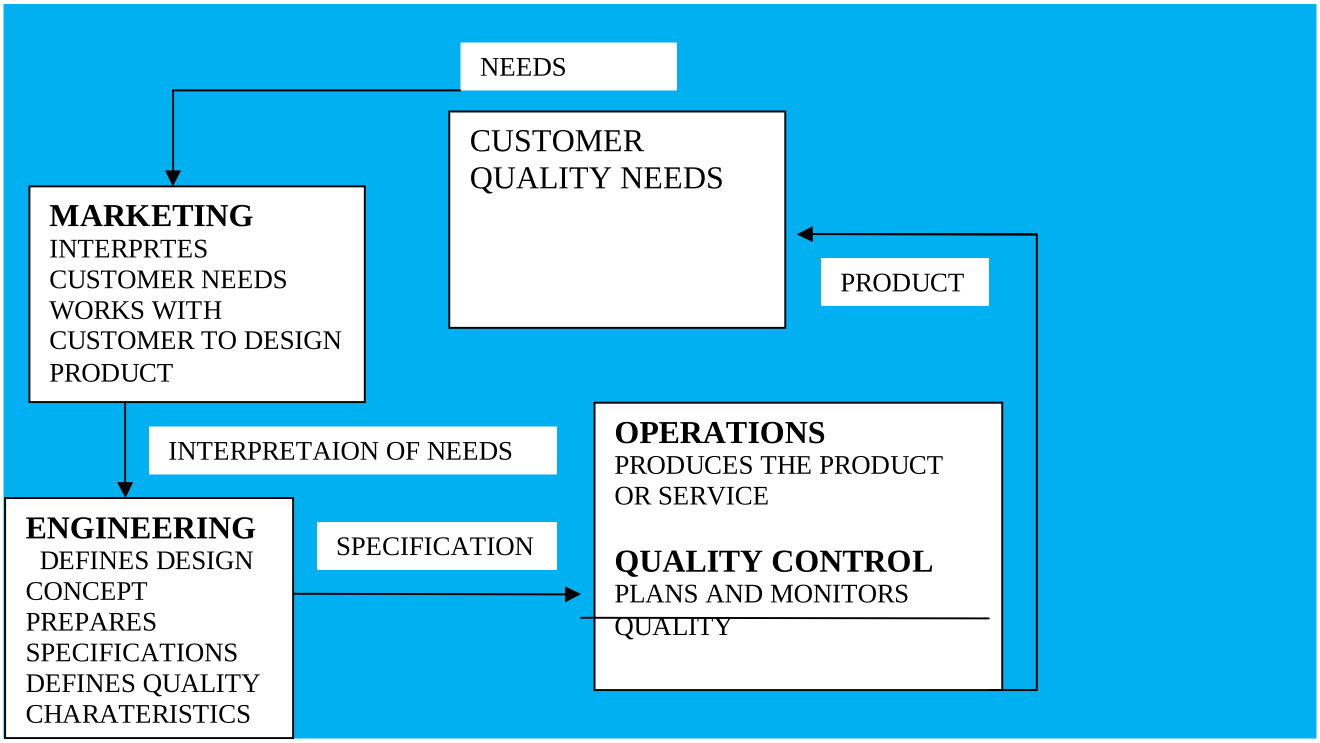
The process of quality planning, control, and improvement requires a continuous interaction between the customers, operations, and other parts of the organization.

The exhibit below how these interactions occur through a quality circle. The customer needs are determined, usually through the marketing function. These needs are either expressed directly by the customer or discovered through a process of market research. Engineering, in conjunction with other departments, designs a product to meet those needs or works with the customer on design specifications that fit within production capabilities.

Once the design concept and specifications have been completed, the quality of design has been established. Operations, as part of the quality team, then produce the product as specified. Operations must continually ensure that the product is produced as specified by insisting on quality of conformance this ordinarily done through properly training, supervision, machine maintenance and operator inspections. In addition to meeting specifications, operations should strive to reduce the variance of its processes and products over time. In this way continuous improvement occurs.

The quality cycle the implementation of planning, control, and improvement of quality through the quality cycle requires this sequence of steps:

- Define quality attributes on the basis of customer needs.
- Decide how to measure each attribute.
- Set quality standards
- Establish appropriate tests for each standard.
- Find and correct causes of poor quality
- Continue to make improvements.



5.7 The Elements of Total Quality Management

TQM is can be defined broadly as managing the entire organization so that it excels on all dimensions of products and services that are important to the customer. This definition is more applicable than another commonly used one – "conformance to specifications". Though valid for goods production, the second definition is problematic for many services. Precise specifications for service quality are hard to define and measure. It is possible, however, to find out what is important to the customer, and then create the kind of organizational culture that motivates and enables the worker to do what is necessary to deliver a quality service.

The philosophical elements of TQM stress the operation of the firm using quality as the integrating element. The generic tools consist of various **statistical process control (SPC**) methods that are used for problem solving and continuous improvement by quality teams; and **quality function deployment** that is typically used by managers to derive the voice of the customer into the organization.

TQM: MANAGING THE ENTIRE ORGANIZATION SO THAT IT EXCELS IN ALL DIMENSIONS OF PRODUCTS AND SERVICES THAT ARE IMPORTANT TO THE CUSTOMER.

PHILOSOPHICAL ELEMENTS

- Customer- driven quality
- Leadership
- Continuous improvement
- Employee participation and development
- Quick response
- Design quality and prevention
- Management by fact
- Partnership development
- Corporate responsibility and citizenship

GENERIC TOOLS

- **SPC TOOLS**

1. PROCESS FLOW CHARTS
2. CHECK SHEETS
3. PARETO ANAYSIS AND HISTOGRAM
4. CAUSE AND EFFECT DIAGRAMS
5. RUN CHARTS
6. SCATTER DIAGRAMS
7. CONTROL CHARTS
8. QUALITY FUNCTION DEPLOYMENT

TOOLS OF THE QC DEPARTMENT

■ SQC METHODS

1. SAMPLING PLANS
2. PROCESS

Continuous Improvement (CI): Continuous improvement is an integral part of total quality management system. Specifically continuous improvement seeks continual improvement of machinery, materials, labor utilization, and production methods through application of suggestions and ideas of team members.

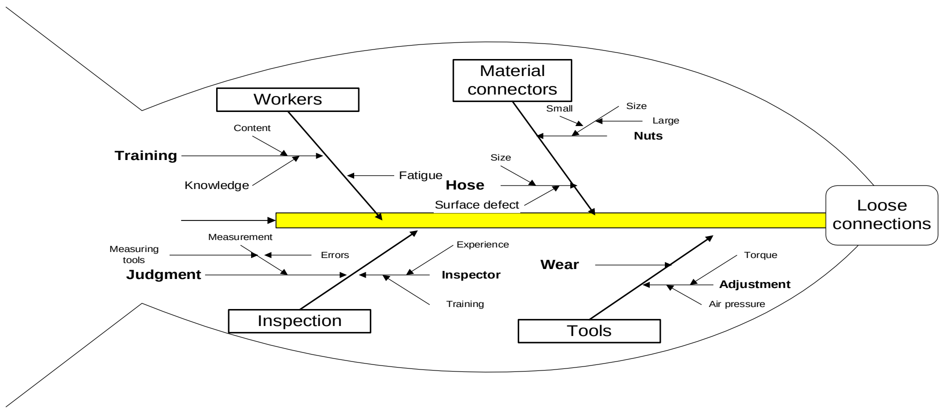
Tools and Procedures of CI

The approaches companies take to CI as a process range from very structure programs utilizing Statistical Process Control (**SPC**) tools to simple suggestion systems relying on brain storming.

Some common SPC tools used for problem solving and continuous improvement:

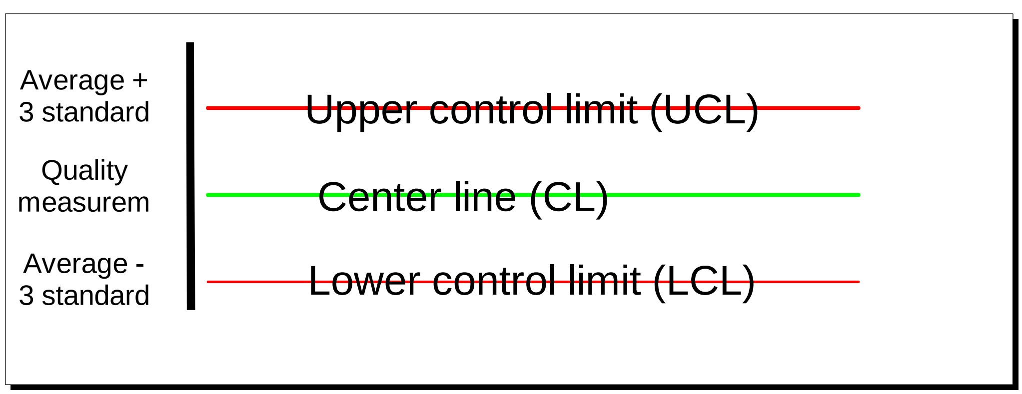
- **Cause and effect diagram**: a tool that uses a graphical description of the process elements to analyze sources of process variation.

Cause and effect diagram (fig.1)



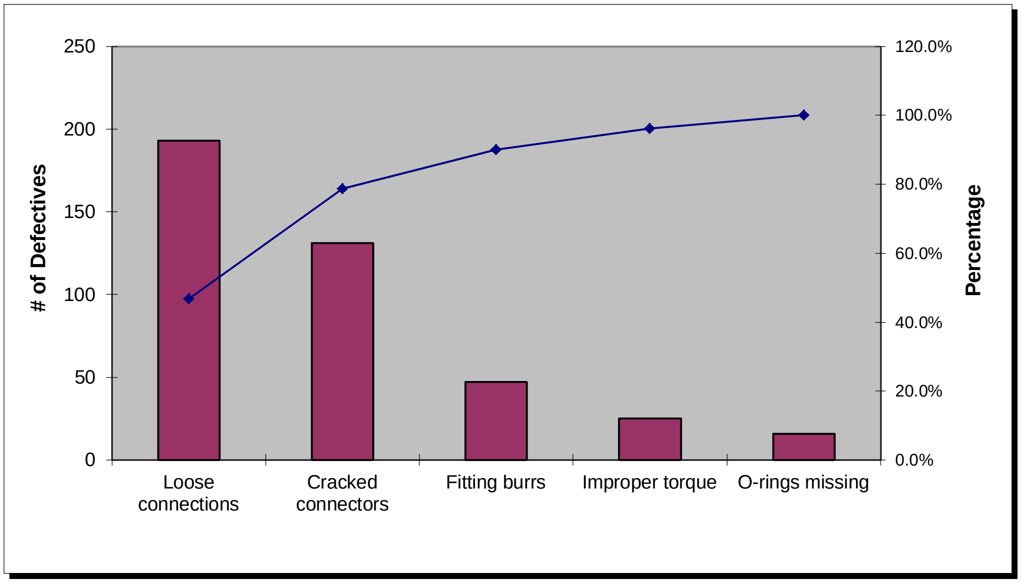
- **Run chart:** a time sequence chart showing plotted values of a characteristic.
- **Scatter Diagram:** also known as a correlation chart. A graph of the values of one characteristic versus another characteristic.
- **Control charts:** A time sequence chart showing plotted values of statistic, including central line and one or more statistically derived control limits.

Process Control Chart (fig.2)



- **Histogram:** a distribution showing the frequency of occurrences between the high and low range of data.
- **Pareto analysis:** a coordinated approach for identifying, ranking, and working to Permanently eliminate defects**.** Focuses on important error sources

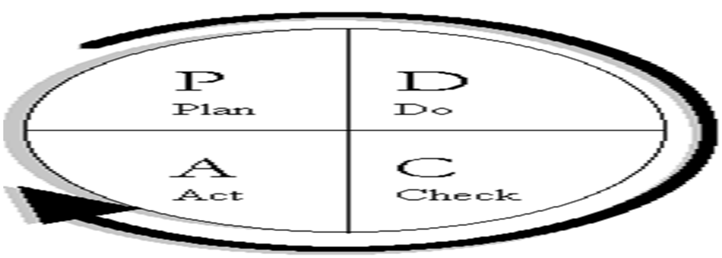
Pareto Diagram (Figure 3)



- **Check sheet:** an organized method for recording data.
- **PDCA**: another tool is the PDCA (plan – Do- Check-Act) cycle or often called the Deming Wheel, which conveys the sequential and continual nature of the CI process.

The plan phase of the cycle is where an improvement area and specific problem with it is identified. It is also where the analysis is done. The do phase of the PDCA cycle deals with implementing the change. The check phase deals with evaluating data collected during the implementation. The objective is to see if there is a good fit between the original goal and actual results. During the act phase, the improvement is codified as the new standard procedure and replicated in similar processes through out the organization.

PDCA/Deming Wheel,



■ ISO 9000

ISO 9000 is s series of standards agreed up on by the International Organization for Standardization (ISO) and adopted in 1987. More than 100 countries now recognize the 9000 series for quality standards and certification for international trade.

Employee Empowerment

Getting employees involved in product & process improvements

- Techniques
- Support workers
- Let workers make decisions
- Build teams & quality circles

Quality Circles

Group of employees from same work area meet regularly to solve quality-related problems. Facilitator trains & helps with meetings. The quality circles begun in Japan in 1960s, the concept of quality circles is based on the participating style of management. It assumes that productivity will improve through an uplift of morale and motivations which are in turn achieved through consultation and discussion in informal groups. One organizational mechanism for worker participation in quality is the quality circle. It is typically an informal group of people that consists of operators, supervisors, managers and so on who get together to improve ways to make the product or deliver the service. According to Juran, quality circle defined as “a group of work force level people, usually from within one department, who volunteer to meet weekly (on company time) to address quality problems that occur within their department.” Quality circle members select the problems and are given training is problem-solving techniques. A quality circle can be an effective productivity improvement tool because it generates new ideas and implements them. Where the introduction of quality circle is capably planned and where the company environment is supporting they are highly successful.

The benefits fall into two categories: those are measurable saving and improvement in the attitudes and behaviour of people. Quality circles pursue two types of problems, those concerned with the personal well-being of the worker and those concerned with the well-being of company.

- **Benchmarking**

Selecting best practices to use as a standard for performance

- ☐ Determine what to benchmark
- ☐ Form a benchmark team
- ☐ Identify benchmarking partners
- ☐ Collect and analyze benchmarking information
- ☐ Take action to match or exceed the benchmark

Just-in-Time (JIT)

Just-In-Time (JIT) Manufacturing is a philosophy rather than a technique. By eliminating all waste and seeking continuous improvement, it aims at creating manufacturing system that is response to the market needs.

The phase just in time is used to because this system operates with low WIP (Work-In- Process) inventory and often with very low finished goods inventory. Products are assembled just before they are sold, subassemblies are made just before they are assembled and components are made and fabricated just before subassemblies are made. This leads to lower WIP and reduced lead times. To achieve this organizations have to be excellent in other areas *e.g.* quality.

According to Voss, JIT is viewed as a "*Production methodology which aims to improve overall productivity through elimination of waste and which leads to improved quality*". JIT provides an efficient production in an organization and delivery of only the necessary parts in the right quantity, at the right time and place while using the minimum facilities".

Relationship to quality:

- JIT cuts cost of quality
- JIT improves quality
- Better quality means less inventory and better, easier-to-employ JIT system

Six sigma

Is a philosophy and methods companies use to eliminate defects in their products & services.

A measurement denoting near perfection, representing six standard Deviations or 3.4 defects per million operations; the ideal against which actual performance is measured. It seeks to reduce the variation in the processes that lead to defects

Six Sigma was born in Motorola and developed by Mikel J. Harry. Motorola won Malcolm Baldridge Quality Award in 1987.

Benefits of Six Sigma

- It allows managers:
- To readily describe the performance of a process in terms of its variability.
- To compare different processes using a common metric. This metric is defects per million opportunities- DPMO (defect per million opportunities).
    - This calculation requires three pieces of data:
    - Unit: the item produced/ being serviced.
    - Defect: Any item/event that does not meet the customer's requirements.

- Opportunity: a chance for defects.

Sigma	Defects per Million	Yield
6.0	3.4	99.9997%
5	233	99.977
4	6210	99.379
3	66807	93.32
2.5	158,655	84.1
2	308,538	69.1
1.5	500,000	50
1.4	539,828	46.0
1.3	579,260	42.1
1.2	617,911	38.2
1.1	655,422	34.5
1.0	691,462	30.9
0.5	841,345	15.9
0	933,193	6.7

- The higher the sigma level, the lower the defect rate.
- The lower the defect rate, the higher the quality.

Example: ‘Y’ department performed 535 specific operations last month. Of these, 43 were defective (they fell outside the acceptable range of outcomes). This means that 492 of the operations were successful. The yield was: 492 ÷ 535 = 91.9% Sigma somewhere between 2.5 and 3.

Six Sigma is carried out as projects and mostly uses a standard approach called DMAIC (define, measure, analyze, improve and control) cycle-developed by General Electric.

5.8 STATISTICAL QUALITY CONTROL

The subject of statistical quality control (**SQC**) can be divided into acceptance sampling and process control.

- **Acceptance sampling:** involves testing a random sample of existing goods and deciding whether to accept an entire lot based on the quality of the random sample.
- **Statistical process control (SPC):** involves testing a random sample of output from a process to determine whether the process is producing items within a pre-selected range. When the tested output exceeds that range, it a signal to adjust the production process to force the output back into the acceptable range.This is accomplished by adjusting the process itself. Acceptance sampling is frequently used in purchasing or receiving situations, while process control is in a production situation of any type.

Quality control for both acceptance sampling and process control measures either attributes or variables. Goods or services may be observed to be either good or bad, or functioning or malfunctioning.

The following sections describe some standard approaches to developing acceptance sampling plans and process control procedures.

■ **Acceptance sampling**

Design of a single sampling plan for attributes

Acceptance sampling is performed on goods that already exist to determine what percentages of products conform to specifications. These products may be items received from another company and evaluated by the receiving department or they may be components that have passed through a step and are evaluated by company personnel either in production or later in the warehousing function. Whether inspection should be done at all is addressed in the following example.

Acceptance sampling is executed through a sampling plan. In this section, the planning procedure for a single sampling plan is illustrated- i. e., a plan in which the quality is determined from the evaluation of one sample.

A single sampling plan is defined by **n** and **c,** where **n** is the number of unitsin the sample and **c** is the acceptance number. The size of **n** may vary from one up to all the items in the lot (usually denoted as N) from which it is drawn. The acceptance number **c** denotes the maximum number of defective items that can be found in the sample before the lot is rejected. Values for **c** and **n** are determined by the interaction of four factors (**AQL,** $\propto$

LTPD and β) that quantify the objectives of the products producer and its customers.

The objective of the producer is to ensure that the sampling plan ha a low probability of rejecting good lots. Lots are defined as high quality if they contain no more than a specified level of defectives, termed as **acceptance quality level** (AQL). The objective of the consumer is to ensure that the sampling plan has a low probability of accepting bad lots. Lots are defined as low quality if the percentage of defectives is greater than a specified amount, known as **Lot Tolerance percent Defective (LTPD)**. The probability associated with rejecting a high quality lot is denoted by the Greek letter alpha (α) and is termed the producer's risk. The probability associated with accepting a low quality lot is denoted by the letter beta (β) and is termed the consumer's risk. The selection of particular values for AQL, α LTPD, and β is an economic decision based on a cost trade-off or simply, more typically, on company policy or contractual requirements.

Example 1: Total (100%) inspection is justified when the cost of a loss incurred by not inspecting is greater than the cost of inspection. For example, suppose a faulty item results in a $10 loss. If the average percentage of defective items in a lot is 3%, the expected cost of faulty item is .003 x $10, or $.30 each. Therefore, if the cost of inspecting each item is less $.30, the economic decision is to perform 100% inspection.

The following example, using an excerpt from a standard acceptance sampling table, illustrates how the four parameters - AQL, α ,LTPD, and β -are used in developing a sampling plan.

Excerpt from a sampling plan. Table for $\propto$=0.05, β = 0.1

C	LTPD /AQL	n. AQL
0	44.890	0.052
1	10.946	0.355
2	6.509	0.818
3	4.890	1.366
4	4.057	1.970
5	3.549	2.613

Example 2: High-Tech industries manufacture Z-brand radar scanners used to detect speed traps. The printed circuit boards in the scanners are purchased from an outside vendor. The vendor produces the

boards to an AQL of 2 percent defectives and is willing to run a 5% risk (α) of having lots of this level or fewer defectives rejected. High-tech considers lots of 8% or more defectives (LTPD) unacceptable and wants to ensure that it will accept such poor quality lots no more than 10% of the time(β). A large shipment has just been delivered. What values of n and c should be selected to determine the quality of this lot?

SOLUTION: The parameters of the problem are AQL = 0.02, α =0, 05, LTPD = 0.08, and β =0.10. We can use the above table to find **c** and **n**.

First, divide LTPD by AQL (0.08 /.02 = 4). Then, find the ratio in column 2 of the table that is equal to or just greater than the amount (i.e, 4). This value is 4.057, which is associated with c =4.

Finally, find the value in column 3 that is in the same row as c=4, and divide that quantity by AQL to obtain n (1. 970 /.02) = 98.5).

The appropriate sampling plan is c = 4, n = 99.

■ PROCESS QUALITY CONTROL

Process quality control utilizes inspection (or testing) of the product or service while it is being produced. It is concerned with monitoring quality while the product or service is being produced.

Typical objective of process control plans are to provide timely information on whether currently produced items are meeting design specifications and to detect shifts in the process that signal that future products may not meet specifications. The actual control phase of process control occurs when corrective action is taken such as a worn part is replaced, a machine overhauled or a new supplier found. Process control concepts, especially statistically based control charts, are being used in service as well as in manufacturing.

Periodic samples of the output of a production process are taken. When, after inspection of the sample, there is a reason to believe that the process quality characteristics have been changed, the process is stopped and a search is made for **assignable cause.**

This cause could be a change in the operator, the machine, or the material. When the causes have been found and corrected, the process is started again.

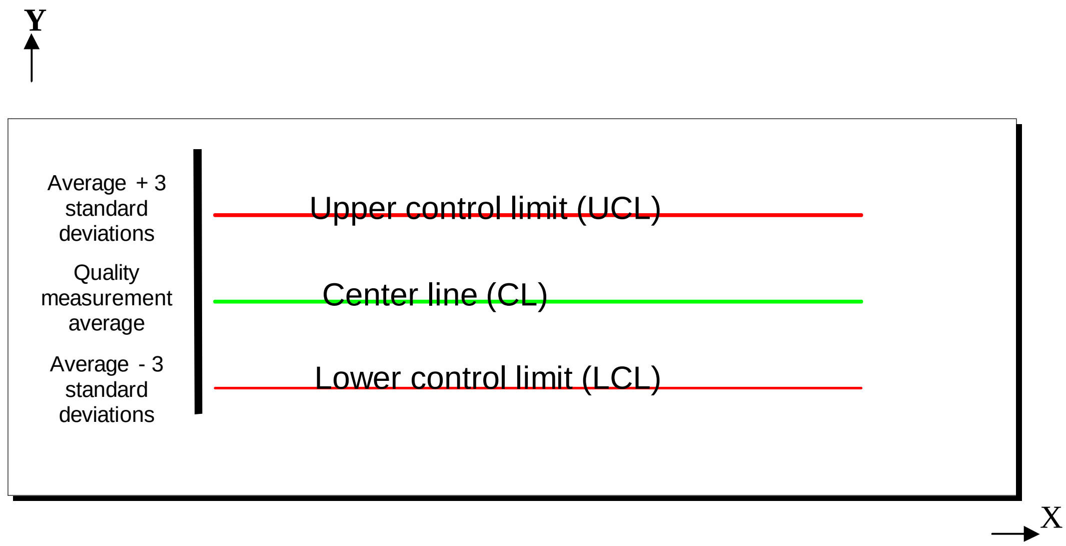
Process control is based on two key assumptions, one of which is that random variability is basic to any production process. No matter how perfectly a process is designed, there will be some random variability, also called common causes, in quality characteristics form one unit to the next. For example, a machine filling cereals boxes will not deposit exactly the same weight in each box; the amount filled will vary around some average figure. The aim of process control is to find the range of natural random variation of the process and to ensure that production stays within this range.

The second principle of process control is that production processes are not usually found in a state of control. Due to lax procedures, untrained operators, improper machine maintenance, and so on, the variation being produced is usually much larger than necessary. The first job of process control managers is to seek out these sources of unnecessary variation, also called special causes, and bring the process under statistical control where the remaining variation is due to random causes.

A process control can be brought to a **state of control** and can be maintained

in this state through the use of quality control charts (also called process charts or control charts

Fig. process Control chart

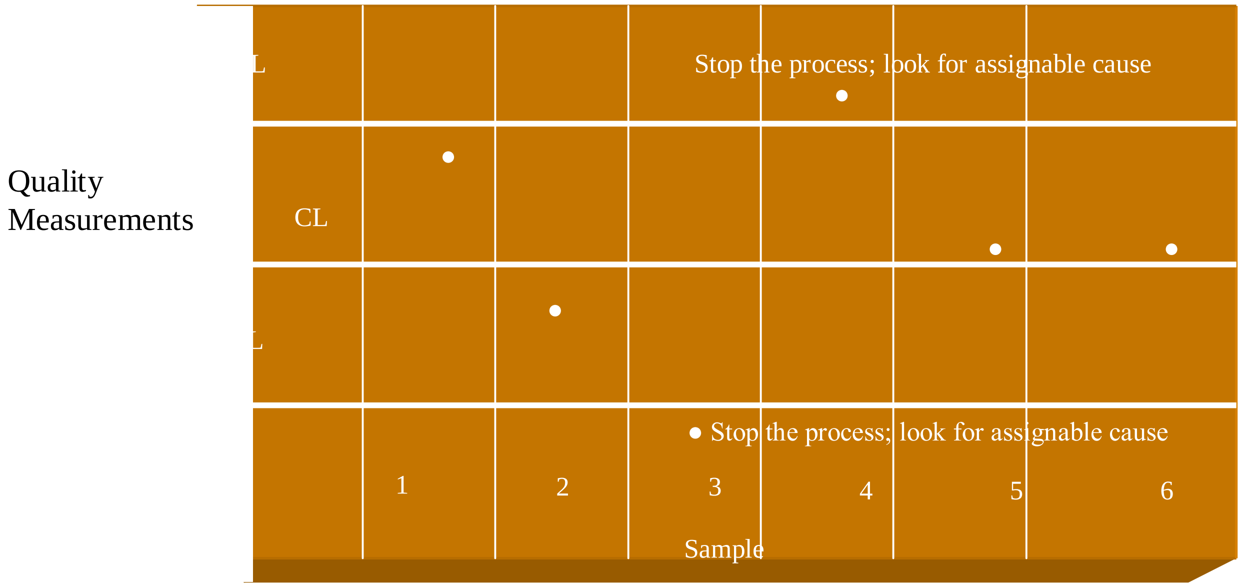


In the control chart shown in the above fig. the y-axis represents the quality characteristic that is being controlled, while the x-axis represents time or a particular sample taken from the process.

The **center line (CL)** of the chart is the average quality characteristic being measured.

The **Upper Control Limit** (**UCL)** represents the maximum acceptable random variation, and the **Lowe control Limit (LCL)** indicates the minimum the acceptable random variation when a state of control exists. Generally speaking, the upper and lower control limits are set at ± three standard deviations form the mean. If a normal probability distribution is assumed, these control limits will include 99.74 percent of the random variations observed.

After a process has been brought to steady -state operation, periodic samplers are taken and plotted on the control chart (see fig. below). When the measurement falls with in the control limits, the process is stopped and a search is made for an assignable cause. Through this procedure the process is maintained in a constant state of statistical control and there is only natural random variation in the process's output. Quality can be measured for control charts by attributes or by variables as discussed next.



PROCESS CONTROL WITH ATTRIBUTES MEASUREMENTS: USING P CHARTS

Attribute measurement uses a discrete scale by counting the number of defective items or the number of defects per unit. When the quality specifications are complex, it will usually be necessary to use attribute measurements. In this case a complicated set of criteria can be used to define a defective unit or a defect. For example, a color TV set may be classified as a defective if any of a number of functional tests fail or if the appearance of the cabinet is not satisfactory. We can use a simple statistics to create a p chart with an upper control limit (UCL) and a lower control limit (LCL). We can draw these control limits on a graph and then plot the fraction defective of each individual sample tested. The process is assumed to be working correctly when the samples, which are taken periodically during the day, continue to stay between the control limits.

When quality is measured by attributes, the quality characteristic is the percentage of defective units in the process. This percentage is estimated by taking a sample of n units at random from the process at a specified time intervals. For each sample, the observed percent defective (**p)** in the sample is computed. The observed values of p are plotted on the chart, for each sample.

To get the center line and control limits of the p control chart, we take a large number of samples of n units each. The **p** value is computed for each sample and then averaged over all samples to yield a value

$\bar{P}$. This value of $\bar{P}$ is used as the center line, since it represents the best available estimate of the true average percent defective of the process. We also use the value of $\bar{P}$ to compute the upper and lower control limits as follows:

FORMULAE:

$$\bar{P} = \frac{\text{Total number of defects from all samples}}{\text{Number of samples x Sample size}}$$

$$S_p = \sqrt{\bar{P}\left(\frac{1-\bar{P}}{n}\right)}$$

$$UCL = \bar{P} + z\,S_p$$

$$LCL = \bar{P} - z\,S_p$$

Where $\bar{P}$ is the fraction of defective, S_p is the standard deviation, n is the sample size and z is the number of standard deviation for a specific confidence. Typically z = 3 (99.7% confidence) or z = 2.58 (99 % confidence) are used.

Therefore , substituting z =3 and $S_p = \sqrt{\bar{P}\left(\frac{1-\bar{P}}{n}\right)}$, the UCL and LCL can be computed as follows:

$$UCL = \bar{P} + 3\sqrt{\bar{P}\left(\frac{1-\bar{P}}{n}\right)}$$

$$LCL = \bar{P} - 3\sqrt{\bar{P}\left(\frac{1-\bar{P}}{n}\right)}$$

Example

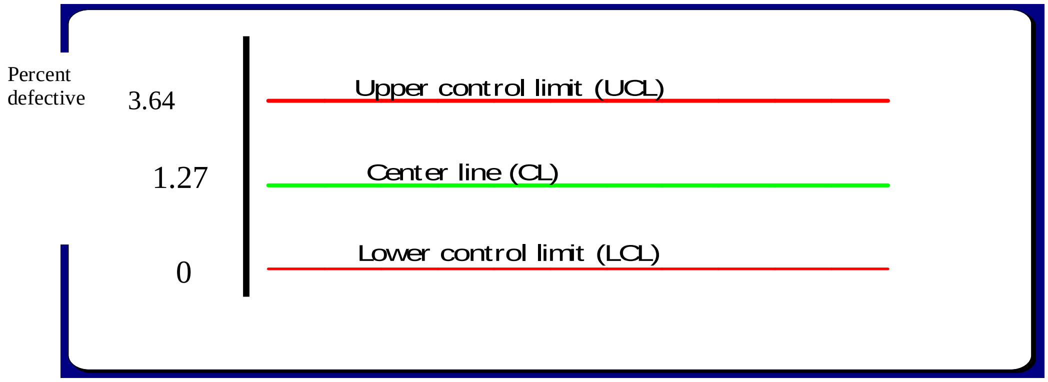
Suppose samples of 200 records are taken from a data entry operation at 2-hour intervals to control the data entry process. The percentage of records in error for the past 11 samples is found to be .5, 1.0, 1.5, 2.0, 1.5, .5, 1.0, 1.5, and 2.0 percent. The average of these11 sample percentage yields a $\bar{p}$ = 1.27 %, which is the center line of the control chart. The upper and lower control limits are

$$UCL = 0.0127 + 3\sqrt{0.0127\frac{(1-0.0127)}{200}} = 0.0364$$

$$LCL = 0.0127 - 3\sqrt{0.0127\frac{(1-0.0127)}{200}} = -.0110$$

When the LCL is < 0, it is rounded up to 0 because a negative percentage is impossible.

Thus, we have the following chart



After the P control is constructed with its center line and upper and lower line limits, samples of the process being controlled are taken and plotted on the chart. If the sample percentage falls within the control limits no action is taken. If the sample percentage falls out side the control limits, the process is stopped and search for an assignable cause (material, operator, or machine) is made. After the assignable cause is found the process is restored tom operating condition and production or service is resumed.

PROCESS CONTROL WITH VARIABLE MEASUREMENTS: USING $\bar{X}$ AND R CHARTS

Variables measurement utilizes a continuous scale for such factors as length, height, volume and weight. Examples of variables measurement are the dimension of parts, the viscosity of liquids, and the time it takes to wait on tables in a restaurant.

Control charts are also used for measurements of variables. In this case, a measurement of a continuous variable is made when each item is inspected. As a result two values are computed from the sample: a measure of central tendency (usually the average), and a measure of variability (the range or standard deviation). With these values, two control charts are developed: one for the mean and the second for variability of the process. When the process is found to be out of control on either of these charts, it is stopped and a search for an assignable cause is made.

There are four issues to address in creating a control chart: the size of the samples, number of samples, frequency of samples, and control limits.

Size of samples: for industrial applications in process control, it is preferable to keep the sample size small. There are two main recons: first, the sample needs to be taken within a reasonable lengeth of time; otherwise, the process might change while the samples are taken. Second, the larger the sample, the more it costs to take.

Sample sizes of four or five units seem to be the preferred numbers. The means of samples of this size have an approximately normal distribution, no matter what the distribution of the parent population looks like. Sample sizes greater than five give narrower control limits and thus more sensitivity. For detecting finer variations of a process, it may be necessary, in fact, to use larger sample sizes. However, when sample sizes exceed 15 or so, it would be better to use $\bar{X}$ charts with standard deviation σ rather than $\bar{X}$ charts with the range R.

Number of samples: once the chart has been set up, each sample taken can be compared to the chart and a decision can be made about whether the process is acceptable. To set up the chart, however, statistics suggest that 25 or so samples be taken.

Frequency of samples: how often to take a sample is a trade- off between the cost of sampling (along with the cost of the unit if it is destroyed as part of the test) and the benefit of adjusting the system.

Control Limits: standard practice in statistical process control for variables is to set control limits three standard deviations above the mean and below. This means that 99.7% of the sample means are expected fall within these control limits (that is within 99.7% confidence interval). Thus, is one sample mean falls outside this obviously wide band, we have strong evidence that the process is out of control.

How to construct $\bar{X}$ and R charts

If the standard deviation of the process distribution is known, the $\bar{X}$ chart may be defined

CL = $\bar{\bar{\chi}}$

UCL $\bar{X}$ = $\bar{\bar{\chi}}$ + $ZS\overline{X}$ and LCL $\bar{X}$ = $\bar{\bar{\chi}}$ - $ZS\overline{X}$

Or

UCL $\bar{X}$ = $\bar{\bar{\chi}}$ + $A_2\bar{R}$ and LCL $\bar{X}$ = $\bar{\bar{\chi}}$ - $A_2\bar{R}$

Where $s_x = s/\sqrt{n}$= standard deviation of sample means.

S =standard deviation of the process distribution.

N = sample size

$\bar{\bar{\chi}}$ = average sample of means or a target value for the process.

Z = number of standard deviations for specified confidence (especially z=3).

$\overline{R}$ = the average of several past R values (see below for its computation)

A_2= a constant that includes three standard deviations in terms of the range.

An $\bar{X}$ **chart is** the plot of the means of the samples that are taken form the process.

$\overline{\overline{\chi}}$ is an average of the means.

$\bar{X} = \frac{\sum_{i=1}^{n} x_i}{n}$ where $\bar{X}$ **=**mean of the sample

i **=** item number

n = Total number of items in the sample

The average sample of means is computed as follows:

$\overline{\overline{\chi}} = \frac{\sum_{j=1}^{m} \bar{x}_j}{m}$ Where $\overline{\overline{\chi}}$ = the average of the means of the sample

j= sample number

m=total number of samples

The control limits for the range chart are computed as follows:

$\overline{R} = \frac{\sum_{j=1}^{m} R_j}{m}$

Where $\overline{R}$ = average of the measurement differences R for all samples

R_j= difference between the highest and lowest measurement in the sample.

j= sample number

m=total number of samples

CL= $\overline{R}$

$UCL_R = D_4$ $\overline{R}$

$LCL_R = D_3$ $\overline{R}$

Where D_3 and D_4 are constants that provide three standard deviation limits for the range Values for this constants can obtained from statistical table.

Process capability

Motorola made process capability and product design famous by adopting its now well known**six – sigma limits**. Six- sigma is a short-cut for saying six-standard deviations form the mean. When we design a part, we specify that certain dimensions should be within a range. These design limits are often referred to as **the upper and lower specification limits or the upper or lower tolerance limits.** Note that these are different from the upper and lower control limits that we specified for the process.

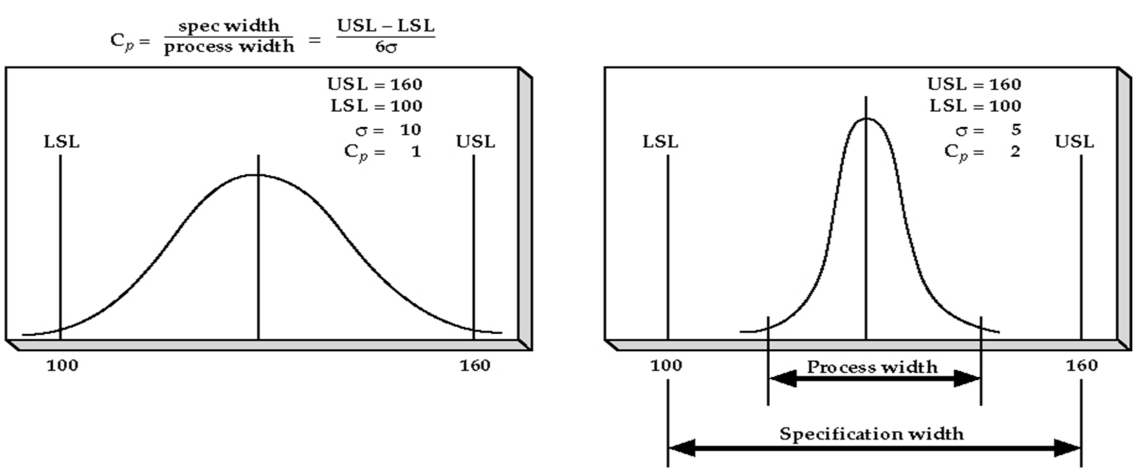
Process capability Index ($\mathbf{c}_{pk}$)

The process capability index is used to measure how well our process is capable of producing relative to the design tolerances. Once a process is under control, another aspect of continuous improvement is the ability of the process to meet, or exceed, its specifications. The capability index shows how well the parts being produced fit into the range specified by the design limits. If the design limits are larger than the three sigma allowed in the process, then the mean of the process can be allowed to drift- off center before readjusting, and high percentages of good parts will be produced.

This ability can be determined by the process capability index **Cp** – the ratio of the specification width to process width:

$$\mathbf{Cp} = \frac{specification width}{process width}$$

Fig. **Process capability Index Examples**



If the process is centered within specification range,**Cp**≥ 1will be a good indicator of the capability of the process to meet its specifications, since the process width will be within the specification width. In practical use, the specification width is computed as the difference between the upper specification limit (USL) and the lower specification limit (LSL). The process width is computed by using six standard deviations of the process measurement being monitored (6δ). The logic for 6δ is that most the variation of a process measurement is included within ± 3standard deviations of the mean, or a total of 6 standard deviations. Thus, we have:

Computation of $\mathbf{C_p} = \dfrac{\mathbf{USL - LSL}}{6\delta}$

If the process is centered in the specification range and cp =1, the process is considered to be minimally capable of meeting the specifications. A process with cp< 1 must be improved by reducing the standard deviation to become capable.

For the normal distribution, if Cp= 1 and the process is centered within the specification and under statistical control, then 99.74% of the product produced will lie within the specifications.

One problem with the Cp measure is that it requires the process to be centered in the specification range for an accurate measure of process capability. Because of this problem, another more widely used measure (C_{pk}) has been devised.

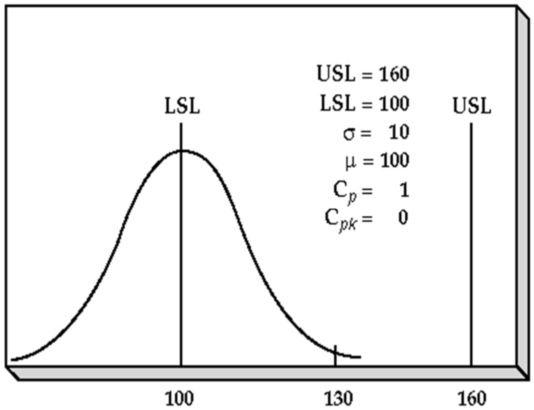
The capability index (C_{pk}) is calculated as the smallest number as follows:

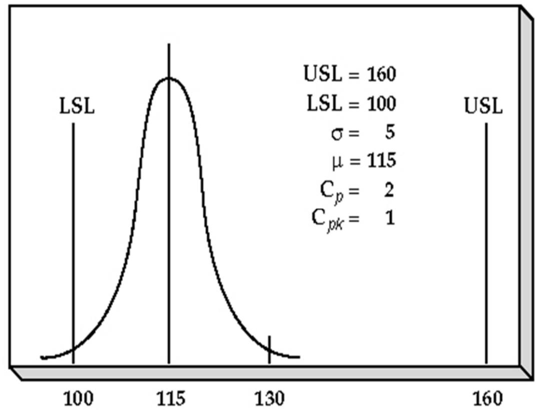
$$C_{pk}=\min\left[\frac{USL-\mu}{3\sigma}\right] \text{ or } \left[\frac{\mu-LSL}{3\sigma}\right]$$

Where σ = the process standard deviation and μ = the process mean value.

This more complicated measure of process capability overcomes the centering problem by calculating the process capability for each half of the normal distribution and then taking the minimum of the two calculations. The result shown in the fig., below shows $Cpk_{=0,}$ while Cp=1. This figure illustrates that the use of Cp index when the process is not centered gives the wrong answer, since the process is not fully capable of meeting the specifications, whereas Cpk gives the correct answer with Cpk =0

Fig. a. Fig. b





A further example is given in fig. b ,where Cpk= 1, even though the distribution is not centered. In this case, the process is capable of meeting the specifications but could be improved by shifting the mean closer to the center of the specification range. Because Cpk reflects more accurately the actual process capability, it is the measure commonly used in industry.

Activity 5.2

Answer the following questions before continuing to the next section.

1. What is total quality management and why it is important for business organozation? Explain.

____

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2. What is the role of statistical quality control in quality management**?**

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____

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Checklist

If you understand the following words or phrases put a tick (✓) mark in the box, otherwise read the section again.

- **Quality circle** -- ☐
- **Employee empowerment** -- ☐
- **Six sigma** --- ☐
- **Just in time** -- ☐
- **Continuous improvement** --- ☐

Self-check exercise 5

Part I. Write "true" if the statement is correct and "false" if the statement is incorrect

1. Internal failure costs are associated with scrap, rework, and downtime.
2. The delivery of quality products and services to customers is important, for reasons that include profitability as well as social responsibility.
3. Continuous improvement is based on the philosophy that any aspect of an organization can be improved.
4. Quality circles empower employees to improve productivity by finding solutions to work-related problems in their work area.
5. Benchmarking requires the comparison of your firm to other organizations; it is not appropriate to benchmark by comparing one of your divisions to another of your divisions.
6. Pareto charts are a graphical way of identifying the few critical items from the many less important ones.
7. The quality of services is more difficult to measure than the quality of goods because both the intangible differences between service products and consumers' intangible expectations are poorly defined

Part II; Choose the best answer from the listed alternatives

1. "Quality is defined by the customer" is
   A. an unrealistic definition of quality
   B. a user-based definition of quality
   C. a manufacturing-based definition of quality
   D. a product-based definition of quality

E. the definition proposed by the American Society for Quality

2. "Making it right the first time" is
   A. an unrealistic definition of quality
   B. a user-based definition of quality
   C. a manufacturing-based definition of quality
   D. a product-based definition of quality
   E. the definition proposed by the American Society for Quality
3. According to the manufacturing-based definition of quality,
   A. quality is the degree of excellence at an acceptable price and the control of variability at an acceptable cost
   B. quality depends on how well the product fits patterns of consumer preferences
   C. even though quality cannot be defined, you know what it is
   D. quality is the degree to which a specific product conforms to standards
   E. quality lies in the eyes of the beholder
4. Which of the following is **not** one of the major categories of costs associated with quality?
   A. prevention costs
   B. appraisal costs
   C. internal failures
   D. external failures
   E. none of the above
5. ISO 9000 seeks standardization in terms of
   A. products
   B. production procedures
   C. suppliers' specifications
   D. procedures to manage quality
   E. all of the above
6. Total quality management emphasizes
   A. the responsibility of the quality control staff to identify and solve all quality-related problems
   B. a commitment to quality that goes beyond internal company issues to suppliers and customers
   C. a system where strong managers are the only decision makers
   D. a process where mostly statisticians get involved
   E. ISO 14000 certification
7. Total quality management emphasizes

A. the responsibility of the quality control staff to identify and solve all quality-related problems

B. a commitment to quality that goes beyond internal company issues to suppliers and customers

C. a system where strong managers are the only decision makers

D. a process where mostly statisticians get involved

E. ISO 14000 certification

8. Techniques for building employee empowerment include

A. building communication networks that include employees

B. developing open, supportive supervisors

C. moving responsibility from both managers and staff to production employees

D. building high-morale organizations

E. All of the above are techniques for employee empowerment

9. The process of identifying other organizations that are best at some facet of your operations and then modeling your organization after them is known as

A. continuous improvement

B. employee empowerment

C. benchmarking

D. copycatting

E. patent infringement

10. Which of the following is **true** regarding control charts?

A. Values above the upper and lower control limits indicate points out of adjustment.

B. Control charts are built so that new data can be quickly compared to past performance data.

C. Control charts graphically present data.

D. Control charts plot data over time.

E. All of the above are true

Answer key for self-check exercise

Self-check exercise 1

True or false	1. True	2. False	3. False	4. False	5. False			
Choose	1. D	2. D	3. D	4. C	5. B	6. B	7. D	8. C

Self-check exercise 2

True or false	1. False	2. true	3. true	4. False	5. true	6. true	7. true	8. true
Choose	1. C	2. C	3. C	4. B	5. C	6. B	7. D	8. E
	9. B	10. D						

Self-check exercise 3

True or false	1. True	2. True	3. True	4. True	5. True	6. True	7. True	8. False
	9. False	10. False	11. False	12. True	13. False			
Choose	1. A	2. E	3. E	4. D	5. D	6. C	7. E	8. C
	9. A	10. C	11. A	12. C	13. B	14. A		

Self-check exercise 4

True or false	1. False	2. true	3. true	4. true	5. False	6. false	7. true	
Choose	1. B	2. A	3. D	4. B	5. D	6. C	7. E	8. B
	9. A	10. D						

Self-check exercise 5

True or false	1. True	2. True	3. true	4. False	5. True	6. False	7. True	
Choose	1. B	2. C	3. D	4. E	5. D	6. B	7. B	8. E
	9. C	10. E						