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OPERATIONS MANAGEMENT

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Table of contents

Contents page

CHAPTER FOUR: OPERATIONS PLANNING AND CONTROL

CHAPTER FIVE: QUALITY CONTROL AND IMPROVEMENT

CHAPTER ONE

INTRODUCTION TO OPERATIONS MANAGEMENT

LEARNING OBJECTIVES

After successful completing this chapter you should be able to:

- Define the term operations management
- Identify major historical developments in operations management.
- Explain the evolution of operation management
- Distinguish service operations from manufacturing operations
- Identify the operation management decision making areas
- Understand the current trends in operations management
- Measure the productivity of any organization
- Identify current trends in operations management.
- Describe the flow of information between operations management and other business functions.

Key Brain Storming questions

- What is operations management?
- Discus the Historical Development of OM
- What is Differences between Manufacturing and Service Organization
- Operations Management Decisions
- Productivity Measurement

1.1. WHAT IS OPERATIONS MANAGEMENT?

Every business is managed through three major functions: finance, marketing, and operations management. 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.

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

Operations management (OM) is the business function that plans, organizes, coordinates, and controls the resources needed to produce a company's goods and services. Operations management is a management function. It involves managing people, equipment, technology, information, and many other resources. Operations management is the central core function of every company.

This is true whether the company is large or small, provides a physical good or a service, is for profit or not for profit. Every company has an operations management function. Actually, all the other organizational functions are there primarily to support the operations function.

Without operations, there would be no goods or services to sell. The marketing function provides promotions for the merchandise, and the finance function provides the needed capital. It is the operations function, however, that plans and coordinates all the resources needed to design, produce, and deliver the merchandise to the various retail locations. Without operations, there would be no goods or services to sell to customers.

Role of Operations Management

The role of operations management is to transform a company's inputs into the finished goods or services. Inputs include human resources (such as workers and managers), facilities and processes (such as buildings and equipment), as well as materials, technology, and information. Outputs are the goods and services a company produces.

FIGURE 1-2 The transformation process

At a factory the transformation is the physical change of raw materials into products, such as transforming leather and rubber into sneakers, denim into jeans, or plastic into toys. At an airline it is the efficient movement of passengers and their luggage from one location to another. At a hospital it is organizing resources such as doctors, medical procedures, and medications to transform sick people into healthy ones.

Operations management is responsible for orchestrating all the resources needed to produce the final product. This includes designing the product; deciding what resources are needed; arranging schedules, equipment, and facilities; managing inventory; controlling quality; designing the jobs to make the product; and designing work methods.

Basically, operations management is responsible for all aspects of the process of transforming inputs into outputs. Customer feedback and performance information are used to continually adjust the inputs, the transformation process, and characteristics of the outputs.

For operations management to be successful, it must add value during the transformation process. We use the term value added to describe the net increase between the final value of a product and the value of all the inputs.

Value added: The greater the **value added**, the more productive a business is. An obvious way to add value is to reduce the cost of activities in the transformation process. Activities that do not add value are considered a waste; these include certain jobs, equipment, and processes.

Efficiency: it means being able to perform activities well, and at the lowest possible cost. An important role of operations is to analyze all activities, eliminate those that do not add value, and restructure processes and jobs to achieve greater efficiency. Today's business environment is more competitive than ever, and the role of operations management has become the focal point of efforts to increase competitiveness by improving value added and efficiency.

Self check questions

1. What is operation?
2. What is management?
3. What is operations management?

1.2HISTORICAL DEVELOPMENT

The importance of operations management was not always recognized by business. In fact, following World War II American corporations were dominated by marketing and finance functions. U.S. companies were left to fill these markets: the post-World War II period of the 1950s and 1960s represented the golden era for U.S. business. The 1970s and 1980s things changed. American companies experienced large declines in productivity growth, and international competition began to be a challenge in many markets. In the 1980s and 1990s operations became the function at the core of organizational competitiveness.

Concept	Time	Explanation
Industrial Revolution	Late 1700s	Brought in innovations that changed production by using machine power instead of human power.
Scientific management	Early 1900s	Brought the concepts of analysis and measurement of the technical aspects of work design, and development of moving assembly lines and mass production.
Human relations movement	1930s to 1960s	Focused on understanding human elements of job design, such as worker motivation and job satisfaction.
Management science	1940s to 1960s	Focused on the development of quantitative techniques to solve operations problems.
Computer age	1960s	Enabled processing of large amounts of data and allowed widespread use of quantitative procedures.
Just-in-time systems (JIT)	1980s	Designed to achieve high-volume production with minimal inventories.
Total quality management (TQM)	1980s	Sought to eliminate causes of production defects.
Reengineering	1980s	Required redesigning a company's processes in order to provide greater efficiency and cost reduction.
Environmental issues	1980s	Considered waste reduction, the need for recycling, and product reuse.
Flexibility	1990s	Offered customization on a mass scale.
Time-based competition	1990s	Based on time, such as speed of delivery.
Supply chain management	1990s	Focused on reducing the overall cost of the system that manages the flow of materials and information from suppliers to final customers.
Global competition	1990s	Designed operations to compete in the global market.
Electronic commerce	Late 1990s; early twenty-first century	Used the Internet for conducting business activity.

1.3 DIFFERENCES BETWEEN MANUFACTURING AND SERVICE ORGANIZATIONS

Organizations can be divided into two broad categories: manufacturing organizations and service organizations, each posing unique challenges for the operations function. There are two primary distinctions between these categories.

First, manufacturing organizations produce physical, tangible goods that can be stored in inventory before they are needed. By contrast, service organizations produce intangible products that cannot be produced ahead of time.

Second, in manufacturing organizations most customers have no direct contact with the operation. Customer contact is made through distributors and retailers. Example a customer who buy a car from retailer. However, in service organizations the customers are typically present during the creation of the service. Hospitals, colleges, theaters, and barber shops are examples of service organizations in which the customer is present during the creation of the service.

The differences between manufacturing and service organizations are not as clear cut as they might appear, and there is much overlap between them. Most manufacturers provide services as part of their offering, and many service firms manufacture physical goods that they deliver to their customers or consume during service delivery. For example, a manufacturer of furniture may also provide shipment of goods and assembly of furniture. On the other hand, a barber shop may sell its own line of hair care products.

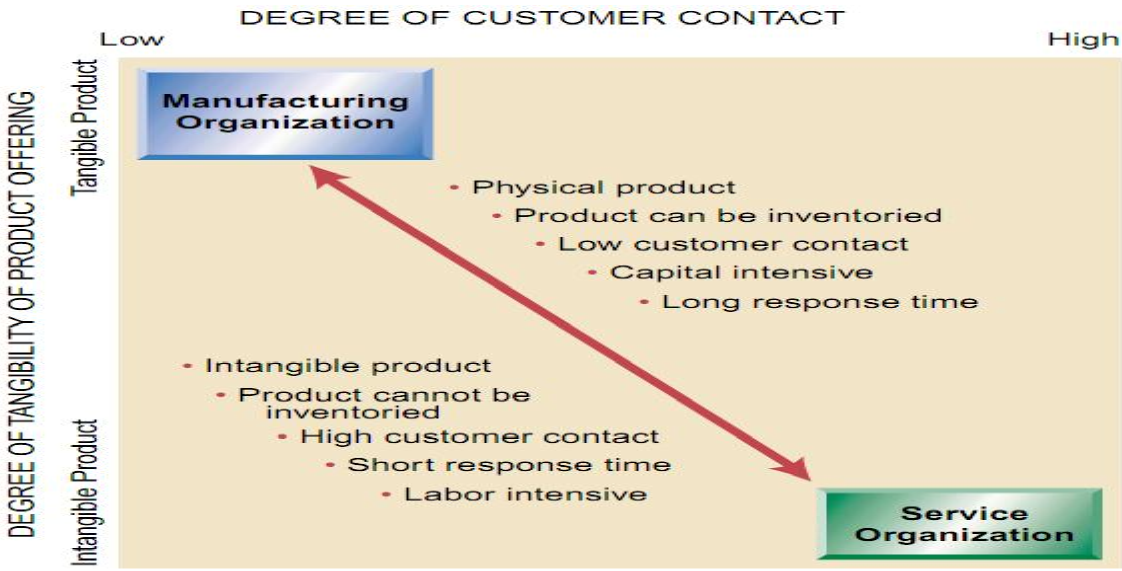


FIGURE 1-3 Characteristics of manufacturing and service organizations

Even in pure service companies some segments of the operation may have low customer contact while others have high customer contact. The former can be thought of as "back room" or "behind the scenes" segments.

Quasi-Manufacturing

In addition to pure manufacturing and pure service, there are companies that have some characteristics of each type of organization. For these companies it is difficult to tell whether they are actually manufacturing or service organizations. Think of a post office, an automated warehouse, or a mail-order catalog business. These companies have low customer contact and are capital intensive, yet they provide a service. We call these companies **quasi-manufacturing** organizations.

1.4 OPERATIONS MANAGEMENT DECISIONS

Strategic Decisions

Long-term decisions that set the direction for the entire organization are called strategic decisions. They are broad in scope and set the tone for other, more specific decisions. They address questions such as: What are the unique features of our product? What market do we plan to compete in? What do we believe will be the demand for our product?

Tactical Decisions

Short-term decisions that focus on specific departments and tasks are called tactical decisions. Tactical decisions focus on more specific day-to-day issues, such as the quantities and timing of specific resources. Strategic decisions are made first and determine the direction of tactical decisions, which are made more frequently and routinely. Therefore, we have to start with strategic decisions and then move on to tactical decisions. Tactical decisions must be aligned with strategic decisions, because they are the key to the company's effectiveness in the long run. Tactical decisions provide feedback to strategic decisions, which can be modified accordingly.

OM decisions are critical to all types of companies, large and small. In large companies these decisions are more complex because of the size and scope of the organization. Large companies typically produce a greater variety of products, have multiple location sites, and often use domestic and international suppliers. Managing OM decisions and coordinating efforts can be a complicated task, yet the OM function is critical to the company's success.

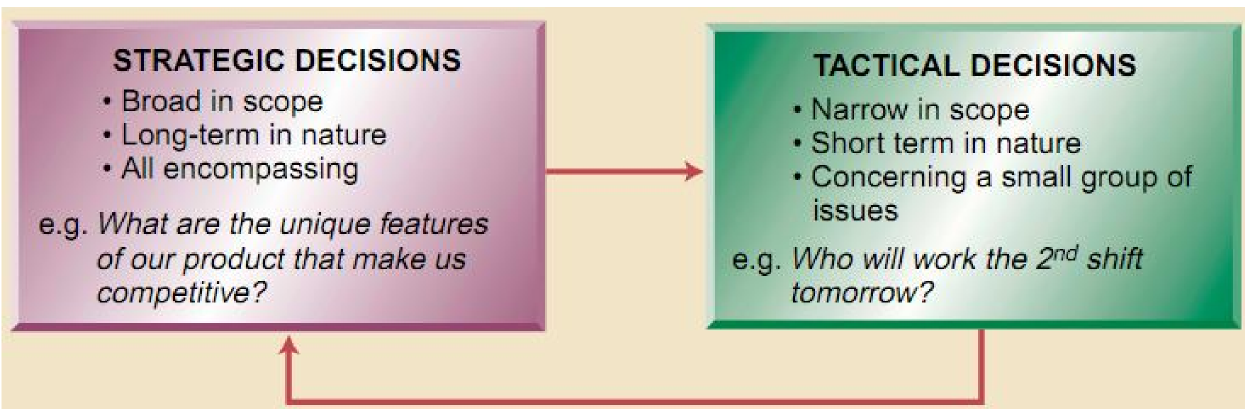


FIGURE 1-4 The relationship between strategic and tactical decisions

1.5 PRODUCTIVITY

Business strategy and supporting operations strategy make an organization more competitive in the marketplace. One of the most common ways to measure company's competitiveness is by measuring productivity. Operations management is responsible for managing the transformation of many inputs into outputs, such as goods or services. A measure of how efficiently inputs are being converted into outputs is called **productivity**.

1.5.1 Measuring productivity

It has been said, "If you can't measure it, you can't manage it". This is particularly true of productivity. Now we come to the main question of how we know that we are managing our operation system well. This concerns the efficiency with which we are converting the input in to outputs. Productivity measures how well resources are used. It is computed as a ratio of outputs (goods and services) to inputs (e.g., labor and materials). The more efficiently a company uses its resources, the more productive it is: $\mathbf{productivity = \frac{Output}{Input}}$

Productivity is used for making comparison or to measure improvement. Productivity is a relative term i.e. it gives sense only when we compare it with: company's previous performance, with other similar company's performance or with the performance of leader of the industry.

Many measures of productivity are possible, and *all are rough approximations*. Values of output may be measured by: what the *customers pay (dollar values of the output)* or simply by the *number of units* produced (in manufacturing industry) or *customers served (in service industry)*.

The values of inputs can be measured by: *their cost* or simply by the number of *hours* worked.

Productivity may be expressed as:

A. ***Total factor productivity measure*:** is the ratio of all output to all input i.e. total outputs/total inputs. Total inputs include all resources used in the production of goods and services: labor, capital, raw materials, and energy.

For example, let's say that the weekly dollar value of a company's output, such as finished goods and work in progress, is Birr 10,200 and that the value of its inputs, such as labor, materials, and capital, is Birr 8600. The company's total weekly productivity would be computed as follows:

$$\text{productivity} = \frac{\text{Output}}{\text{Input}} = \frac{10{,}200\ \text{Birr}}{8600\ \text{Birr}} = \mathbf{1.186}$$

B. ***Multi factor productivity*:** measures only a sub set of these inputs. i.e. **output**/ (l*abor + capital)*, **output**/ (*labor+ capital + materials)*, **output**/ (*materials + energy).*

For example, let's say that output is worth $382 and labor and materials costs are $168 and $98, respectively. A multifactor productivity measure of our use of labor and materials would be:

$$\text{Multifactor productivity} = \frac{\text{output}}{\text{labor} + \text{materials}}$$

$$\text{Multifactor productivity} = \frac{\text{Birr } 382}{\text{Birr } 168 + \text{Birr } 98} = 1.436$$

C. ***Single factor (partial productivity) measure*:** is the ratio of output to a single resource (inputs). i.e. *output/labor, output/capital , output/material, output/energy* etc.

Examples of the calculation of partial productivity:

1. A bakery oven produces 346 pastries in 4 hours. What is its productivity?
   Machine productivity = number of pastries/oven time

$$\text{Machine productivity} = \frac{346 \text{ pastries}}{4 \text{ hours}} = \mathbf{86.5\ pastries/hour}$$

2. Two workers paint tables in a furniture shop. If the workers paint 22 tables in 8 hours, what is their productivity?

$$\text{Labor productivity} = \frac{22 \text{ tables}}{2 \text{ workers} * 8 \text{ hours}} = \mathbf{1.375\ tables/hour}$$

Measurement is only the first step in improving productivity. Understanding the factors which affect productivity and selecting the appropriate improvement factors in any given situation is the second step.

1.5.2 Interpreting Productivity Measures

To interpret the meaning of a productivity measure, it must be compared with a similar productivity measure. For example, if one worker at a pizza shop produces 17 pizzas in two hours, the productivity of that worker is 8.5 pizzas per hour. This number by itself does not tell us very much. However, if we compare it to the productivity of two other workers, one who produces 7.2 pizzas per hour and another 6.8 pizzas per hour, it is much more meaningful. We can see that the first worker is much more productive than the other two workers. But how do we know whether the productivity of all three workers is reasonable? What we need is a standard.

It is also helpful to measure and compare productivity over time. Let's say that we want to measure the total productivity of our three pizza makers (our "labor") and we compute a labor productivity measure of 7.5 pizzas per hour. This number does not tell us much about the workers' performance. However, if we compare weekly productivity measures over time, perhaps over the last four weeks, we get much more information:

Week	1	2	3	4
Productivity (pizzas/labor-hour)	5.4	6.8	7.1	7.5

Now we see that the workers' productivity is improving over time. In fact, productivity changed from 5.4 to 7.5 pizzas per labor-hour, resulting in an increase of 7.5/5.4 1.39, or an increase of 39 percent. But what if we find out that our main competitor, a pizzeria down the street, has a productivity of 9.5 pizzas per labor-hour? This productivity rate is 26.7 percent (9.5/7.5 1.267) higher than our productivity in week 4. Suddenly we know that even though our productivity is going up, it should be higher. We may have to analyze our processes and increase our productivity in order to be competitive. By comparing our productivity over time and against similar operations, we have a much better sense of how high our productivity really is.

A company that competes based on speed would probably measure productivity in units produced over time. However, a company that competes based on cost might measure productivity in terms of costs of inputs such as labor, materials, and overhead. The important thing is that our productivity measure provides information on how we are doing relative to the competitive priority that is most important to us.

1.5.3 Productivity and Competitiveness

Productivity is essentially a scorecard of how efficiently resources are used and a measure of competitiveness. Productivity is measured on many levels and is of interest to a wide range of people. Productivity can be measured for individuals, departments, or organizations. It can track performance over time and help managers identify problems. Similarly, productivity can be measured for an entire industry and even a country.

The economic success of a nation and the quality of life of its citizens are related to its competitiveness in the global marketplace. Increases in productivity are directly related to increases in a nation's standard of living. That is why business and government leaders continuously monitor the productivity at the national level and by industry sectors.

1.5.4 Productivity and the Service Sector

Service sector companies have a unique challenge when trying to measure productivity. The reason is that traditional productivity measures tend to focus on tangible outcomes, as seen with goods-producing activities. Services primarily produce intangible products, such as ideas and information, making it difficult to evaluate quality. Consequently, accurately measuring productivity improvements can be difficult. A good example of the difficulty in using traditional productivity measures in the service sector is the emergency room. Here inputs are the medical staff, yet outputs may not exist if no one needed treatment on that shift. In that case, by traditional measures, productivity would be zero! The real issue in this type of environment is the level of readiness, and the challenge is to adequately measure it.

1.5.5 Factors that affect productivity

Productivity stands tall on four important pillars of Capital, Quality, Management and Technology. These pillars are also responsible for positively as well as negatively affecting the productivity of the organization.

A. **CAPITAL:** An existing machine or facility if it is not functioning up to full capacity or turning out products which are not acceptable can lower productivity. A new machine or repair of existing machine would require capital input.
B. **QUALITY:** Poor quality products would not meet customer requirements and would need repairs and reworks on the product to meet the standards.
C. **MANAGEMENT** With better scheduling, planning, coordinating and controlling activities of management the machine operations can be carried to improve productivity.
D. **TECHNOLOGY** Technological improvements have increased productivity. A machine of today would outperform machine of yesterday but may not with stand machines of

tomorrow. **CAUTION:** Without careful planning technology can reduce productivity as it often leads to increased costs, inflexibility or mismatched operations. All leads to reduction in value.

Other Factors Affecting Productivity

Standardization: We live in a world where for the sake of convenience, reliability and safety, majority of the products and services have been standardized. If for a moment any process whether it relates to manufacturing or services is made standard less, the vital concept of compatibility would be lost. Think for a moment if there is a fire at a Public school or at a crowded stadium, if there is no standardization of fire hose attached to the fire truck and fire hydrant present at the site, no effort would succeed in putting out the fire and saving the lives of the people.

Use of Internet: Use of Internet/Extranet especially for the services side, even though there are knowledge base applications available for the manufacturing side as well but primarily it has the been the services side which has been able to exploit the resourcefulness of the Internet.

Computer viruses: A lot of time IT based services industry have fallen a prey to computer viruses and hackers.

Searching for lost or misplaced items: This speaks low about the coordinating activities and can lead to loss in production time and increase in idle time. Often this also leads to increase in replacement costs.

Scrap rates: Any aberration in the raw materials or processed product can lead to increase in scrap. The increase in scrap rate in fact can decrease the utilization of resources in general and raw material.

New workers: Organizations spend millions of Dollars every year to train their employees. A trained workforce is not only reliable and dependable but also ensures productivity.

1.5.6 Improving productivity

There are several ways in which operations manager can improve productivity. These may be classified as:

- Increasing output while keeping input constant
- Decreasing input while keeping output constant
- Increasing output at higher rate than increasing input
- Decreasing output at lower rate than decreasing input
- Increasing output while decreasing input (most challenging but effective).

Self- assessment questions

I Short answer questions

1. Define the term operation management
2. Distinguish between manufacturing and service operations
3. Explain the factors that affect productivity and the means to improve productivity
4. Explain the historical evolution of production function
5. What are the various decisions and their applications made by operations managers in operations management system?
6. Explain the concept of productivity with example.
7. Determine daily labor productivity for **TY** Cupcake Shoppe which turns out 400 assorted cupcakes per day using two bakers who work eight hours per day at 12 Birr per hour.
8. Calculate the change in labor productivity if the bakery increased production from 300 loaves to 380 loaves on Friday. On all days, three employees work eight hours at a rate of 8 Birr per hour each. How can this be explained?

II. Multiple choice questions

1. Of the following which one is correct about operations management?
   a) production management deals basically with the management of banks and hospitals
   b) operations management is wider in scope than production management
   c) production management evolved from operations management
   d) operation management focuses on maximizing input investment
2. from operations management points of view, in any organization values can be created through:
   a) transformation
   b) transportation
   c) group technology
   d) ergonomics

3. From input-transformation –output process, which one best represent the component of automobile factory?
   a) Steel, sheet and engine
   b) Tools, equipment and power
   c) Library, laboratory and network
   d) Doctor, nurse and facility
4. Pick the correct statement
   a) Unlike service, manufacturing is labor intensive
   b) Unlike manufacturing, service is easy to automate
   c) Unlike service, manufacturing is sensitive to location
   d) Unlike manufacturing, service output is customize
5. All the following leads to productivity improvement except:
   a) Increase input at lower rate output
   b) Decrease input and keep output constant
   c) Decrease output at lower rate than input
   d) Keep output constant, and increase input
6. From OM decision which one is strategic decision?
   a) Inventory planning and control
   b) Facility location
   c) Production planning and scheduling
   d) Maintenance and replacement

CHAPTER TWO

OPERATIONS STRATEGY AND COMPETITIVENESS

LEARNING OBJECTIVES

After successful completing this chapter you should be able to:

- Explain the role of operations strategy in the organization.
- Explain the relationship between business strategy and operations strategy.
- Describe how an operations strategy is developed.
- Identify competitive priorities of the operations function.
- Explain the strategic role of technology.

Key Brain Storming questions

- What is strategy?
- What is the difference between a 'top-down' and a 'bottom-up' view of operations strategy?
- What is the difference between a 'market requirements' and an 'operations resource' view of operations strategy?
- How can an operations strategy be put together?

2.1 WHAT IS STRATEGY?

To maintain a competitive position in the marketplace, a company must have a long-range plan. This plan needs to include the company's long-term goals, an understanding of the marketplace, and a way to differentiate itself from its competitors. All other decisions made by the company must support this long-range plan. Otherwise, each person in the company would pursue goals that he or she considered important, and the company would quickly fall apart.

Strategy is not particularly easy to define. The word derives from the Greek word 'strategos' meaning 'leading an army'. And although there is no direct historical link between Greek military practice and modern ideas of strategy, the military metaphor is powerful. Both military and business strategy can be described in similar ways, and include some of the following.

- Setting broad objectives that direct an enterprise towards its overall goal.
- Planning the path (in general rather than specific terms) that will achieve these goals.

- Stressing long-term rather than short-term objectives.
- Dealing with the total picture rather than stressing individual activities.
- Being detached from, and above, the confusion and distractions of day-to-day activities.

Here, by ‘strategic decisions’ we mean those decisions which are widespread in their effect on the organization to which the strategy refers, define the position of the organization relative to its environment, and move the organization closer to its long-term goals. But ‘strategy’ is more than a single decision; it is the total pattern of the decisions and actions that influence the long-term direction of the business.

2.2 What is operations strategy?

Operations strategy is concerned with setting broad polices and plans for using the resources of the firm to best support the firm’s long term competitive strategy. In short, OM strategy specifies the means by which operations implements the firm’s corporate strategy. Operations strategy links long and short term operation decisions to corporate strategy. Operation strategy is derived from business strategy which in turn is derived from corporate strategy.

Corporate strategy this relates to the organization as a whole. How should the business fulfill its long-term objectives and satisfy its mission? A mission here means a statement of the purpose or the main reason for the organization’s existence. For example, a business school’s mission statement may be: ‘to be amongst the top ten business schools in reign, providing programs at undergraduate, postgraduate and executive levels.’ Similarly, a mission for a construction firm may be: ‘to provide quality dam and highway bridges both at home and overseas.

Business Strategy: is the long-range plan of a business, designed to provide and sustain shareholder value. For a company to succeed, the business strategy must be supported by each of the individual business functions, such as operations, finance, and marketing.

Operations strategy: is a long-range plan for the operations function that specifies the design and use of resources to support the business strategy. In today’s highly competitive, Internet-based, and global marketplace, it is important for companies to have a clear plan for achieving their goals.

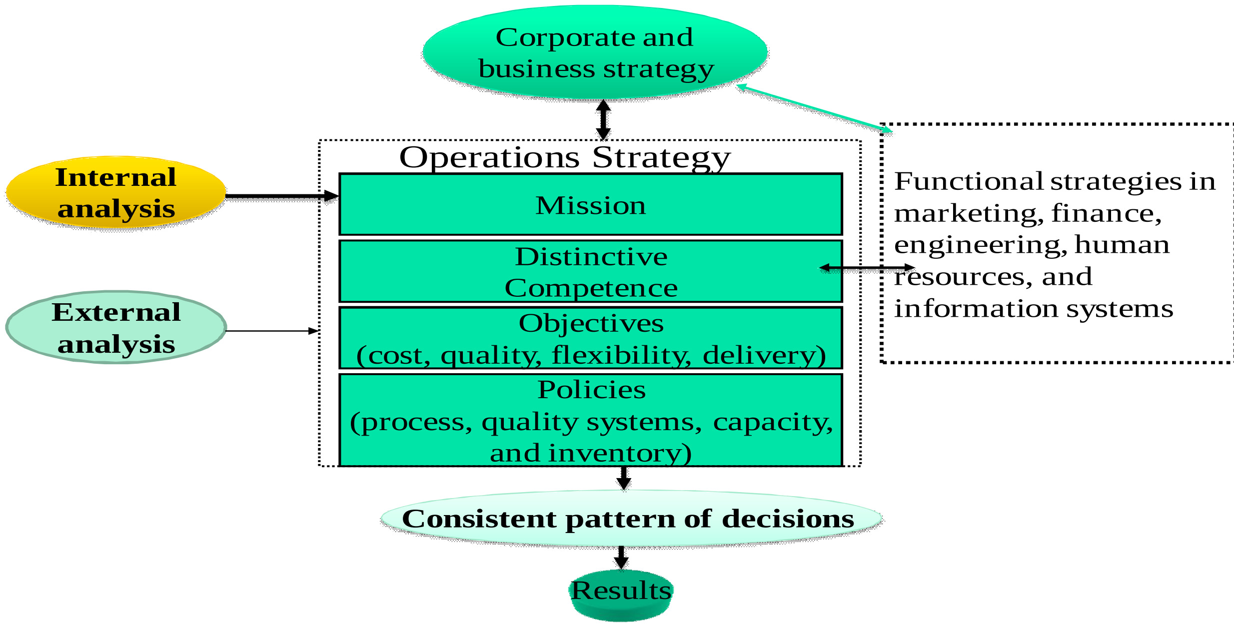


Figure 2.1 Operations Strategy Model

2.3 THE ROLE OF OPERATIONS STRATEGY

The role of operations strategy is to provide a plan for the operations function so that it can make the best use of its resources. Operations strategy specifies the policies and plans for using the organization's resources to support its long-term competitive strategy. Remember that the operations function is responsible for managing the resources needed to produce the company's goods and services. Operations strategy is the plan that specifies the design and use of resources to support the business strategy. This includes the location, size, and type of facilities available; worker skills and talents required; use of technology, special processes needed, special equipment; and quality control methods. The operations strategy must be aligned with the company's business strategy and enable the company to achieve its long-term plan.

The Importance of Operations Strategy

Operations strategy did not come to the forefront until the 1970s. Up to that time U.S. companies emphasized mass production of standard product designs. There were no serious international competitors, and U.S. companies could pretty much sell anything they produced. However, that changed in the 1970s and 1980s. Japanese companies began offering products of superior quality at lower cost, and U.S. companies lost market share to their Japanese counterparts. In an attempt to survive, many U.S. companies copied Japanese approaches. Unfortunately, merely copying these approaches often proved unsuccessful; it took time to really understand Japanese approaches. It became clear that Japanese companies were more competitive because of their operations strategy; that is, all their resources were specifically designed to directly support the company's overall strategic plan.

Harvard Business School professor Michael Porter says that companies often do not understand the differences between operational efficiency and strategy. **Operational efficiency** is performing operations tasks well, even better than competitors. **Strategy**, on the other hand, is a plan for competing in the marketplace. An analogy might be that of running a race efficiently, but it may be the wrong race. Strategy is defining in what race you will win. Operational efficiency and strategy must be aligned; otherwise you may be very efficiently performing the wrong task. The role of operations strategy is to make sure that all the tasks performed by the operations function are the right tasks.

2.4 DEVELOPING A BUSINESS STRATEGY

A company's business strategy is developed after its managers have considered many factors and have made some strategic decisions. These include developing an understanding of what business the company is in (the company's mission), analyzing and developing an understanding of the market (environmental scanning), and identifying the company's strengths (core competencies). These three factors are critical to the development of the company's long-range plan, or business strategy. In this section, we describe each of these elements in detail and show how they are combined to formulate the business strategy.

2.4.1 Mission

Every organization, from IBM to the Boy Scouts, has a mission. The mission is a statement that answers three overriding questions:

- What business will the company be in ("selling personal computers," "operating an Italian restaurant")?
- Who will the customers be, and what are the expected customer attributes ("homeowners," "college graduates")?
- How will the company's basic beliefs defines the business ("gives the highest customer service," "stresses family values")?

Following is a list of some well-known companies and parts of their mission statements:

- *Dell Computer Corporation*: "to be the most successful computer company in the world"
- *Delta Air Lines:* "worldwide airlines choice"
- *IBM:* "translate advanced technologies into values for our customers as the world's largest information service company"
- *Lowe's:* "helping customers build, improve and enjoy their homes"
- *Ryder:* "offers a wide array of logistics services, such as distribution management, domestically and globally"

If a company does not have a well defined mission it may pursue business opportunities about which it has no real knowledge or that are in conflict with its current pursuits, or it may miss opportunities altogether.

2.4.2 Environmental Scanning

A second factor to consider is the external environment of the business. This includes trends in the market, in the economic and political environment, and in society. These trends must be analyzed to determine business opportunities and threats. Environmental scanning is the process of monitoring the external environment. To remain competitive, companies have to continuously monitor their environment and be prepared to change their business strategy, or long-range plan, in light of environmental changes. Environmental scanning allows a company to identify opportunities and threats. Just because a company is an industry leader today does not mean it will continue to be a leader in the future. The external business environment is always changing. To stay ahead of the competition, a company must constantly look out for trends or changing patterns in the environment, such as marketplace trends. These might include changes in customer wants and expectations, and ways in which competitors are meeting those expectations. For example, we are seeing changes in the use of technology, such as point-of-sale scanners, automation, computer-assisted processing, electronic purchasing, and electronic order tracking.

In addition to market trends, environmental scanning looks at economic, political, and social trends that can affect the business. **Economic** trends include recession, inflation, interest rates, and general economic conditions. **Political** trends include changes in the political climate—local, national, and international—that could affect a company. Companies seek customers and suppliers all over the globe. Many have changed their strategies in order to take advantage of global opportunities, such as forming partnerships with international firms, called strategic alliances. Finally, **social** trends are changes in society that can have an impact on a business.

2.4.3 Core Competencies

The third factor that helps define a business strategy is an understanding of the company's strengths. These are called **core competencies**. In order to formulate a long-term plan, the company's managers must know the competencies of their organization. Core competencies could include special skills of workers, such as expertise in providing customized services or knowledge of information technology. Another example might be flexible facilities that can handle the production of a wide array of products. To be successful, a company must compete in markets where its core competencies will have value.

Highly successful firms develop a business strategy that takes advantage of their core competencies or strengths. To see why it is important to use core competencies, think of a student developing plans for a successful professional career. Let's say that this student is particularly good at mathematics but not as good in verbal communication and persuasion. Taking advantage of core competencies would mean developing a career strategy in which the student's strengths could provide an advantage, such as engineering or computer science. On the other hand, pursuing a career in marketing would place the student at a disadvantage because of a relative lack of skills in persuasion. Increased global competition has driven many companies to clearly identify their core competencies and outsource those activities considered noncore. Outsourcing is when a company obtains goods or services from an outside provider. By outsourcing noncore activities a company can focus on its core competencies.

2.5 DEVELOPING AN OPERATIONS STRATEGY

Once a business strategy has been developed, an operations strategy must be formulated. This will provide a plan for the design and management of the operations function in ways that support the business strategy. The operations strategy relates the business strategy to the operations function. It focuses on specific capabilities of the operation that give the company a competitive edge. These capabilities are called **competitive priorities**. By excelling in one of these capabilities, a company can become a winner in its market.

2.5.1 Competitive Priorities and Competitive Advantage

Operations managers must work closely with marketing in order to understand the **competitive** situation in the company's market before they can determine which competitive priorities are important. Many firms strive for competitive advantage, but few truly understand what it is or how to achieve and keep it. Competitive advantage can be viewed as any activity that creates superior value above its rivals. The strongest competitive advantage is a strategy that can't be imitated by other companies.

In general, a competitive advantage can be gained by offering the customer a greater value than the competitors. The key to developing an effective operations strategy lies in understanding how to create or add value for customers i.e. how to gain competitive advantage.

Specifically, competitive advantage can be gained (value can be added) through the competitive priority (priorities that are selected to support a given strategy). Generally there are possible competitive priorities for process which fall in to four groups:

A. Cost: Competing based on cost means offering a product at a low price relative to the prices of competing products. The need for this type of competition emerges from the business strategy. The role of the operations strategy is to develop a plan for the use of resources to support this type of competition. Note that a low-cost strategy can result in a higher profit margin, even at a competitive price. Also, low cost does not imply low quality.

To develop this competitive priority, the operations function must focus primarily on cutting costs in the system, such as costs of labor, materials, and facilities. Companies that compete based on cost study their operations system carefully to eliminate all waste. They might offer extra training to employees to maximize their productivity and minimize scrap. Also, they might invest in automation in order to increase productivity. Generally, companies that compete based on cost offer a narrow range of products and product features, allow for little customization, and have an operations process that is designed to be as efficient as possible.

B. Quality: Many companies claim that quality is their top priority, and many customers say that they look for quality in the products they buy. Yet quality has a subjective meaning; it depends on who is defining it. *Quality is a major influence on customer satisfaction or dissatisfaction Quality is defined differently depending on who is defining it Quality is consistent conformance to customers' expectations.* For example, to one person quality could mean that the product **lasts a long time**. To another person quality might mean **high performance**. When companies focus on quality as a competitive priority, they are focusing on the dimensions of quality that are considered important by their customers.

Quality as a competitive priority has two dimensions. The first is **high-performance design**. This means that the operations function will be designed to focus on aspects of quality such as superior features, close tolerances, high durability, and excellent customer service. The second dimension is **goods and services consistency**, which measures how often the goods or services meet the exact design specifications.

A company that competes on this dimension needs to implement quality in every area of the organization.

a. **Product Design Quality**: which involves making sure the product meets the requirements of the customer.

b. **Process Quality:** deals with designing a process to produce error-free products. This includes focusing on equipment, workers, materials, and every other aspect of the operation to make sure it works the way it is supposed to. Companies that compete based on quality have to address both of these issues: the product must be designed to meet customer needs, and the process must produce the product exactly as it is designed.

C. Time: Time or speed is one of the most important competitive priorities today. Companies in all industries are competing to deliver high-quality products in as short a time as possible. Companies like FedEx, Lens Crafters, United Parcel Service (UPS), and Dell compete based on time. Today’s customers don’t want to wait, and companies that can meet their need for fast service are becoming leaders in their industries.

Making time a competitive priority means competing based on all time-related issues, such as *rapid delivery* and *on-time delivery*.

a. **Rapid delivery:** refers to how quickly an order is received;

b. **On-time delivery**: refers to the number of times deliveries are made on time.

When time is a competitive priority, the job of the operations function is to critically analyze the system and combine or eliminate processes in order to save time. Often companies use technology to speed up processes, rely on a flexible workforce to meet peak demand periods, and eliminate unnecessary steps in the production process.

D. Flexibility As a company's environment changes rapidly, including customer needs and expectations, the ability to readily accommodate these changes can be a winning strategy. This is flexibility.

There are two dimensions of flexibility. One is the ability to *offer a wide variety* of goods or services and *customize* them to the unique needs of clients. This is called **product flexibility**. A flexible system can quickly add new products that may be important to customers or easily drop a product that is not doing well. Another aspect of flexibility is the ability to rapidly increase or decrease the amount produced in order to accommodate changes in the demand. This is called **volume flexibility**.

Also, flexible companies typically do not compete based on cost, because it may take more resources to customize the product. However, flexible companies often offer greater customer service and can meet unique customer requirements. To carry out this strategy, flexible companies tend to have more general-purpose equipment that can be used to make many different kinds of products. Also, workers in flexible companies tend to have higher skill levels and can often perform many different tasks in order to meet customer needs.

2.5.2 The Need for Trade-Offs

You may be wondering why the operations function needs to give special focus to some priorities but not all. Aren't all the priorities important? As more resources are dedicated to one priority, fewer resources are left for others. The operations function must place emphasis on those priorities that directly support the business strategy. Therefore, it needs to make **trade-offs** between the different priorities. For example, consider a company that competes on using the highest quality component parts in its products. Due to the high quality of parts, the company may not be able to offer the final product at the lowest price. In this case, the company has made a trade-off between quality and price. Similarly, a company that competes on making each product individually based on customer specifications will likely not be able to compete on speed. Here, the trade-off has been made between flexibility and speed.

It is important to know that every business must achieve a basic level of each of the priorities, even though its primary focus is only on some. For example, even though a company is not competing on low price, it still cannot offer its products at such a high price that customers would not want to pay for them. Similarly, even though a company is not competing on time, it still has to produce its product within a reasonable amount of time; otherwise, customers will not be willing to wait for it.

One way that large facilities with multiple products can address the issue of trade-offs is using the concept of plant-within-a-plant (PWP), introduced by well-known Harvard professor Wickham Skinner. The PWP concept suggests that different areas of a facility be dedicated to different products with different competitive priorities. These areas should be physically separated from one another and should even have their own separate workforce. As the term suggests, there are multiple plants within one plant, allowing a company to produce different products that compete on different priorities. For example, hospitals use PWP to achieve specialization or focus in a particular area, such as the cardiac unit, oncology, radiology, surgery, or pharmacy. Similarly, department stores use PWP to isolate departments, such as the Sears auto service department versus its optometry center.

2.5.3 Order winners and qualifiers

The terms 'order winner' and 'order qualifier' were coined by Terry Hill, professor at the London business school, and refers to the process of how internal operational capabilities are converted to criteria that may lead to *competitive advantage and market success*. Hill emphasized the interactions and co-operations between operations and marketing. The operations people are responsible for providing the order winning and order qualifying criteria-identified by marketing – that enables products to win orders in the market place. This process starts with the cooperatives strategy and ends with the criteria that either keeps the company in the running (i.e. order qualifier) or wins the customers business.

Terry Hill has coined the terms order winner and qualifies to describe marketing oriented priorities that are key to competitive success:

- ***An order qualifier*** *is a screening criterion that permits a firm's products to even be considered as possible candidates for purchase. In short, order qualifier can be defined as the minimum elements or characteristics that a firm or its products must have in order to even be considered as a potential supplier* or source.
- ***An order winner*** *is a criterion that differentiates the products or services of one firm from another. In general, order winner is a characteristic of a firm that distinguishes it from its competition so that it is selected as the source of purchase.*

2.5.4 Translating Competitive Priorities into Production Requirements

Operations strategy makes the needs of the business strategy specific to the operations function by focusing on the right competitive priorities. Once the competitive priorities have been identified, a plan is developed to support those priorities. The operations strategy will specify the design and use of the organization's resources; that is, it will set forth specific operations requirements. These can be broken down into two categories.

a. **Structure**: Operations decisions related to the design of the production process, such as characteristics of **facilities** used, selection of appropriate **technology**, and flow of goods and services through the facility.
b. **Infrastructure**: Operations decisions related to the planning and control systems of the operation, such as **organization** of the operations function, **skills and pay** of workers, and **quality control** approaches. Together, the structure and infrastructure of the production process determine the nature of the company's operations function.

The structure and infrastructure of the production process must be aligned to enable the company to pursue its long-term plan.

2.6 STRATEGIC ROLE OF TECHNOLOGY

Over the last decade we have seen an unprecedented growth in technological capability. Technology has enabled companies to share real-time information across the globe, to improve the speed and quality of their processes, and to design products in innovative ways. Companies can use technology to help them gain an advantage over their competitors. For this reason technology has become a critical factor for companies in achieving a competitive advantage. In fact, studies have shown that companies that invest in new technologies tend to improve their financial position over those that do not. However, the technologies a company acquires should not be decided on randomly, such as following the latest fad or industry trend. Rather, the selected technology needs to support the organization's competitive priorities. Also, technology needs to be selected to enhance the company's core competencies and add to its competitive advantage.

2.6.1 Types of Technologies

There are three primary types of technologies. They are differentiated based on their application, but all three areas of technology are important to operations managers.

a. Product technology: which is any new technology developed by a firm. An example of this would include Teflon, the material used in no-stick fry pans. Teflon became an emerging technology in the 1970s and is currently used in numerous applications. Other examples include CDs and flat-screened monitors. Product technology is important as companies must regularly update their processes to produce the latest types of products.

b. Process technology: is the technology used to improve the process of creating goods and services. Examples of this would include computer aided design (**CAD**) and computer-aided manufacturing (**CAM**). These are technologies that use computers to assist engineers in the way they design and manufacture products. Process technologies are important to companies, as they enable tasks to be accomplished more efficiently.

c. Information technology: enables communication, processing, and storage of information. IT has grown rapidly over recent years and has had a profound impact on business. Just consider the changes that have occurred due to the **Internet**. The Internet has enabled electronic commerce and the creation of the virtual marketplace and has linked customers and buyers. Another example of IT is enterprise resource planning (**ERP**), which functions via large software programs used for planning and coordinating all resources throughout the entire enterprise. ERP systems have enabled companies to reduce costs and improve responsiveness but are highly expensive to purchase and implement. Consequently, as with any technology, investment in ERP needs to be a strategic decision.

2.6.2 Technology as a Tool for Competitive Advantage

Technology can be acquired to improve processes and maintain up-to-date standards. Technology can also be used to gain a competitive advantage. For example, by acquiring technology a company can improve quality, reduce costs, and improve product delivery. This can provide an advantage over the competition and help gain market share. However, investing in technology can be costly and entails risks, such as overestimating the benefits of the technology or incurring the risk of obsolescence due to rapid new inventions.

Technology should be acquired to support the company’s chosen competitive priorities, not just to follow the latest market fad. Also, technology may require the company to rethink its strategy.

For example, when the Internet became available, it was generally assumed that it would replace traditional ways of doing business. This has not turned out to be the case. In fact, for many companies the Internet has enhanced traditional methods. Physical activities such as shipping, warehousing, transportation, and even physical contact must still be performed. As you can see, acquiring technology is an important strategic decision for companies. Operations managers must consider many factors when making a purchase decision.

Self check Questions

I Multiple Choice Questions

1. In business, there are several types of business organization, what are these?

A. Private

B. Public and Voluntary

C. Voluntary and Private

D. Public, Private and Voluntary

2. Strategic decision making can take place at various levels of an organization, what are the three most common?

A. Operational, board, and industrially

B. Governmental, locally, and individually

C. Corporate, Business, and Functional

D. Board of Directors, Chief Executive, and Junior Management

3. Which of the following is not typically considered to be a core competency?

A. Workforce

B. Mission

C. Market understanding

D. Technology

E. Facilities

4. Order winners and qualifiers:

A. Are consistent between manufacturing and service organizations

B. Only matter when responding to formal competitive bid requests

C. Remain constant over time

D. Change over time

E. Only apply to quasi-manufacturing firms

II Short answer questions

1. What is strategy?
2. What is the difference between a ‘top-down’ and a ‘bottom-up’ view of operations strategy?
3. What is the difference between a ‘market requirements’ and an operations resource’ view of operations strategy?
4. How can an operations strategy be put together?

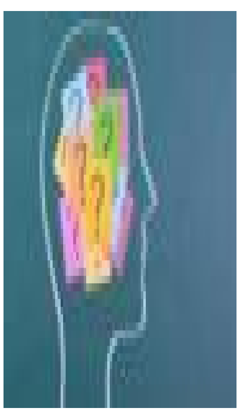
CHAPTER -THREE

DESIGN OF THE OPERATION SYSTEM

Learning Objectives:

After reading this unit, you should be able to:

- Define the term design
- Explain the objectives of design
- Distinguish product design and service design
- Explain the product development process
- Explain the factors(techniques) to be considered while designing the product
- Understand the factors to be considered while designing service
- Appreciate the concepts of process design
- Appreciate the concept of facility location and facility layout
- Understand when does a location decision arise
- Explain the location options
- Determine the factors that affect location decision and facility layout
- Understand methods of evaluating potential locations
- Explain the types of lay out
- Explain the concepts of line balancing
- Understand the meaning of work measurement
- Explain method of time study



Key Brain Storming questions

- Why is good product and service design important?
- What are the stages in product and service design?
- Why should product and service design and process design be considered interactively?
- How should interactive design be managed?

3.1 PRODUCT AND SERVICE DESIGN

3.1 .1 What Is Design?

Design is the process of structuring of components parts /activities of products so that as a unit it can provide value for the customer. Product is designed in terms of size, color, shape, content and other related dimensions. Design greatly affects operation by specifying the products that will be made and it is the prerequisite for operations to occur.

Who is responsible for developing design?

It is generally true that design decision is not the sole responsibility of operations department. What to produce rather is an interactive decision of: marketing, purchasing, finance, engineering, etc. and involves active participations of customers, suppliers, creditors, government agencies and other stakeholders.

For example, the financial division must raise capital and prepare budgets for research and development of new products and processes as well as for the other large expenditures that may be necessary. The legal department must review warranty information and assess potential product liability during the product design process. The purchasing department must interact with the engineering groups to determine what materials are required to produce the products so that appropriate vendors are selected. All these activities require good communication and coordination from initial product design stage through the introduction of the product in to the market.

Generally, new product decisions affect not only the production system, but other functional units in the organization as well. Through close cooperation between operations, marketing and other functions, the design can be integrated with dimensions regarding process, quality, capacity and inventory.

3.1.2 Objectives of design

The objectives of design may vary from situations to situations and from organization to organization. An obvious reason includes:

- To be competent (by offering new products or services).
- To reduce cost and increase profit.
- To develop new products or services as alternatives to downsizing.
- To design products/services that have customer appeal
- To increase quality and level of customer satisfaction

3.1.3. Reason for product design or redesign

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. When productivity gains result in the need for fewer workers, developing new products or services can mean adding jobs and retaining people instead of letting them go. 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. The desire to achieve cost reductions in labor or materials can also be a motivating factor.

Self check questions

1. What we design?
2. Design is strategic decision. Explain
3. Who is responsible for product design?.
4. Design answer the question what to produce. Do you agree?
5. How design and redesign reduce cost

3.1.4 Philosophies towards product design and development

There are three fundamentally different ways to introduce new products.

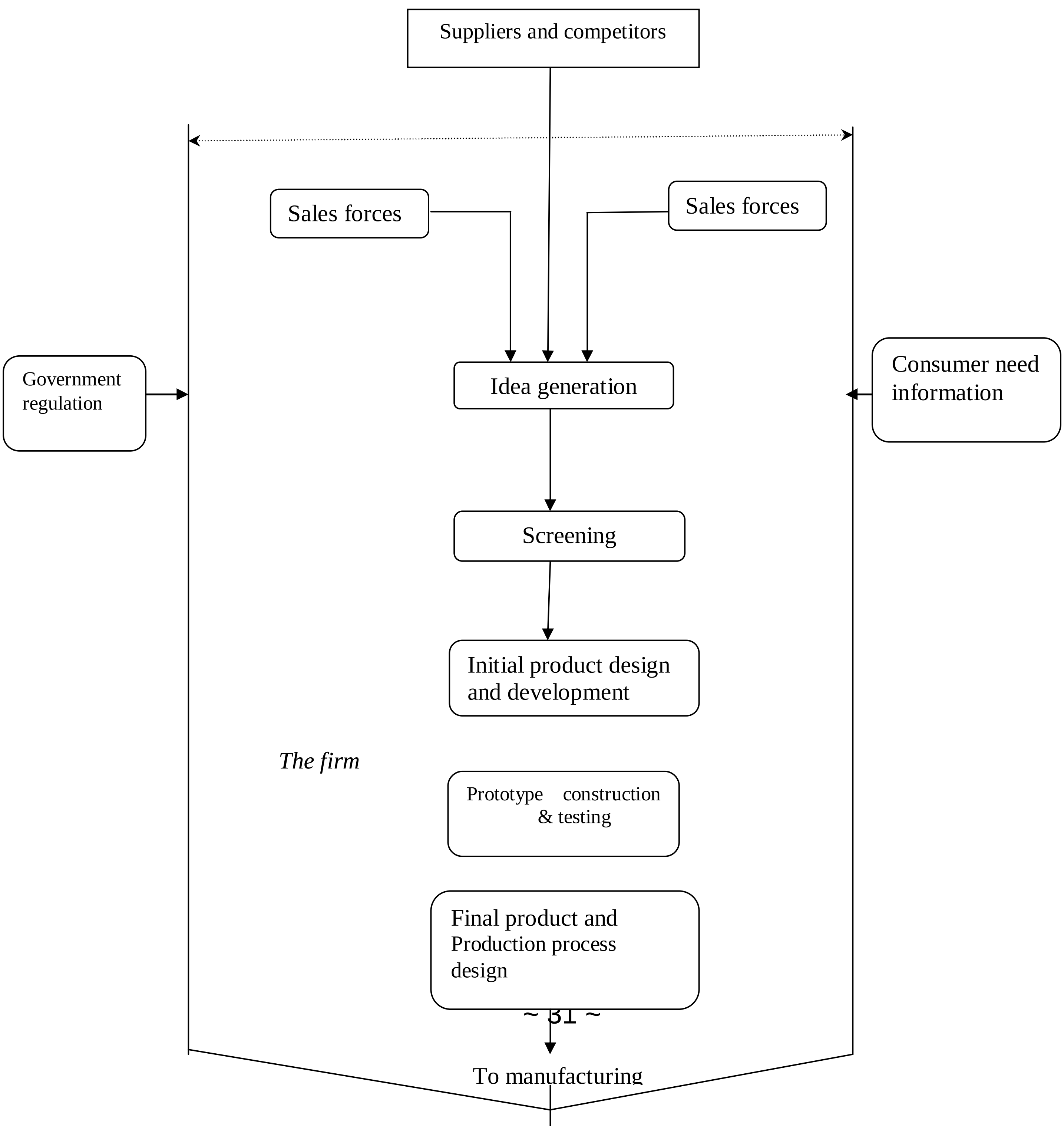
I. *Market pull*: according to this view, the market is the primary basis for determining the products a firm should make with little regard to the existing technology. Customer's wants and needs play the primary role for new product development and design. A firm should make what it can sell. So it is required to undertake customers' survey and market research to determine customer's need.

II. *Technology push philosophy*: in this view, technology is the primary determinant of the product that the firm should make with little regard for the market. One should sell what can be produced i.e. the existing technology determine what kind of product to be produced .The assumption is that the firm should pursue a technology based advantages by developing superior technology and products. The products are pushed to the market and the marketing's job is to create demand for these superior products.

III. *Inter functional philosophy*: stated that product design and development is neither market pull nor technology push. Rather it is inter functional and interactive process of customers, marketing, finance, engineering and other related functional areas.

3.1.5 Product development process

Product development is not a single step, but rather, it is the result of sequential activities. The following explanation introduces the basic steps that one should pass through while developing new product.



Step 1: Idea generations: The first step to develop new product is to generate as much ideas as one can. Ideas for new products can rise from a variety of sources within and external to the firm. Let us see the common source of ideas.

- ***Customer*:** customers are the principal source to generate new ideas. A product is useless if nobody wants it. Manufacturers are always trying to develop new products that meet the needs and demands of customers. Marketing can tap this source of ideas in a number of ways, such as the use of focus group, surveys, and the analysis of buying patterns.
- ***Competitors*:** are other important sources of ideas. By studying the competitors product or service and how it operates (e.g. pricing policies, return polices, warranties and so on), an organization can learn a great deal that can help to achieve design improvement. Beyond that some companies buy competitor's newly designed product the moment it appears on the market. Using the procedure called ***reverse engineering*** them then carefully dismantles and inspects the product which may uncover product improvement that can be incorporated in their own product.
- ***Research and development(R&D)*:** plays an important role in developing new products and advancing technologies. The purpose of R$D is to generate new ideas and concepts and to develop these ideas and concepts in to useful products.
- ***New technology*:** another source of new ideas is new technology. In 1970s, for example, the development of semiconductors, microchips, and microprocessors revolutionized the electronic industries. This leads to many improvements in the design and functions of numerous items such as television sets and business machines. These new innovations replaced products based on older technologies. Also, entirely new products such as home video equipments, electronic games, and many others were created.

Step 2: Screening: not all new ideas should be developed in to new products and hence the second step is screening. The purpose of screening is to eliminate ideas that do not appear to have a high potential for success and there for avoid expensive development costs. It is not uncommon for development costs to run as high as 50 to 60 percents of the total cost of producing a new product.

Generally three major criteria (feasibility study) are used in initial screening.

Market feasibility, financial feasibility and technical feasibility

Evaluate the new ideas in terms of whether the product has market or not as the market feasibility proposed, does the product confirm the design objective as per the technical design(availability of technology and skilled labor), and how well the product quality performance and costs confirm to the design objectives. Before a new product idea is put in to preliminary design, it should be subjected to analysis organized around these three tests. After initial development, more extensive analysis may be conducted through test market and pilot operations before a final operation is made to introduce the product.

To assist in product analysis, several methods have been developed. One is a check list scoring method that involves developing a list of factors along with a weight for each. If the total score is above a certain minimum level the new product idea may be selected for further development. Alternatively, the method may be used to rank product ideas in priority order for selection.

Screening by check list: by this formula the weights have been multiplied by the product characteristic scores and added. See the following example.

Product characteristics	*poor*	Fair	Good	Very good	Excellent	Weight
Selling price		♣				15
Product quality				♣		10
Sales volume			♣			20
Operations computability	♣					10
Competitive advantage		♣				10
Technical compatibility				♣		25
Fit with strategy				♣		20
						100%

Each rating in the table is valued as follows: poor =1, fair=2, good=3, v.good=4, excellent=5

The total weight in the example can be evaluated as follows:

$$(0.15x2)+(0.1x4)+(0.2x3)+(0.1x1)+(0.1x4)+(.15x2)+(0.2x4)=2.9$$

Step 3: Initial (preliminary) product design

This stage of the product -design process is concerned with developing the best design for the new product ideas. It is the translation of ideas in to products. At this stage only a bare bones of a product will be defined. Preliminary product design must specify the product completely. At the end of the product design phase, the firm has a set of product specifications and engineering drawing (or computer image) specified in sufficient detail that production prototype can be built and tested. In the preliminary design tradeoffs between cost, quality and product performances are considered. The result should be a product design which is competitive in the market place and produce able by operations.

Step 4: Prototype construction: if the preliminary product design is approved, a prototype/s may be built for further testing and analysis. Several prototypes which closely resembles with the final products may be made by hand from some artificial materials such as plastics, mud, clay, wood etc. For example**,** the auto industry regularly makes clay models of new automobiles.

Step 5: Prototype testing: A model is tested for its physical properties or uses under actual operating conditions. Testing of prototypes is aimed at verifying marketing and technical performance. One way to assess market performance is to build enough prototypes to support a test market for the new product. The purpose of a test market is to gather quantitative data on customer acceptance of the new product. Prototype is also tested for technical product performance. In general, such testing is important in uncovering any problems and correcting them prior to full scale production.

For example, auto manufacturer perform extensive road tests on new models; similar experiments are performed on tires, airplanes, and sports equipments. Prototype testing for many consumer product such as food or laundry product may consist of consumer panels which judge the product as typical consumers.

Step 6: Final product design: prototype testing may indicate certain changes in the preliminary product design. If changes are made the product may be tested further to ensure final product performance. During the final phase these changes are incorporated in to the design specification. Drawing and specifications for the product are to be developed at this stage. And go for full scale operations.

The process of new product development described so far can be thought of as a filter. A great many ideas originate at the beginning, but only a few are successfully introduced to the market as a product. David Uman has depicted this process of elimination graphically as shown below. The greatest reduction takes place before preliminary product design begins. Thus one must place great weight on the initial screening phase.

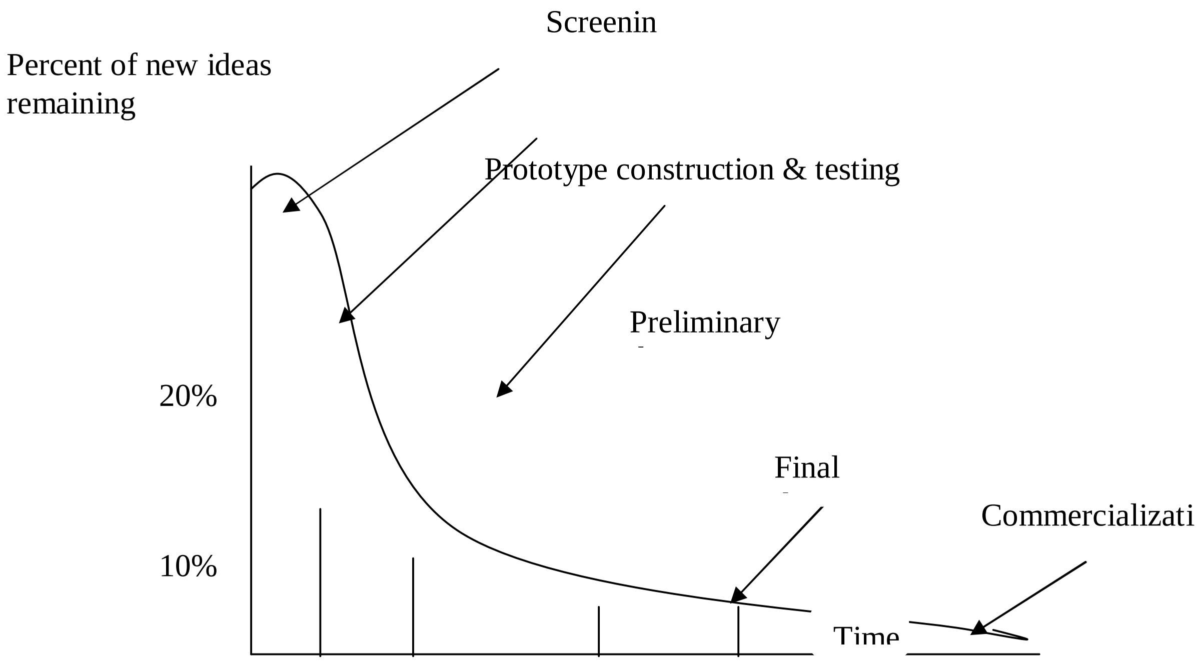


Fig. Mortality (survival) curve of new product ideas

NB: In actual practice, the new product development process does not proceed sequentially from beginning to end; some steps may skipped and others may be repeated several times.

Self check questions

1. What is reverse engineering?
2. What is prototype?
3. List new product development stage.
4. What is mortality curve?
5. What are the bases to conduct feasibility study?
6. Why prototype is developed?

3.1.6 Product design techniques

This section provides an overview of various approach or techniques to product design.

1. **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) which can be assembled in to 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. Controlling the number of different components which go in to products is of great importance to operations, since this makes it possible to produce more efficiently in longer runs while also allowing standardizations of process and equipment.

2. Robust design*:*

Some products will perform as designed only within a narrow range of conditions, while other product will as designed over a broader range of conditions. The latter case describes a product that has robust design. Consider a pair of fine leather boots-obviously not made for walking through mud or snow. Now consider a pair of heavy rubber boots-just used for mud or snow. The rubber boots have a design that is more robust than the fine leather boots. *The more the robust a product is, the less likely that it will fail due to a change in the environment in which it is used or in which it perform.*

3. Sequential engineering

Traditionally, products were designed and manufactured following the sequential engineering methods, where people from different departments work one after the other on successive phases of development. This method of production is in a linear format. The different steps are done one after another, with all attention and resources focused on that one task. After it is completed it is left alone and everything is concentrated on the next task. The product is first completely defined by the engineering design department, and then the manufacturing department take over and define the manufacturing process, etc. This was a lengthy process, and often led to a lot of design changes as the prototype testing began, due to production problems, delays or design flaws. This is therefore a slow and costly approach, often leading to a low-quality and less competitive product.

4. 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.*

This approach is intended to cause the developers, from the outset, to consider all elements of the product life cycle from conception through disposal, including quality, cost, schedule, and user requirements. This results in the product development team clearly understanding what the product requires in terms of mission performance, environmental conditions during operation, budget, and scheduling. In this method, several teams within an organization work simultaneously to develop new products and services and this therefore allows a more streamlined approach. Decision making involves full team participation and involvement. The team often consists of product design engineers, manufacturing engineers, marketing personnel, purchasing, finance, and suppliers, and the role of the leader is to supply the basic foundation and support for change, rather than to tell the other team members what to do.

In concurrent engineering, different tasks are tackled at the same time, and not necessarily in the usual order. This means that info found out later in the process can be added to earlier parts, improving them, and also saving a lot of time. Examples from companies using Concurrent Engineering techniques show significant increases in overall quality, 30-40% reduction in project times and costs, and 60-80% reductions in design changes after release.

Using concurrent engineering is preferable than sequential/hierarchical engineering. In general, concurrent engineering states that, while designing the product consider the following points simultaneously.

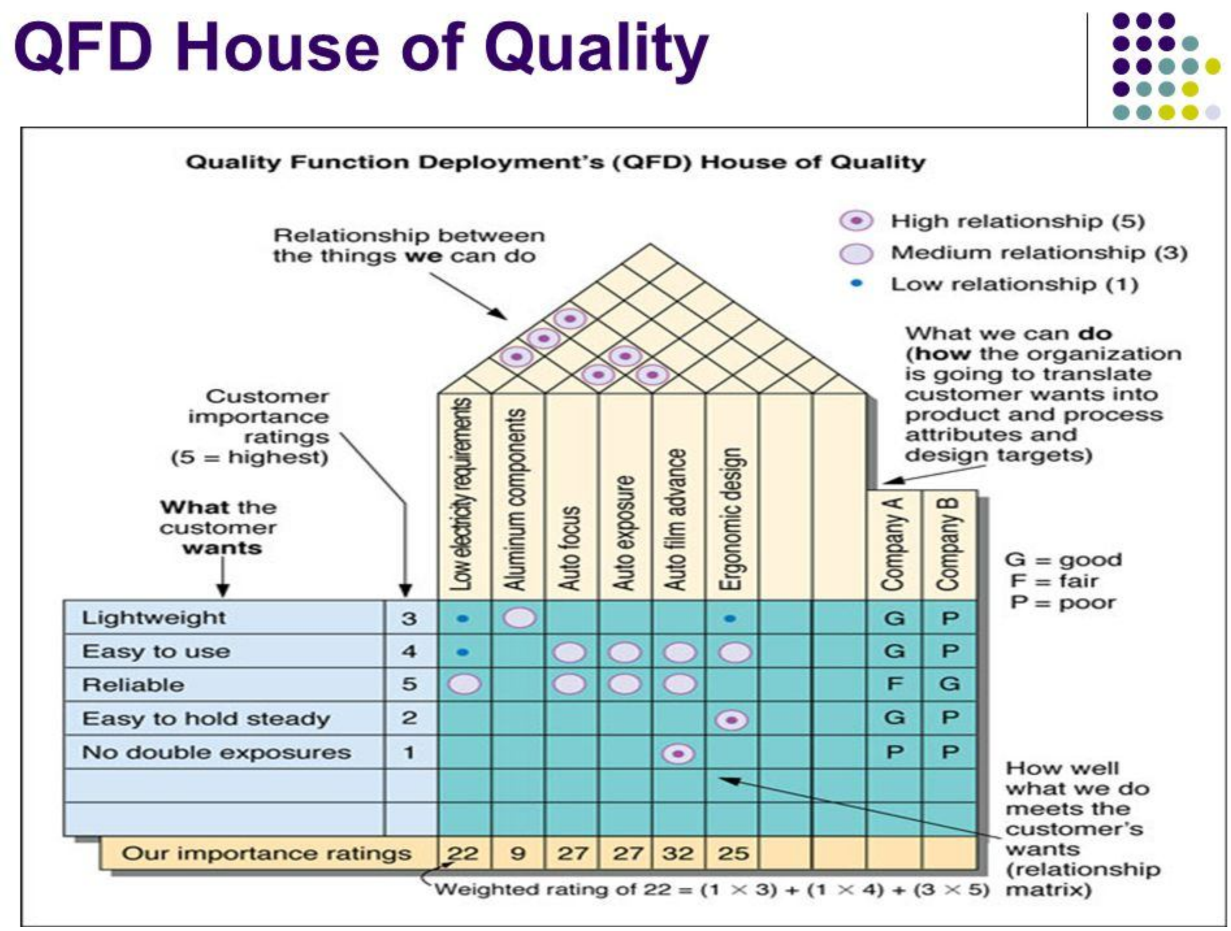
5. Quality function deployment (QFD)

Making design decisions concurrently rather than sequentially requires superior co-ordination amongst all the participants involved in designing, producing, procuring and marketing. QFD is a powerful tool that translates voice of the customer into design requirements and specifications of a product. It is uses inter-functional teams from design, marketing and manufacturing.

QFD process begins with studying and listening to customers to determine the characteristics of a superior product. Through marketing research, the consumers product needs and preferences are defined and broken down into categories called “Customer Requirements” and they are weighed based on their relative importance to the customer.

Customer requirements information forms the basis for a matrix called ***house of quality***. By building house of quality matrix, the cross functional QFD teams can use customer feedback to make a engineering, marketing and design decisions.

The matrix helps to translate customer requirements in to concrete operating or engineering goals. QFD is a communication and planning tool that promotes better/understanding of customer demands, promotes better understanding of design interactions, involves manufacturing in the design process and provides documentation of the design process.



6. Design for manufacturability (DFM):

Design for manufacturability (also sometimes known as **design for manufacturing** or **DFM**) is the general engineering practice of designing products in such a way that they are easy to manufacture. The concept exists in almost all engineering disciplines, but the implementation differs widely depending on the manufacturing technology. DFM describes the process of designing or engineering a product in order to facilitate the manufacturing process in order to reduce its manufacturing costs. DFM will allow potential problems to be fixed in the design phase which is the least expensive place to address them. Other factors may affect the manufacturability such as the type of raw material, the form of the raw material, dimensional tolerances, and secondary processing such as finishing.

Manufacturability refers to the ease with which the product can be manufactured. Three concepts are closely related to designing for easy of production. These are:

- ***Simplifications***: is a design or redesign strategy that improves the manufacturability, serviceability, or reliability of a product or service by reducing the complexity of its design. Often a product or parts may be needlessly complex because of a designers or product engineer's bias toward technological sophistication or perhaps because of incremental design changes that have been made over a period of years.
- ***Specifications***: is a detail description of material, parts, or products including physical dimensions. These specifications profiled production department with precise information about the characteristics of products to be produced.
- ***Standardization***: refers to a design activity that reduce variety amount a group of product or parts. Standardization of groups of products or parts usually results in higher volume for each product or part model which can leads to lower production costs, higher product quality, greater ease of automation, and lower inventory investment.

7. Design for procurement:

Is another strategy used in concurrent engineering. It places explicit considerations of component parts supply during the initial development of product- service design. What is the supply base for the required component parts? What is the capacity of that supply base? At what cost can parts be made and at what level of conformance quality? Design for procurement extends the DFM concepts to the early stage in the creations of value, before in-house production begins.

8. Design for environment:

Is a product development approach that broadens the concepts of design for manufacturability even further to include the environmental impact of a design, from the extraction of raw materials to their disposals.

9. Design for disassembly:

Design for disassembly has become increasingly important in the context of the extensive environmental regulation with which business must now comply. More and more, manufacturers are beginning to understand and accept the fact that they are responsible for the item they make from start to finish. In Germany, a law has been passed that requires manufacturers to recover all the non consumable materials used in their products. Soft drinks and beer makers have had little difficulty in meeting the requirement, but automobile manufacturers have found it to be a problem. As a result BMW has designed the first completely recyclable car. Using a design for disassembly philosophy today can help to prevent such environmental liabilities.

10. Group technology (GT):

According to Schroeder, GT groups parts or products with similar characteristics in to families, and sets aside groups of machines for their productions. Families may be based on size, shape, manufacturing, (or routing) requirement or demand. The goal is to identify a set of products with similar processing requirements and minimize machine changeovers or setups. For example all bolts might be assigned to the same family because they all require the same basic processing steps regardless of the size or shape. According to Mark D. Hannan, GT is an engineering and manufacturing strategy based on the development and exploitations of commonalities among parts, equipments, or processes. For instance, a company that makes metal parts might group its products according to shape and the type of metal or alloy they are made of.

11. Value analysis(VA) and Value engineering(VE)*:*

The term VE and VA are used almost interchangeably but they are not identical. Value engineering focuses on pre- production design improvement while VA (even though is a related techniques) takes place during the production process when it is clear that a new product is a success. Both VE and VA are an important and powerful approach for improvement in the performance of the product, system, or procedure and reduction in cost without jeopardizing their function.

The basic objective of VE &VA is to achieve equivalent or better performance at a lower cost while maintaining all functions and quality requirements. It does this largely by identifying and eliminating hidden, invisible, and unnecessary cost. VE & VA should not be treated as a mere cost reduction techniques or cheapening of the product. It is more comprehensive and the improvement in value is attained without any sacrifices in quality, reliability, maintainability, availability, aesthetics etc.

12. Computer aided design (CAD) & computer aided manufacturing (CAM)

CAD is an electronic system for designing new parts or products or altering existing ones, replacing drafting traditionally done by hand. The heart of CAD is a powerful desktop computer and graphics soft ware that allow a designer to manipulate geometric shapes. The designer can create drawings and view them from any angle on a display monitor. Thus, this system allows a user to create visual display on a computer terminal screen. Using the design data stored in the computer's memory, manufacturing engineers and other users can quickly obtain print outs of plan and specifications for a part or product. CAD cut the cost of product development and sharply reduces the time to market for new products.

CAM is an electronic system which is used to design production process and control machine tools and material flow through programmable automation.

CAD /CAM integrate the design and manufacturing functions by translating final design specification in to detailed machine instruction for manufacturing an item. CAD/CAM is quicker , less error prone than human, eliminate duplications between engineering and manufacturing, allow engineers to see how the various parts of a design interact with each other without having to build a prototype.

13. Taguchi's approach:

Japanese engineer Genichi Taguchi's approach is based on the robust design. His premise is that it is often easier to design a product that is insensitive to be environmental factors, either in manufacturing or in use, than to control the environmental factors. The central feature of Taguchi's approach-and the feature used most often by U.S. companies-is parameter design. This involves determining the specification settings for both the product and the process that will result in robust design in terms of manufacturing variations, product deterioration, and conditions during use.

The Taguchi approach modifies the conventional statistical methods of experimental design. Consider this example. Suppose a company will use 12 chemicals in a new product it intends to produce. There are two suppliers for these chemicals, but the chemical concentrations vary slightly between the two suppliers. Classical design of experiments would require 2^{12} = 4,096 test runs to determine which combination of chemicals would be optimum. Taguchi's approach would involve only testing a portion of the possible combinations. Relying on experts to identify the variables that would be most likely to affect important performance, the number of combinations would be dramatically reduced, perhaps to, say, 32. Identifying the best combination in the smaller sample might be a near-optimal combination instead of the optimal combination. The value of this approach is its ability to achieve major advances in product or process design fairly quickly, using a relatively small number of experiments. Critics charge that

Taguchi's methods are inefficient and incorrect, and often lead to non optimal solutions. Nonetheless, his methods are widely used and have been credited with helping to achieve major improvements in U.S. products and manufacturing processes.

Self help questions

1. ____________ refers to the process of disassembling a product to analyze its structures and features.
   A. Engineering
   B. Re-engineering
   C. Reverse engineering
   D. Concurrent engineering
   E. Assembly line
   F. Disassembly line
   G. Remanufacturing
2. ___________helps the product to perform in broad range of condition
   A. Concurrent engineering
   B. Robust design
   C. Design for procurement
   D. None
3. What is the difference between sequential and concurrent engineering
4. QFD helps to translate customer requirements in to concrete operating or engineering goals. Do you agree?
5. What do mean by module?
6. What are some of the competitive advantages of concurrent engineering?

3.1.7 Issues in Product Design

1. Standardization

An important issue that often arises in both product/service design and process design is the degree of standardization. Standardization refers to the extent to which there is absence of variety in a product, service, or process. Standardized products are made in large quantities of identical items; calculators, computers, and beers are examples. Standardized service implies that every customer or item processed receives essentially the same service. An automatic car wash is a good example; each car, regardless of how clean or dirty it is, receives the same service. Standardized processes deliver standardized service or produce standardized goods.

Standardization carries a number of important benefits as well as certain disadvantages. Standardized products mean *interchangeable parts,* which greatly lower the cost of production while increasing productivity and making replacement or repair relatively easy compared with that of customized parts. Design costs are generally lower. For example, General Motors recently has attempted to standardize key components of its automobiles across product lines; components such as brakes, electrical systems, and other "under-the-skin" parts would be the same for all GM car models. By reducing variety, GM saves time and money while increasing quality and reliability in its products. Another benefit of standardization is reduced time and cost to train employees and reduced time to design jobs. Similarly, scheduling of work, inventory handling, and purchasing and accounting activities become much more routine.

Standardization also has disadvantages. A major one relates to the reduction in variety. This can limit the range of customers to whom a product or service appeals. Customers may reluctantly accept a product only because nothing else suits their needs. But that creates a risk that a competitor will introduce a better product or greater variety (a feature of lean production), and realize a competitive advantage. Another disadvantage is that a manufacturer may freeze (standardize) a design prematurely and, once frozen, it may find compelling reasons to resist modification. A familiar example of this is the keyboard arrangement of typewriters and computer keyboards. Studies have demonstrated that another arrangement of keys would be more efficient, but the cost of replacing all of the equipment in existence and retraining millions of typists and word processors would not be worth the benefit. Obviously, designers must consider important issues related to standardization when making choices.

2. Customization

Companies like standardization because it enables them to produce high volumes of relatively low-cost products, albeit products with little variety. Customers, on the other hand, typically prefer more variety, although they like the low cost. The question for producers is how to resolve these issues without (1) losing the benefits of standardization and (2) incurring a host of problems that are often linked to variety. These include increasing the resources needed to achieve design variety; increasing variety in the production process, which would add to the skills necessary to produce products, causing a decrease in productivity; creating an additional inventory burden during and after production, by having to carry replacement parts for the increased variety of parts; and adding to the difficulty of diagnosing and repairing failed products. The answer, at least for some companies, is mass customization, a strategy of producing standardized goods or services, but incorporating some degree of customization in the final product or service. Several tactics make this possible. One is *delayed differentiation,* and another is *modular design*

I. **Delayed differentiation** is a postponement tactic: the process of producing, but not quite completing, a product or service, postponing completion until customer preferences or specifications are known. There are a number of variations of this. In the case of goods, almost-finished units might be held in inventory until customer orders are received, at which time customized features are incorporated, according to customer requests. For example, furniture makers can produce dining room sets, but not apply stain, allowing customers a choice of stains. Once the choice is made, the stain can be applied in a relatively short time, thus eliminating a long wait for customers, giving the seller a competitive advantage. Similarly, various e-mail or Internet services can be delivered to customers as standardized packages, which can then be modified according to the customer's preferences. The result of delayed differentiation is a product or service with customized features that can be quickly produced, appealing to the customers' desire for variety and speed of delivery, and yet one that for the most part is standardized, enabling the producer to realize the benefits of standardized production. This technique is not new. Manufacturers of men's clothing, for example, produce suits with pants that have legs that are unfinished, allowing customers to tailor choices as to the exact length and whether to have cuffs or no cuffs. What is new is the extent to which business organizations are finding way to incorporate this concept into a broad range of products and services.

II. **Modular design** is a form of standardization. Modules represent groupings of component parts into subassemblies, usually to the point where the individual parts lose their separate identity. One familiar example of modular design is computers which have modular parts that can be replaced if they become defective. By arranging modules in different configurations, different computer capabilities can be obtained. For mass customization, modular design enables producers to quickly assemble modules to achieve a customized configuration for an individual customer, avoiding the long customer wait that would occur if individual parts had to be assembled. Modular design is also found in the construction industry. One firm in Rochester, New York, makes prefabricated motel rooms complete with wiring, plumbing, and even room decorations in its factory and then moves the complete rooms by rail to the construction site where they are integrated into the structure.

One advantage of modular design of equipment compared with non modular design is that failures are often easier to diagnose and remedy because there are fewer pieces to investigate. Similar advantages are found in ease of repair and replacement; the faulty module is conveniently removed and replaced with a good one. The manufacture and assembly of modules generally involves simplifications: fewer parts are involved, so purchasing and inventory control become more routine, fabrication and assembly operations become more standardized, and training costs often are relatively low.

The main disadvantages of modular design stem from the decrease in variety: the number of possible configurations of modules is much less than the number of possible configurations based on individual components. Another disadvantage that is sometimes encountered is the inability to disassemble a module in order to replace a faulty part; the entire module must be scrapped-usually at a higher cost.

3. Reliability

Reliability is a measure of the ability of a product, a part, a service, or an entire system to perform its intended function under a prescribed set of conditions. The importance of reliability is underscored by its use by prospective buyers in comparing alternatives and by sellers as one determinant of price. Reliability also can have an impact on repeat sales, reflect on the product's image, and, if it is too low, create legal implications.

The term failure is used to describe a situation in which an item does not perform as intended. This includes not only instances in which the item does not function at all, but also instances in which the item's performance is substandard or it functions in a way not intended. For example, a smoke alarm might fail to respond to the presence of smoke (not operate at all), it might sound an alarm that is too faint to provide an adequate warning (substandard performance), or it might sound an alarm even though no smoke is present (unintended response).

Reliabilities are always specified with respect to certain conditions, called normal operating conditions. These can include load, temperature, and humidity ranges as well as operating procedures and maintenance schedules. Failure of users to heed these conditions often results in premature failure of parts or complete systems. For example, using a passenger car to tow heavy loads will cause excess wear and tear on the drive train; driving over potholes or curbs often results in untimely tire failure; and using a calculator to drive nails might have a marked impact on its usefulness for performing mathematical operations.

4. Recycling

Recycling is sometimes an important consideration for designers. Recycling means re- covering materials for future use. This applies not only to manufactured parts, but also to materials used during production, such as lubricants and solvents. Reclaimed metal or plastic parts may be melted down and used to make different products.

Companies recycle for a variety of reasons, including:

- Cost savings.
- Environment concerns.
- Environmental regulations.

An interesting note: Companies that want to do business in the European Economic Community must show that a specified proportion of their products are recyclable.

The pressure to recycle has given rise to the term design for recycling (DFR), referring to product design that takes into account the ability to disassemble a used product to recover the recyclable parts.

5. **Remanufacturing**

An emerging concept in manufacturing is the remanufacturing of the product. Remanufacturing refers to refurbishing used product by replacing worn out or defective components and reselling the product. This can be done by original manufacturer or another company. Among the products that have remanifurured component are automobiles, printer, copier etc.

There are a number of important reasons for doing this. One is that a remanufactured product can be sold for about 50 percent of the cost of a new product. Another is that the process requires mostly unskilled and semiskilled workers. And in the global market, European lawmakers are increasingly requiring manufacturers to take back used products, because this means fewer products end up in landfills and there is less depletion of natural resources such as raw materials and fuel.

Self check questions

1. Explain the term remanufacturing.
2. What is CAD? Describe some of the ways a product designer can use it.
3. Name some of the main advantages and disadvantages of standardization.
4. What is modular design? What are its main advantages and disadvantages?

3.1.8 Characteristic of good product design

A good product design must ensure the following:

1. ***Function or performance:*** The function or performance is what the customer expects the product to do to solve his/her problem or offer certain benefits leading to satisfaction. For example, a customer for a motor Nbike expects the bike to start with a few kicks on the kick peddle and also expects some other functional aspects such as pick-up, maximum speed, engine power and fuel consumption etc.
2. ***Appearance or aesthetics:*** This includes the style, color, look, feel, etc. which appeals to the human sense and adds value to the product.

3. ***Reliability:*** This refers to the length of time a product can be used before it fails. In other words, reliability is the probability that a product will function for a specific time period without failure
4. ***Maintainability:*** Refers to the restoration of a product once it has failed. High degree of maintainability is desired so that the product can be restored (repaired) to be used within a short time after it breaks down. This is also known as serviceability.
5. ***Availability:*** This refers to the continuity of service to the customer. A product is available for use when it is in an operational state. Availability is a combination of reliability and maintainability. High reliability and maintainability ensures high availability.
6. ***Productibility:*** This refers to the ease of manufacture with minimum cost (economic production). This is ensured in product design by proper specification of tolerances, use of materials that can be easily processed and also use of economical processes and equipments to produce the product quickly and at a cheaper cost.
7. ***Simplification:*** This refers to the elimination of the complex features so that the intended function is performed with reduced costs, higher quality or more customer satisfaction. A simplified design has fewer parts which can be manufactured and assembled with less time and cost. "
8. ***Standardization:*** Refers to the design activity that reduces variety among a group of products or parts. For example, group technology items have standardized design which calls for similar manufacturing process steps to be followed. Standard designs lead to variety reduction and results in economies of scale due to high volume of production of standard products. However, standardized designs may lead to reduced choices for customers.
9. ***Specification:*** A specification is a detailed description of a material, part or product, including physical measures such as dimensions, volume, weight, surface finish etc. These specifications indicate tolerances on physical measures which provide production department with precise information about the characteristics of products to be produced and the processes and production equipments to be used to achieve the specified tolerances (acceptable variations).Interchangeability of parts in products produced in large volumes (mass production and flow-line production) is provided by appropriate specification of tolerances to facilitate the desired fit between parts which are assembled together.

10. ***Safety:*** The product must be safe to the user and should not cause any accident while using or should not cause any health hazard to the user. Safety in storage, handling and usage must be ensured by the designer and a proper package has to be provided to avoid damage during transportation and storage of the product. For example, a pharmaceutical product while used by the patient should not cause some other side effect threatening the user.

3.1.9 SERVICE OPERATION DESIGN

Service is the dominant economic force in the industrialized world today and growth projection indicates this trend will continue. Yet service operation receives far too little emphasis in operation management course and business course in general. Service industry includes banking, insurance, transportation, communication etc.

As discussed in the previous chapter service is an intangible product which is produced and consumed simultaneously. Therefore, services never exist, only the result 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. Thus, service must be produced at the point of consumption. A service product is a process i.e. a methods of doing things. Because of these reasons designing service is challenging than designing manufacturing products.

Generally design of the service is the specifications of how the service should be delivered. Shostack suggest that “blueprint” for services be developed that specify in detail the steps involved in service delivery. These blue prints can be then the basis for job descriptions, employees training programs and performance measurement.

A service blue print is a visual diagram –usually a flow chart-that depicts all of the activities in the service delivery process. As a design tools, they enable management to study and analyze services prior to their actual implementation.

The process of designing a service blueprint involves several steps:

- -*Identifying the sequence of steps*: first it is necessary to map out the sequence of steps that comprise the serve activity. By identifying all operations in the service activity, one can determine what inputs are required and how each operation should be best performed.
- -*Isolating fail points*: once the process is specified, the designer can determine where the system might fail. Design for prevention of failure can then be made.

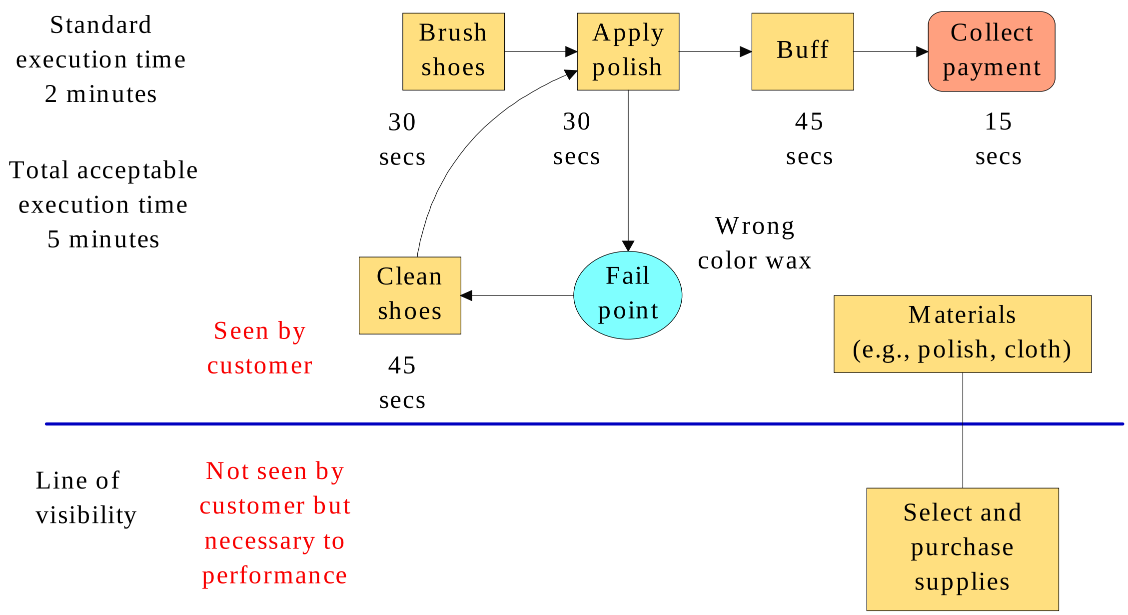
-Establishing time frames: standard time for each activity can be established and costs can then be estimated. Research shows that a customer will tolerate few minutes before lowering his or her assessment of service quality.

-*Analyzing profitability*: by identifying the costs for materials , overheads, and customer services along with forecasts of demand the profitability of the service can be determined; then 'what if' scenarios can be conducted to analyze the sensitivity of profits to changes in costs or pricing structures.

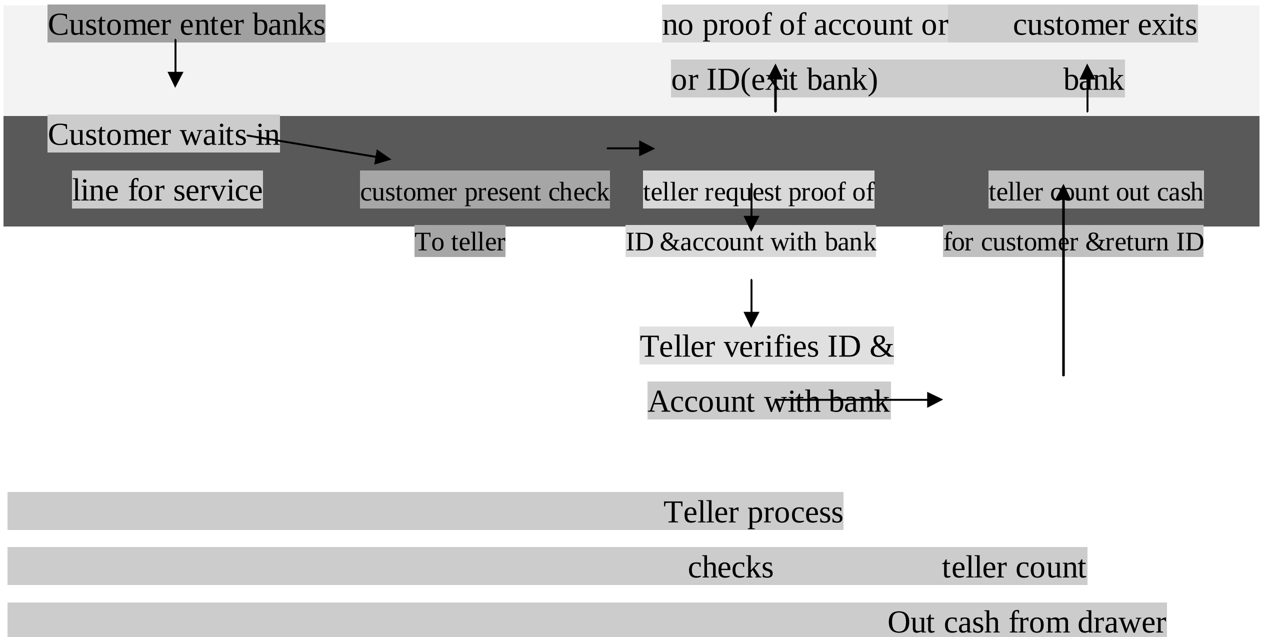
A service blueprint also can be used to redesign the system in order to improve over all services.

Example of service blue print:

a. Shoes polishing process



b. cashing checks in the bank



2.3.4.1. Factors to be considered while designing services

a) Customer contact

Generally, most service operations have high customer contact than manufacturing sector. Customer contact for service operation can be high or low.

If customer contact is high, the customer can disrupt the production process by demanding certain types of services or special treatment. There for high customer contact leads to inefficient production process because of high customer interference. A customer could require special consideration or more processing time and may impose unique requirement in the service provider like in dentist and haircut. All these lead to high degree of inefficiency. A high efficient system is the one with no customer contact, where the order can be processed away from the customer. There for the service designer should identify customer contact points and reduce contacts where appropriate. While designing the service, contact activity should be examined to determine if some elements may be removed from the customer's presence. For example, perhaps a bank teller conducts unnecessary data processing activity during each customer transaction. Such processing activity should be reassigned to 'backroom' areas where they do not interfere with customer service and where they can be more efficiently completed.

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 which drives down costs through standardizing, Prioritizing, and automating processes. Example of low contact system is automatic bank teller transactions.

Characteristics of high-and low- contact services:

- ✓ Low contact in services is used when face to face interaction is not mandatory. High contact operations are used for changing or uncertain 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 customer (the smile factor).
- ✓ High contact services generally require higher prices and more customization due to the variable nature of the service required.

b) ***Service recovery***:

Service recovery is an important part of service design. Service recovery is the ability to quickly compensate for the failure and restore if possible.

c) Cycle of Service

The service provided must be considered not only in a light of a single service encounter but in terms of the entire cycle of service delivery. Every service is delivered in a cycle of services 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 the service delivery. It is the cumulative effect of all of the moments of truth that defines the service provided. Abad moment of truth can cancel out many positive moments. Even when 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.

d) Service guarantee

Many companies are now beginning to offer service guarantees as a way to ensure its satisfactory delivery to the customer. Service guarantee help the service provider to build confidences of the customers towards their service quality level. A service guaranty is like its counterpart the product guarantee, except for one thing: The customer cannot return the service if he/she does not like it. For example, if you did not like your hair cut, you have to live with it that way, until it grows out.

Design guide lines for service

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 purpose.
- ✓ 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 system.

Self check question

1. Service design is more challenging than product design. Why?
2. What is the guide line to design service?
3. What does service guaranty means?
4. How service designs differ from product design?

3.2 PROCESS DESIGN AND SELECTION

3.2.1 Process design

Product design dictates what to produce whereas process design implies how to produce. Processes transform inputs in to outputs. Process flow design, on the other hand, focuses on determining how raw materials, parts, subassemblies, or people flow as they move through the plant. Process design is primarily useful to facilitate analysis by asking why each activity is done and whether it can be improved by eliminating a task, changing the sequence of tasks, combining tasks, or simplifying tasks.

The most common operation management tools used in planning process design are:

- ☞ Assembly drawing
- ☞ Assembly charts
- ☞ Route sheets
- ☞ Flow process charts

An assembly drawing

- It is an exploded view of the product showing its component parts.

An assembly chart

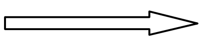
- Uses information provided in the assembly drawing and defines how parts go together, their order of assembly, and the overall material flow pattern.

An operation (or route) sheet

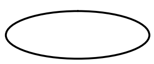
- It specifies the operation and process routing for a particular part. It conveys such information as the type of equipment, tooling, and operations required to complete the part.

A flow process chart

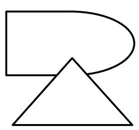
Uses standard American Society of Mechanical Engineers (ASME) symbols to denote what happens to the product as it progresses through the productive facilities. As a rule the fewer the delays and the storage in the process, the better the flow is.



Transportation: movement of product, service or person from one Place to the other.

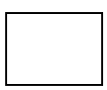


Operation: something is actually being done



Delay: the subject of the study must wait before starting the next step

Storage: the subject is stored, such as finished product in inventory, or Completed papers in a file.



Inspection: the subject is observed for quality and correction

3.2.1 **Process selection**

Process selection decisions determine the type of productive process to be used and the appropriate span of the process. Generally, process selection refers to the way an organization chooses to produce its goods or proved its services. Essentially, process selection requires a thorough understanding of materials and their properties, existing technology, and the desired property of the final product. For example cutting speed depends on the type of materials being cut and the cutting tools (technology) itself. Moreover, marketing factors such as volume demand and product quality are also important factors that influence process selection.

Process selection has major implication for capacity planning, lay out of facility, equipments and design of work systems. Process selection occurs when new products or services are being planned. However it will also occur periodically due to technological or demand changes. Before selecting the process, consider the buying alternatives.

- ***Make or buy decision***:

The very first step in process planning is to consider whether to make or buy some or all of a product or to sub contract some or all of the service. A manufacturer might decide to purchase certain parts rather than make them; some time all parts are purchased, with the manufacturer simply performing assembly operations. Many firms contract out janitorial services, and some contract for repair services. If a decision is made to buy or contract, this lessens (eliminate) the need for process selection.

In make or buy decision, a number of factors are usually considered such as:

- *Availability of capacity (i.e. equipment, skills and tim*e): if the firm has the capacity, it often makes sense to produce an item or perform service in-house.
- *Expertise*: if the firm lacks the expertise to do a job satisfactorily, buying might be reasonable alternative.
- *Quality considerations*: firms that specialize can usually offer higher quality than the organization can attain itself. Conversely, special quality requirement or the ability to closely monitor quality may cause an organization to perform a job itself.
- *The nature of demand*: when demand for an item is high and steady, the organization is often better off doing the work itself. However, wide fluctuations in demand or small order are usually better handled by specialists who are able to combine orders from multiple sources which results in higher volume and tend to offset individual buyer fluctuation.
- *Cost:* any cost savings achieved from buying or making must be weighed against the precedence factors.

If the organization decide to perform some or all of the processing, then the issue of process selection becomes important

3.2.2 Types of processes

In this section we will focus on the two main types of process classifications. First a process is classified by type of product flow. Second a process can be classified by type of customer order. Let us see each classification.

A) process classification based on the 'type of product flow'

There are five basic process types: *job shop, batch, repetitive, continuous, and project*.

1. **Job shop/ intermittent production**

Job-shop production are characterized by manufacturing one or few quantity of products designed and produced as per the specification of customers within prefixed time and cost. The distinguishing feature of this is ***low volume*** and ***high variety*** of products. A job-shop comprises of ***general-purpose machines*** arranged into different departments. Each job demands unique technological requirements, demands processing on machines in a certain sequence.

A job shop usually operates on a relatively ***small scale***. It is used when a low volume of high-variety goods or services will be needed. Processing is intermittent; work shifts from one small job to the next, each with somewhat different processing requirements. High flexibility of equipment and skilled workers are important.

Example: machine shop, furniture, restaurant, hospital, custom jewelry.

Characteristics of a job shop.

- High variety of products and low volume.
- Use of general purpose machines and facilities.
- The storage cost per unit is higher due to jumbled flow pattern
- Variable path material handling equipment like carts, lift trucks, and cranes are used
- The marketing effort is directed toward getting and filling individual customers for varied products.
- Highly skilled operators who can take up each job as a challenge because of uniqueness.
- Large inventory of materials, tools, parts.
- Detailed planning is essential for sequencing the requirements of each product, capacities for each work centre and order priorities.

Advantages

Following are the advantages of Job-shop Production:

- Because of general purpose machines and facilities variety of products can be produced.
- Operators will become more skilled and competent, as each job gives them learning opportunities.
- Full potential of operators can be utilized.
- Opportunity exists for Creative methods and innovative ideas.

Limitations

Following are the limitations of Job-shop Production:

- Higher cost due to frequent set up changes.
- Higher level of inventory at all levels and hence higher inventory cost.
- Production planning is complicated.
- Larger space requirements.

2. **Batch processing**

Is used when a moderate volume of goods or services is desired, and it can handle a moderate variety in products or services. The equipment need not be as flexible as in a job shop, but processing is still intermittent. The skill level of workers doesn't need to be as high as in a job shop because there is less variety in the jobs being processed. Examples of batch systems include bakeries, which make bread, cakes, or cookies in batches; movie theaters, which show movies to groups (batches) of people; and airlines, which carry planeloads (batches) of people from airport to airport. Other examples of products that lend themselves to batch production are paint, ice cream, soft drinks, beer, magazines, and books. Other examples of services include plays, concerts, music videos, radio and television programs, and public address announcements.

Batch Production is characterized by

- Shorter production runs.
- Plant and machinery are flexible.
- Plant and machinery set up is used for the production of item in a batch and change of set up is required for processing the next batch.
- Manufacturing lead-time and cost are lower as compared to job order production.

Advantages

Following are the advantages of Batch Production:

- Better utilization of plant and machinery.
- Promotes functional specialization.
- Cost per unit is lower as compared to job order production.
- Lower investment in plant and machinery.
- Flexibility to accommodate and process number of products.
- Job satisfaction exists for operators.

Limitations

Following are the limitations of Batch Production:

- Material handling is complex because of irregular and longer flows.
- Production planning and control is complex.
- Work in process inventory is higher compared to continuous production.
- Higher set up costs due to frequent changes in set up.

3. Repetitive

When higher volumes of more standardized goods or services are needed, repetitive processing is used. The standardized output means only slight flexibility of equipment is needed. Skill of workers is generally low. Examples of this type of system include production lines and assembly lines. In fact, this type of process is sometimes referred to as assembly. Familiar products made by these systems include automobiles, television sets, pencils, and computers. An example of a service system is an automatic carwash. Other examples of service include cafeteria lines and ticket collectors at sports events and concerts.

4. Continuous

When a very high volume of highly standardized output is desired, a continuous system is used. These systems have almost no variety in output and, hence, no need for equipment flexibility. Production facilities are arranged as per the sequence of production operations from the first operations to the finished product. The items are made to flow through the sequence of operations through material handling devices such as conveyors, transfer devices, etc. As in assembly systems, workers are generally low skilled. Examples of products made in continuous systems include petroleum products, steel, sugar, flour, and salt. Continuous services include air monitoring, supplying electricity to homes and businesses, and the Internet.

Continuous Production is characterized by:

- Dedicated plant and equipment with zero flexibility.
- It usually yields a lower unit cost for the product or service being produced due to economics of scale.
- Storage costs per unit are usually lower, as work in progress inventories move through the plant very quickly.
- The time required for production is very shorter

- fixed path material handling equipment like conveyers, and rails are mostly used
- It requires large investment because it uses special purpose machines etc.
- The marketing effort focuses on developing distribution channels for the large volume of output and persuading customers to accept standardized products.
- Material handling is fully automated.
- Process follows a predetermined sequence of operations.
- Component materials cannot be readily identified with final product.
- Planning and scheduling is a routine action.
- there is a linear sequence of operation with some side flow (if necessary)
- The product is well standardized and must flow from one workstation to the next in a prescribed sequence.

Advantages

Following are the advantages of Continuous Production:

- Standardization of product and process sequence.
- Higher rate of production with reduced cycle time.
- Higher capacity utilization due to line balancing.
- Manpower is not required for material handling as it is completely automatic.
- Person with limited skills can be used on the production line.
- Unit cost is lower due to high volume of production.

Limitations

Following are the limitations of Continuous Production:

- Flexibility to accommodate and process number of products does not exist.
- Very high investment for setting flow lines.
- Product differentiation is limited.

These process types are found in a wide range of manufacturing and service settings. The ideal is to have process capabilities match product or service requirements. Failure to do so can result in inefficiencies and higher costs than are necessary, perhaps creating a competitive disadvantage
Another consideration is that products and services often go through life cycles that begin with low volume, which increases as products or services become better known. When that happens, a manager must know when to shift from one type of process (e.g., job shop) to the next (e.g.,

batch). Of course, some operations remain at a certain level (e.g., magazine publishing), while others increase (or decrease as markets become saturated) over time. Again, it is important for a manager to assess his or her products and services and make a judgment on whether to plan for changes in processing over time.

All of these process types (job shop, batch, repetitive and continuous) are typically on- going operations. However, there are situations that are not ongoing but instead are of limited durations. In such instances, the work is often organized as a project.

5. **Project**

Is used for work that is no routine, with a unique set of objectives to be accomplished in a limited time frame. A project process is one in which there is a very high degree of customization and the job is undertaken to meet specific requirements. Each project is unique. Project process is valued more on the basis of their capabilities to do certain kinds of jobs, rather than to produce specific products at low cost. They tend to take a long time to complete the work. It involves several inter related tasks that must be completed. Resources needed for a project are brought together at the beginning of the project and are disbanded once the project is over.

Examples range from simple to complicated, including such things as putting on a play, consulting, making a motion picture, launching a new product or service, publishing a book, building a dam, and building a bridge. Equipment flexibility and worker skills can range from low to high.

Note: The processes discussed do not always exist in their "pure" forms. It is not unusual to find hybrid processes-processes that have elements of other process types embedded in them. For instance, companies that operate primarily in a repetitive mode, or a continuous mode, will often have repair shops (i.e., job shops) to fix or make new parts for equipment that fails. Also, if volume increases for some items, an operation that began as, say, in a job shop or batch mode may evolve into a batch or repetitive operation. This may result in having some operations in a job shop or batch mode, and others in a repetitive mode.

Self check questions

1. Which of the following is not characteristic of continuous operations?
   A. Planning and scheduling is a routine action
   B. The product is well standardized
   C. The time required for production is very shorter
   D. Uses special purpose equipments
   E. Person with limited skills can be used on the production line
   F. The storage cost per unit is higher
2. Which of the following is an implication of high variety?
   A. Low unit cost
   B. Inflexibility
   C. High volume
   D. Standardization
   E. Low storage cost per unit
   F. None of the above
3. As production move from continuous production to mass production to batch production to project production
   A. Processes become more inflexible
   B. Customer involvement with the process decreases
   C. Product become more standardized
   D. Demand volume increases
   E. Unit cost increases
   F. None of the above
4. __________ It is an exploded view of the product showing its component parts
   A. Assembly drawing
   B. Assembly charts
   C. Route sheets
   D. Flow process charts
   E. None
5. _________________ is characteristics of line/continuous flow except
   A. linear sequence of operation
   B. The product is well standardized
   C. It usually yields a higher unit cost for the product
   D. The time required for production is very shorter
   E. None

B) process classification based on the 'type of customer order'

Another critical dimension affecting process choice is whether the product is made to stock or made to order. Each of these processes has its own advantages and disadvantages.

I. Make- to- order process:

Essentially responds to the customer's request for a product. That is, product is designed and produced entirely to customer's specification. Hence, there is a high degree of customization and products/services variety, product or services are relatively expensive, there is high degree of flexibility, it takes longer time to fill customer order, often there is a high degree of customer satisfaction etc.

Even though process is make to order, a wider range of order specification may remain. In some cases nothing is done until the order is received, and the product is then produced entirely to customer specifications (e.g. haircut). In other cases, components are built up in advance, and the product is merely assembled or prepared at the last minutes to meet the customer's choices. (E.g. restaurant)

III. Make- to- stock

Unlike make to order, in make-to-stock, the cycle begins with the producer. It must have standardized product with less customization. The customers take the product from the stock if the price is acceptable. The firm will build up inventory in anticipation of future demand. The processes are less flexible, the products are cheaper than make to order, it takes less time to fill customer order, and the process can be easily automated

***3.2.3* Process selection decision**

We have classified process according to two dimensions: product flow and type of customer order. Theses dimensions give us six different processes. In a firm, each particular product is produced by one of these six processes; however a mixture of a product often leads to a mixture of process types in the same firm. The six different processes are: process can be

- ✓ Line flow and make to stock. Example oil refinery & flour milling
- ✓ Line flow and make to order. Example automobile assembly & electric utility
- ✓ Intermittent flow & make to stock. Example furniture & fast food
- ✓ Intermittent and make to order. Example restaurant & hospital
- ✓ Project and make to stock. Example speculation home & commercial paintings
- ✓ Project & make to order. Example buildings & ships.

Factors that influence process selection

By and large, six factors appear to influence process selection from among the process mentioned above.

A. Capital requirement: how much capital is needed for inventory, equipment, machinery and facilities? Continuous flow requires more capital as it uses expensive special purpose machine.
B. Market conditions: continuous flow which produce high volume products is preferable if there are more un tapped demands in the market
C. Labor: intermittent and project flow require skilled labor. Unlike intermittent and project flow, continuous flow requires well skilled manager but less skilled labor.
D. Flexibility: intermittent and project flows can be easily adjusted to changes in technology, design and raw materials as they use general purpose machine

A good processes selection decision requires a careful analysis of each of the above factors through several types of studies. A market research study should be done to assess potential demand and other marketing conditions. Whenever possible, future sales should be projected not only as a single figure, but also as a range of possible estimate. Many of the other factors can be considered by an economic analysis of process alternatives. When the market and economic studies have been completed they should be synthesized in to the decision process. In some cases, these studies will indicate a definite preference for one process alternative over another. If this is the case, subjective factors are liable to play only a small role in process selection. Usually, however, process selection will require considerable judgment because of the different cost and risk factors involved.

Self help question

1. Speculation home and commercial paintings uses the process:
   A. continuous and make to stock
   B. project and make to order
   C. continues and make to order
   D. intermittent and make to order
2. Select the correct match
   A. line----furniture
   B. intermittent---oil refinery
   C. shoe factory ----make to order
   D. job shop----hotel

Make to stock is best for hospital. Justfy?

3.3 FACILITY LAYOUT

3.3.1 Facility lay out

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

Facility lay out can also be defined as a decision about the physical arrangement of anything that consumes spaces: person or group of people, a teller window, a machine , a work bench or work station, a department, storage room, a stair way or aisle and so on.

Objective of layout

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

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

Reasons for layout decisions

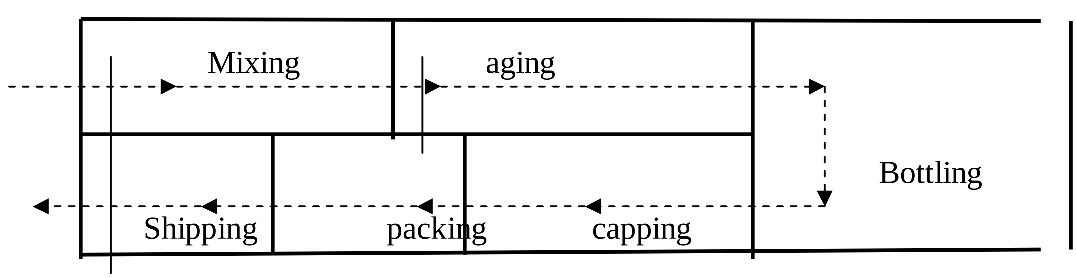
The need for layout planning arises both in the process of designing new facilities and in redesigning existing facility. The most common reasons for redesign of lay out include:

- ✓ Inefficient operations (e.g. high cost, bottlenecks/unbalanced process, excessive material handling costs, unnecessary workers movement, poor space utilization etc).
- ✓ Accidents or safety hazards (high interference from machine such as excessive noise, vibration, fumes/smoke and heats and the like that emitted from machine).
- ✓ Changes in the design of products or services
- ✓ introduction of new products or businesses or changes in the volume of out put
- ✓ changes in methods or equipments
- ✓ morale problems (e.g. lack of face –to- face contact)

3.3.2 Types of layout

The choice of process lay out type depends largely on process choices. Different layouts present managerial challenges, as well as different opportunities to satisfy unmet customer needs. In the following section we will see four different type of layout along with their advantages and disadvantages.

1. ***Product layouts***: with line/continuous process, which are best for repetitive or continuous production, the operation managers dedicate resources to individual products or tasks. This strategy is achieved by product lay out. In which work stations or departments are arranged in a linear path. In this case, resources are arranged around the products route rather than shared across many products. That is, equipments are arranged based on the sequence of operation, and products are move in a continuous path from one department to the next. It is common in high –volume type of operations where products are standardized. Continuous flow (mass production) processing arrangements are usually organized by product layout. An example of product layout is winemaking which uses layout of this type as shown below.



Although product layout often follows a straight line, a straight line is not always best and lay out may take U shapes. U shape lay out has a number of advantages that make it worthy of considerations. In the first case it is more compact; it often requires approximately half the length of the straight production line. In addition, a U shape line permits increased communication among workers on the line because workers are clustered, thus facilitating teamwork. It does not interfere with cross travel of workers. More over flexibility in worker assignment is increased because workers can handle not only adjacent stations but also station opposite sides of the line. Lastly, if materials enter the plant at the same point that finished products leave it, U shaped line minimizes material handling.

Of course, not all situations lend themselves to U shaped lay out. For example, on highly automated lines there is less need for team work and communication. And entry and exit points may be on opposite side of the building. Also, operations may need to be separated because of noise or contamination factors.

The main advantages of product layout include:

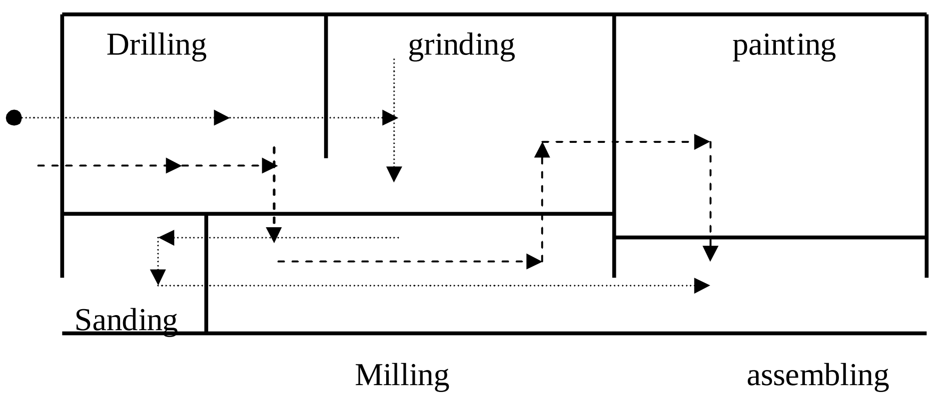
- ✓ Faster processing rates due to mechanized fixed path material handling equipment and the machine pacing of the production rates.
- ✓ Low unit cost due to high volume: the high cost of specialized machine is spread over many units.
- ✓ Routing and scheduling are established in the initial design of the system; they do not require much attention once the system is operating.
- ✓ Less unproductive time due to changes in processes and/or materials.
- ✓ Labor specialization reduces training costs and time, and results in a wide span of supervision.

The primary disadvantages of product layout includes

- ✓ One breakdown in a machine can cause an entire line to shut down
- ✓ The jobs on production lines may provide little satisfaction to workers due to the high level of division of labor and the monotony that usually results.
- ✓ Difficult to avoid machine interference like excessive noise, vibration etc.
- ✓ Difficulty of applying individual based incentive plans since the work is machine paced.
- ✓ The system is fairly inflexible in response to changes in product design
- ✓ Low resource utilization for low volume products or services

2. Process layout

Process lay out is designed to process items or provide services that involves a variety of processing requirements. With a job process, which is best for low volume high variety production, the operations manager must organize resources (employees and equipments) around the process. Process lay out group departments/workstations according to functions or type of activities performed. Thus, all the resources that perform similar tasks are located together, so that materials can be routed through the resources in any order. Generally, process layout consists of functional groupings of machines or labors that do similar works. For example, all drilling presses may be grouped together in one department and all milling machine in another (see the following figure). Depending on their processing requirements, parts may be moved to in different sequences among departments.



Advantages of process layout

- ✓ Because of its flexibility, process layout is less vulnerable to changes in product mix or design. Since it is flexible, idle equipment is usually available to replace machines that are temporarily out of service.
- ✓ Diversity of jobs offer more satisfaction to workers
- ✓ Resources are relatively general purpose and less capital intensive.
- ✓ Systems are not vulnerable to equipment failure
- ✓ It is possible to use individual incentive systems
- ✓ It is easy to avoid machine interference

Disadvantages of process layout

- ✓ Handling and transportation costs are high ,since products must be moved frequently between departments
- ✓ Routing and scheduling is continual challenges
- ✓ Job complexity often reduces the span of supervision and results in higher supervisory costs than with product layout
- ✓ Processing rates tends to be slower
- ✓ Productive time is lost in changing from one product or services to another.
- ✓ Employees in this type of environment might be more loyal to their department than to the company or they might be concerned with technical excellence than with customer satisfaction.

3. Fixed positional layout

The construction of large items, such as heavy machine tools, airplanes, buildings, power plants, dams and the like is usually accomplished in a fixed place, Rather than move the item from one work centre to another, tools and components are brought to one place for assembly. Therefore, in a fixed positional layout, the item being worked on remains stationary, and workers, materials, and equipments are moved about as needed. This is in marked contrast to product and process layouts. Almost always the nature of the product dictates this kind of arrangements: weight, size, bulk, or some other factor makes it undesirable or extremely difficult to move the product.

Lack of storage space can present significant problems, for example, at a construction site in crowded urban locations. Because of the many divers activity carried out on large projects and because of the wide range of skills required, special efforts are needed to coordinate the activities, and the span of control can be quite narrow. For this reasons the administrative burden is much higher than it would be under either of the other layout types. Fixed position layouts are widely used for farming, firefighting, road building, home building, remodeling and repair, and drilling for oil. In each case, compelling reasons bring workers, materials and equipments to the project's location instead of the other way around.

4. **Cellular layout**

Cellular Manufacturing: Cellular manufacturing is a type of layout in which machines are grouped into what is referred to as a cell. Groupings are determined by the operations needed to perform work for a set of similar items, or part families, that require similar processing. The cells become, in effect, miniature versions of product layouts. The cells may have no conveyorzed movement of parts between machines, or may have a flow line connected by a conveyor (automatic transfer). Observe that in the cellular layout, machines are arranged to handle all of the operations necessary for a group (family) of similar parts. Thus, all parts follow the same route although minor variations (e.g., skipping an operation) are possible. In contrast, the functional layout involves multiple paths for parts. Moreover, there is little effort or need to identify part families; the distinction in the figure is merely for purposes of comparison.

There are numerous benefits of cellular manufacturing. These relate to the grouping of equipment and include faster processing time, less material handling, less work-in- process inventory, and reduced setup time.

Group Technology: Effective cellular manufacturing must have groups of identified items with similar processing characteristics. This strategy for product and process design is known as group technology and involves identifying items with similarities in either design characteristics or manufacturing characteristics, and grouping them into part families. Design characteristics include size, shape, and function; manufacturing or processing characteristics involve the type and sequence of operations required. In many cases, design and processing characteristics are correlated, although this is not always the case. Thus, design families may be different from processing families.

Once similar items have been identified, items can be classified according to their families, then a system can be developed that facilitates retrieval from a database for purposes of design and manufacturing. For instance, a design can use the system to determine if there is an existing part similar or identical to one that needs to be designed. It may happen that an existing part, with some modification, is satisfactory. This greatly enhances the productivity of design. Similarly, planning the manufacturing of a new part can include matching it with one of the part families in existence, thereby alleviating much of the burden of specific processing details.

The conversion to group technology and cellular manufacturing requires a systematic analysis of parts to identify the part families. This is often a major undertaking; it is a time-consuming job that involves the analysis of a considerable amount of data. Three primary methods for accomplishing this are visual inspection, examination of design and production data, and production flow analysis.

Visual inspection is the least accurate of the three but also the least costly and the simplest to perform. Examination of design and production data is more accurate but much more time-consuming; it is perhaps the most commonly used method of analysis. Production flow analysis has a manufacturing perspective and not a design perspective, because it examines operations sequences and machine routings to uncover similarities. Moreover, the operation sequences and routings are taken as givens; in reality the existing procedures may be far from optimal.

Conversion to cellular manufacturing can involve costly realignment of equipment. Consequently, a manager must weigh the benefits of a switch from a process layout to a cellular one against the cost of moving equipment as well as the cost and time needed for grouping parts.

Self check questions

1. Which one of the following will be the appropriate layout for project production flow?
   A. Process layout
   B. Functional layout
   C. Fixed positional layout
   D. Product layout
   E. Store layout
   F. None of the above
2. One of the following is not among the objectives of layout decision?
   A. To avoid bottlenecks within the plant
   B. To reduce hazards to employees
   C. To maximize distance movement within the plant
   D. To balance the production process within the plant
   E. To minimize material handling costs
   F. None of the above

3. A special arrangement of machinery and equipment to focus on production of a single product or a group of related product described what layout type?
   A. Product
   B. Process
   C. Fixed
   D. None of the above
4. What are the major differences between process layouts from product layout?
   A. Process layout is used for intermittent processing and product layout is used for repetitive processing
   B. Process layout is functional and product layout is sequential
   C. Process layout is sequential and product layout is functional
   D. Both A and B
   E. None of the above
5. Explain the advantage and disadvantage of process layout

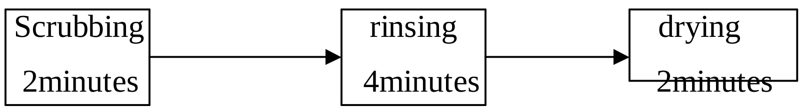
Designing product layout: line balancing

Line balancing is a procedure that can be used to optimize the assignment of tasks to work centers. The goal of line balancing is to obtain task groupings that represent approximately equal time requirements. This minimize the idle time along the line and results in a high utilization of labor and equipment. Idle time occurs if task times are not equal among workstations; some stations are capable of producing at higher rate than others. The fast station will experience periodic waits for the output from slower stations or else be forced in to idleness to avoid buildups of work between stations.

Lines that are perfectly balanced will have a smooth flow of work as activities along the line are synchronized to achieve maximum utilization of labor and equipment. The major obstacle of attaining a perfectly balanced line is the difficulty of forming tasks bundles that have the same duration. There are different causes for this difficulty.

- ✓ One cause of this is that it may not be feasible to combine certain activities in to the same bundle, either because of differences in equipment requirements or because the activities are not compatible (e.g. risk of contamination of paint from sanding).

- ✓ Another cause of difficulty is that differences among elemental tasks lengths cannot always be overcome by grouping tasks.
- ✓ A third cause of an inability to perfectly balance a line is that a required technological sequence may prohibit otherwise desirable task combinations. Consider a series of three operations that have duration of two minutes, four minutes, and two minutes as shown in the following diagram. Ideally, the first and the third operations could be combined at one workstation and have a total time equal to that of the second operation. However, it may not be possible to combine the first and the third operations. In the case of an automatic car wash, scrubbing and drying operations could not realistically, be combined at the same workstation due to the need to rinse cars between the two operations.



In real world, line balancing procedures are very complex and the procedures are heuristics. Line balancing heuristics do not guarantee optimal task assignments.

Terminologies in line balancing

- ✓ *Desired output*: the rate of output that is expected to be attained during operating time
- ✓ *operating time*: total available time during specific period that used for operation
- ✓ *cycle time*: is the maximum time allowed for work on a unit at each work station
- ✓ *Task:* is an element of work. E.g. grasping pen, positioning it on a paper, and writing.
- ✓ *task length*: the amount of time required to complete a single task
- ✓ *precedence relationship*: orders in which the tasks must be performed in the process
- ✓ *assignment rule*: is rule by which individual tasks are going to be assigned to the work station
- ✓ *work station*: a physical location where a particular set of tasks is performed
- ✓ *Work centre*: a physical location where two or more identical work stations are located
- ✓ *Productive time per hour*: the number of minutes in each hour that a work stations is working on the average.

Assignment rules

An assignment rule is a heuristic that establishes the bases for choosing an elemental task for assignment to a work station. There are five rules

- ✓ *longest task first*: assigning the task with the longest time first
- ✓ *shortest task first*: assigning the task with the shortest time first
- ✓ *most number following*: assigning the tasks with the largest number of followers first

- ✓ *least number following*: assigning the tasks with the least number subsequent tasks first
- ✓ *Ranked positional weight*: assign the tasks whose sum of task times of each following task is longest.

Steps in assembly line balancing

Step1. *Draw the precedence diagram*. The diagram consists of circles and arrows. Circle represents individual tasks and arrow indicates the order of task performance.

Step2. *Find the required cycle time* (C) using the formula:

$$C = \frac{operating\ time\ per\ day\ (OT)}{Desired\ output\ in\ unit\ (D)}$$

Step3. Find the *theoretical minimum number of workstations* (Nt) using the formula:

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

Step4. Select primary rule by which tasks are to be assigned to work station, and a Secondary rule to break ties.

Step5. Assign the task to work centers.

After identifying the rule by which tasks are assigned, the next step as assignment. The general rule is, assign tasks, one at a time, to the first work station 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 work station 2, workstation 3, and so on until all tasks are assigned.

Step6. Evaluate the efficiency of the balance derived using the formula:

$$Efficiency = \frac{sum\ of\ task\ times\ (T)}{Number\ of\ workstation\ (Na)\ X\ cycle\ time(C)}$$

Balance delay (in percent) = 100 – efficiency

$$Idle\ time = (number\ of\ workstation\ X\ cycle\ time) - summation\ of\ task\ times$$

N:B If efficiency is unsatisfactory, rebalance using different decision rule.

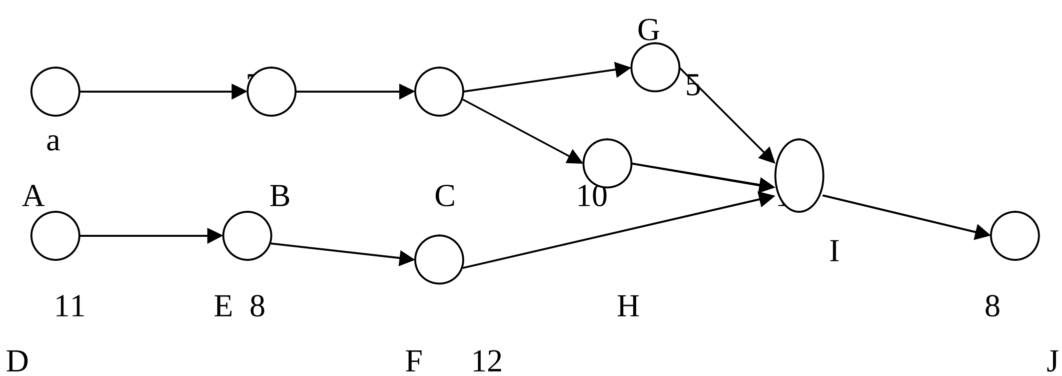
Example: - The model J wagon is to be assembled on a conveyer belt. The assembly tasks that must be performed on each wagon are shown below. If 144 wagons are produced per hour, find the balance that minimizes the number of workstation, subject to cycle time and precedence constraints.

Assembly time and steps for model J wagon

Task	Task time (in seconds)	description	tasks that must precede
A	12	position rear axle support and hand fasten 4 screws to nut	---
B	7	insert real axle	A
C	8	tighten real axle support screws to nuts	B
D	11	position front axle assembly and fasten with screw	---
E	8	tighten front axle assembly screw	D
F	12	position rear wheel #1 and fasten hubcap	E
G	5	position rear wheel#2 hubcap	C
H	10	position front wheel #1 and fasten hubcap	C
I	12	position front wheel #2 and fasten hubcap	F,G ,H
J	8	position wagon handle shaft on front axle assembly And hand fasten bolt and nut	I

Solution

Step1. Draw the precedence diagram



Step 2 Determine cycle time: since time stated in seconds, first compute available production time in terms of seconds i.e. 60X 60 =3600 seconds. Then,

$$C = \frac{OT}{D} = \frac{3600}{144} = 25 \text{ seconds}$$

Step3. Find the theoretical minimum number of work station (Nt)

$$NT = \frac{\Sigma T}{C} = \frac{93}{25} = 3.72 \approx 4 \text{ workstation (rounded up)}$$

Step4. Select the assignment rule i.e. primary rule to assign the tasks and secondary rule to break ties if there is any.

Let as select largest positional weight as a primary rule and the most number of following as secondary rule.

Task	largest positional weight	number following
A	62	6
B	50	5
C	43	4
D	51	4
E	40	3
F	32	2
G	25	2
H	30	2
I	20	1
J	8	--

Step5. Make task assignments to form work station1, workstation 2 and so forth until all tasks are assigned.

Work station	available time	eligible (feasible) tasks	assigned	idle time
1	25	A,D	A	--
	13	B,D	D	--
	2	B,E	--	2
2	25	B,E	B	--
	18	C,E	C	--
	10	E,G,H	E	--
	2	F,G,H	--	2
3	25	F,G,H	F	--
	13	G,H	H	--
	3	G	--	3

4	25	G	G	--
	20	I	I	--
	8	J	J	--

Step6. Measure efficiency

$$\text{Efficiency} = \frac{\Sigma T}{Na \times C} = \frac{93}{4 \times 25} = 93\%$$

Balanced delay = 100% - 93% = 7% OR

Balanced delay = 1- percentage of idle time

$$\text{Percentage of idle time} = \frac{\Sigma \text{idle time}}{Na \times C} = 7/100 = .07$$

Therefore balanced delay = 1-0.07 = 0.93 = 93%

What do we do if a task time is greater than cycle time?

For example, if the assembly line contains a task whose task times is 30 seconds, how do we deal with this task?

There are several ways that we may be able to accommodate the 30 second task in a 25-second cycle time.

- ✓ Split the task: can we split the task so that complete units are processed in two work station?
- ✓ 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 parallel work station it may be necessary to assign the task to two work stations that would appear in parallel.
- ✓ Use a more skilled worker: because this task exceeds the cycle time a faster worker may be able to meet the extra minutes required.
- ✓ Work over time and lastly, if possible redesign the product to reduce the task time slightly.

Self help question

1. For the set of tasks given below, do the following:
   - A. Develop the precedence diagram.(2 mark)
   - B. Determine the maximum cycle time in minutes for a desired output of 288 units in a 600 hours. (0.5 mark)
   - C. Balance the line using the shortest task heuristic. Break ties with the most following tasks heuristic. (2 marks)
   - D. Calculate efficiency and the percentage idle time for the line.(0.5 mark)

Task	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	**M**	**N**
Task time (minutes)	*100*	*50*	*25*	*39*	*45*	*100*	*15*	*50*	*69*	*50*	*25*	*79*	*79*	*50*
precedence	-	*A*	*B*	*B*	*C,D*	*E*	*E*	*E*	*H*	*F,G*	*J*	*I,K*	*L*	*M*

3.4 WORK MEASUREMENT

Work measurement is concerned with determining the length of time it should take to complete the job. Job times are vital inputs for manpower planning, estimating labor costs, scheduling, budgeting, and designing incentive systems. Moreover, from the workers' standpoint, time standards provide an indication of expected output. Time standards reflect the amount of time it should take an average worker to do a given job working under typical conditions. The standards include expected activity time plus allowances for probable delays.

A standard time is the amount of time it should take a qualified worker to complete a specified task, working at a sustainable rate, using given methods, tools and equipment, raw material inputs, and workplace arrangement. Whenever a time standard is developed for a job, it is essential to provide a complete description of the parameters of the job because the actual time to do the job is sensitive to all of these factors; changes in anyone of the factors can materially affect time requirements. Organizations develop time standards in a number of different ways. Although some small manufacturers and service organizations rely on subjective estimates of job times, the most commonly used methods of work measurement are:

- Stopwatch time study
- Historical times
- Predetermined data
- Work sampling

3.4.1 Stopwatch time study

Stopwatch time study was formally introduced by Frederick Winslow Taylor in the late nineteenth century. Today it is the most widely used method of work measurement. It is especially appropriate for short, repetitive tasks. Stopwatch time study is used to develop a time standard based on observations of one worker taken over a number of cycles. That is then applied to the work of all others in the organization who perform the same task. The basic steps in a time study are:

1. Define the task to be studied, and inform the worker who will be studied cycles.
2. Determine the number of cycles to observe.
3. Time the job, and rate the worker's performance.
4. Compute the standard time.

The analyst who studies the job should be thoroughly familiar with it since it is not unusual for workers to attempt to include extra motions during the study in hope of gaining a standard that allows more time per piece (i.e., the worker will be able to work at a slower pace and still meet the standard). Furthermore, the analyst will need to check that the job is being performed efficiently before setting the time standard.

In most instances, an analyst will break all but very short jobs down into basic elemental motions (e.g., reach, grasp) and obtain times for each element. There are several reasons for this: One is that some elements are not performed in every cycle, and the breakdown enables the analyst to get a better perspective on them. Another is that the worker's proficiency may not be the same for all elements of the job. A third reason is to build a file of elemental times that can be used to set times for other jobs. This use will be described later.

Workers sometimes feel uneasy about being studied and fear changes that might result. The analyst should make an attempt to discuss these things with the worker prior to studying an operation to allay such fears and to enlist the cooperation of the worker.

The number of cycles that must be timed is a function of three things: (1) the variability of observed times, (2) the desired accuracy, and (3) the desired level of confidence for the estimated job time. Very often the desired accuracy is expressed as a percentage of the mean of the observed times. For example, the goal of a time study may be to achieve an estimate that is within 10 percent of the actual mean. The sample size needed to achieve that goal can be determined using this formula:

$$n = \left(\frac{zs}{ax}\right)^2$$

Where

z = Number of normal standard deviations needed for desired confidence

s = Sample standard deviation

a = Desired accuracy percentage

x = Sample mean

- Theoretically, a t rather than a z value should be used because the population standard deviation is unknown. However, the use of z is simpler and provides reasonable results when the number of observations is 30 or more, as it generally is. In practice, z is used almost exclusively.

An alternative formula used when the desired accuracy is stated as an amount (e.g., within one minute of the true mean) instead of percentage is:

$$n = \left(\frac{zs}{e}\right)^2$$

Where: e= accuracy or maximum acceptable error

To make a preliminary estimate of sample size, it is typical to take a small number of observations (i.e., 10 to 30) and compute values of x and s to use in the formula for n. toward the end of the study, the analyst may want to recomputed n using revised estimate of x and s based on the increased data available.

Note: these formulas may or may not be used in practice, depending on the person doing the time study. Often, an experienced analyst will rely on his or her judgment in deciding on the number of cycles to time.

Example1: a time analyst want to estimate the time required to perform a certain job. A preliminary study yielded a mean of 6.4 minutes and standard deviation of 2.1 minutes. The desired confidence is 95%. How many observations will be need (including those already taken) if the desired maximum error is

A. ± 10% of sample mean?

B. One half minute?

Solution

A. S=2.4 minutes, x=6.4 minutes, Z= 1.96, a=10%

n= $(\frac{zs}{ax})^2$= n= $(\frac{1.96*2.1s}{0.1*6.4})^2$= 41.36 (round up to 42)

B. E=0.5

n= $(\frac{zs}{e})^2$ = n= $(\frac{1.96*2.1}{0.5})^2$= 67.77(round up to 68)

Development of a time standard involves computation of three times: the observed time (OT), the normal time (NT) and the standard time 9ST)

Observed time: the observed time is simply the average of the recorded time. Thus,

OT=$\frac{\sum xi}{n}$

Where OT=Observed time

$\sum xi$ = sum of recorded time

n= number of observations

Note: if a job element does not occur each cycle, it is average time should be determined separately and that should be included in the observed time, OT

Normal time: the normal time is the observed time and adjustment for worker performance. It is computed by multiplying the observed time by a performance rating

NT=OT*PR

Where: NT= normal time

PR= performance rating

This assumes that a single performance rating has been made for the entire job. If rating are made on an element by element basis, the normal time is obtained by multiplying each element‘s average time by its performance rating and summing those values.

NT=$\sum(xj * PRj)$

Where: xj= average time for element j

PRj= performance rating for element j

The reason for including this adjustment factor is that the worker being observed may be working at a rate different from a "normal" rate, either to deliberately slow the pace or because his or her natural abilities differ from the norm. For this reason, the observer assigns a performance rating, to adjust the observed times to an "average" pace. A normal rating is 1.00. A performance rating of .9 indicates a pace that is 90 percent of normal, whereas a rating of 1.05 indicates a pace that is slightly faster than normal. For long jobs, each element may be rated; for short jobs, a single rating may be made for an entire cycle.

When assessing performance, the analyst must compare the observed performance to his or her concept of normal. Obviously, there is room for debate about what constitutes normal performance, and performance ratings are sometimes the source of considerable conflict between labor and management. Although no one has been able to suggest a way around these subjective evaluations, sufficient training and periodic recalibration by analysts using training films can provide a high degree of consistency in the ratings of different analysts.

Standard Time: Normal time is the length of time a worker should take to perform a job if there are no delays or interruptions. It does not take into account such factors as personal delays (getting a drink of water or going to the restroom), unavoidable delays (machine adjustments and repairs, talking to a supervisor, waiting for materials), or rest breaks. The standard time for a job is the normal time plus an allowance for these delays.

The standard time is

ST = NT X AF

Where

ST = Standard time

AF = Allowance factor

Allowances can be based on either job time or time worked (e.g., a workday). If allowances are based on the job time, the allowance factor must be computed using the formula

AFjob =1+A; A=allowance percentage based on job time

This is used when different job have different allowances. If allowances are based on the percentage of time worked (i.e., the work day), the approximate formula is

AF day=$\frac{1}{1-A}$; A= allowance percentage based on work day. This is used when jobs are the same or similar and have the same allowance factors.

Example 2 : compute allowance factor for the two cases

A. Allowance is 20% of job time

B. Allowance is 20% of work time

A. AF=1+A=1.20 or 120%

B. AF=$\frac{1}{1-A}$=$\frac{1}{1-0.2}$=1.25 or 125%

- In practice allowance may be based on the judgment of the time study analyst, working sampling or negotiation between labor and the management.

Example 3: a time study of an assembly operation yielded the following observation times for one elements of the job, for which the analyst gave a performance rating of 1.13. Using an allowance of 20% of job time, determine the appropriate standard time for this operation

observation	Time, X (minutes)	observation	Time (minutes)
1	1.12	6	1.18
2	1.15	7	1.14
3	1.16	8	1.14
4	1.12	9	1.19
5	1.15	total	10.35

Solution:

n=9, PR=1.13,A=0.20

A. OT=$\frac{\sum xi}{n}$=$\frac{10.35}{9}$=1.15 minutes

B. NT=OT*PR=1.15*1.13=1.30 minutes

C. ST=NT*(1+A)=1.30(1.20)=1.56 minutes

Note: if an abnormally short time has been recorded, it typically would be assumed to be the result of observation error and this discarded, if one of the observation on example 3 had been 0.10, it would have be discarded. However, if an abnormally long time has been recorded, the analyst would want to investigate that observation to determine whether some irregularity occurring aspect of the task (e.g., retrieving a dropped tool or part) exists, which should legitimately be factored into the job time

Despite the obvious benefits that can be derived from work measurement using time study, some limitations also must be mentioned. One limitation is the fact that only those jobs that can be observed can be studied. This eliminates most managerial anti creative jobs, because these involve mental as well as physical aspects. Also, the cost 'Of the study rules out its use for irregular operations and infrequently occurring jobs. Finally, it disrupts the normal work routine, and workers resent it in many cases.

3.4.2 Standard elemental times

Standard elemental times are derived from a firm's own historical time study data. Over the years, a time study department can accumulate a file of elemental times that are common to many jobs. After a certain point, many elemental times can be simply retrieved from the file, eliminating the need for analysts to go through a complete time study to obtain them.

The procedure for using standard elemental times consists of the following steps:

1. Analyze the job to identify the standard elements.
2. Check the file for elements that have historical times, and record them. Use time study to obtain others, if necessary.
3. Modify the file times if necessary (explained below).
4. Sum the elemental times to obtain the normal time, and factor in allowances to obtain the standard time.

In some cases, the file times may not pertain exactly to a specific task. For instance, standard elemental times might be on file for "move the tool 3 centimeters" and "move the tool 9 centimeters," when the task in question involves a move of 6 centimeters. However, it is often possible to interpolate between values on file to obtain the desired time estimate.

One obvious advantage of this approach is the potential savings in cost and effort created by not having to conduct a complete time study for each job. A second advantage is that there is less disruption of work, again because the analyst does not have to time the worker. A third advantage is that performance ratings do not have to be done; they are generally averaged in the file times. The main disadvantage of this approach is that times may not exist for enough standard elements to make it worthwhile, and the file times may be biased or inaccurate.

The method described in the following section is a variation of this approach, which helps avoid some of these problems.

3.4.3 Predetermined time standards

Predetermined time standards involve the use of published data on standard elemental times. A commonly used system is methods-time measurement (MTM), which was developed in the late 1940s by the Methods Engineering Council. The MTM tables are based on extensive research of basic elemental motions and times. To use this approach, the analyst must divide the job into its basic elements (reach, move, turn, disengage), measure the distances involved (if applicable), rate the difficulty of the element, and then refer to the appropriate table of data to obtain the time for that element. The standard time for the job is obtained by adding the times for all of the basic elements. Times of the basic elements are measured in time measurement units (TMUs); one TMU equals .0006 minute. One minute of work may cover quite a few basic elements; a typical job may involve several hundred or more of these basic elements. The analyst needs a considerable amount of skill to adequately describe the operation and develop realistic time estimates.

A high level of skill is required to generate a predetermined time standard. Analysts generally take training or certification courses to develop the necessary skills to do this kind of work. Among the advantages of predetermined time standards are the following:

1. They are based on large numbers of workers under controlled conditions.
2. The analyst is not required to rate performance in developing the standard.
3. There is no disruption of the operation.
4. Standards can be established even before a job is done.

Although proponents of predetermined standards claim that the approach provides much better accuracy than stopwatch studies, not everyone agrees with that claim. Some argue that many activity times are too specific to a given operation to be generalized from published data. Others argue that different analysts perceive elemental activity break- downs in different ways, and that this adversely affects the development of times and produces varying time estimates among analysts. Still others claim that analysts differ on the degree of difficulty they assign a given task and thereby obtain different time standards.

3.4.4 Work sampling

Work sampling is a technique for estimating the proportion of time that a worker or machine spends on various activities and the idle time.

Unlike time study, work sampling does not require timing an activity, nor does it even involve continuous observation of the activity. Instead, an observer makes brief observations of a worker or machine at random intervals and simply notes the nature of the activity. For example, a machine may be busy or idle; a secretary may be typing, filing, talking on the telephone, and so on; and a carpenter may be carrying supplies, taking measurements, cutting wood, and so on. The resulting data are counts of the number of times each category of activity or non activity was observed.

Although work sampling is occasionally used to set time standards, its two primary uses are in (1) ratio-delay studies, which concern the percentage of a worker's time that involves unavoidable delays or the proportion of time a machine is idle, and (2) analysis of non repetitive jobs. In a ratio-delay study, a hospital administrator, for example, might want to estimate the percentage of time that a certain piece of X-ray equipment is not in use. In a non repetitive job, such as secretarial work or maintenance, it can be important to establish the percentage of time an employee spends doing various tasks.

Non repetitive jobs typically involve a broader range of skills than repetitive jobs, and workers in these jobs are often paid on the basis of the highest skill involved. Therefore, it is important to determine the proportion of time spent on the high-skill level. For example, a secretary may take dictation, do word processing, file, answer the telephone, schedule appointments, and does other routine office work. If the secretary spends a high percentage of time filing instead of doing word processing or taking shorthand, the compensation will be lower than for a secretary who spends a high percentage of time doing word processing and taking shorthand. Work sampling can be used to verify those percentages and can therefore be an important tool in developing the job description. In addition, work sampling can be part of a program for validation of job content that is needed for "bona fide occupational qualifications"-that is, advertised jobs requiring the skills that are specified.

Work sampling estimates include some degree of error. Hence, it is important to treat work sampling estimates as approximations of the actual proportion of time devoted to a given activity. The goal of work sampling is to obtain an estimate that provides a specified confidence not differing from the true value by more than a specified error. For example, a hospital administrator might request an estimate of X-ray idle time that will provide a 95 percent confidence of being within 4 percent of the actual percentage. Hence, work sampling is designed to produce a value, p, which estimates the true proportion, p, within some allowable error, e: p ± e. The variability associated with sample estimates of p tends to be approximately normal for large sample sizes. The amount of maximum probable error is a function of both the sample size and the desired level of confidence.

For large samples, the maximum error e can be calculated using the formula:

$$e=z\sqrt{\frac{p(1-p)}{n}}$$

where:

Z=number of standard deviations needed to achieve desired confidence level

P= sample proportion (the number of occurrences divided by sample size)

n=sample size

In most instances, management will specify the desired confidence level and amount of allowable error, and the analyst will be required to determine the sample size sufficient to obtain these results. The appropriate value for n can be determined by formula:

$$n=\left(\frac{z}{e}\right)^2 \text{ p (1-P)}$$

Example 1: the manager of a small super market chain wants to estimate the proportion of time stock clerks spend making price changes on previously marked merchandises. The manager wants a 98% confidence that the resulting estimate will be within 5% of the true value. What sample size should she use?

Solution

e=0.05, z=2.33, p=is unknown

When no sample estimate of p is available, a preliminary estimate of a sample size, can be obtained by using p=0.50. After 20 or so observations, a new estimate of p can be obtained from those observations and a revised value of n computed using the new p. it would be prudent to re-compute the value of n at two or three points during the study to obtain a better indication of the necessary sample size. Thus, the initial estimate of n is

$$n=\left(\frac{2.33}{0.05}\right)^2 \text{ 0.50 (1-0.50) =542.89 or 543 observations}$$

Suppose that, in the first 20 observations, stock clerks were found to be changing price twice, making p=2/20=0.10. The revised estimate of n at that point would be

$n=(\frac{2.33}{0.05})^2$ 0.10 (1-0.10) = 195.44 =196

Suppose a second check is made after a total of 100 observations, and p=0.10 at this point (including the initial 20 observations). Re-computing n yields

$n=(\frac{2.33}{0.05})^2$ 0.11 (1-0.89) = 212.60 or 213

Perhaps the manager might take one more check to settle on a final value of n. if the computed value of n is less than the number of observation already taken; sampling would be terminated at that point.

Note: If the resulting value of n is noninteger, round up.

Determining the sample size is only one part of work sampling. The overall procedure consists of the following steps:

1. Clearly identify the worker(s) or machine(s) to be studied.
2. Notify the workers and supervisors of the purpose of the study to avoid arousing suspicions.
3. Compute an initial estimate of sample size using a preliminary estimate of p, if available (e.g., from analyst experience or past data). Otherwise, use p = .50.
4. Develop a random observation schedule.
5. Begin taking observations. Recompute the required sample size several times during the study.
6. Determine the estimated proportion of time spent on the specified activity.

Careful problem definition can prevent mistakes such as studying the wrong worker or wrong activity. Similarly, it is important to inform related parties of the purpose and scope of the study to reduce unnecessary fears that might be generated by unannounced data collection. It is also important to obtain random observations to achieve valid results. Observations must be spread out over a period of time so that a true indication of variability is obtained. If observations are bunched too closely in time, the behaviors observed during that time may not genuinely reflect typical performance. The degree to which observations should be spread out will depend in part on the nature of the activity studied; a decision on this is usually best left to the analyst.

Self help question

1. The first step in work sampling is
   A. Notifying purpose of the study to the workers and supervisors
   B. Computing an initial estimate of sample size
   C. Developing a random observation schedule.
   D. Identifying the worker or machine to be studied
   E. Determining the estimated proportion of time spent on the specified activity
   F. Making observation
2. A time study analyst wants to estimate the number of observation that will be needed to achieve a specified maximum error, with a confidence of 95.5%. A preliminary study yielded a mean of 5.2 minutes and a standard deviation of 1.1 minutes. What would be the maximum number of observations needed if a maximum allowable error is ±6% of sample size
   A. 49.72
   B. 30.25
   C. 25.12
   D. 12
3. The analyst has been asked to prepare an estimate of the proportion of time that a turret lathe operator spends adjusting the machine, within 90% of confidence level. Based on previous experience, the analyst believes the proportion will be approximately 30%. If the analyst uses a sample size of 400 observations, what is the maximum possible error that will be associated with the estimates?
   A. 0.38
   B. 0.49
   C. 0.59
   D. 0.28
4. What is time standard? What factors must be taken into account when developing standards?
5. What are the main uses of time study information?
6. What is work sampling? How does it differ from time study?

3.5 FACILITY LOCATIOS

3.5.1 Facility location

Facility location decisions are, strategic, long term and non repetitive in nature. Without sound and careful location planning in the beginning itself, the new facility may pose continuous operating disadvantages, for the future operations. Location decisions are based on a host of factors; some are subjective, qualitative, and intangible while some others are objectives, quantitative and tangible.

Traditionally, location theorists have dealt with industrial plant/factory location. However, the concept of plant location has now been generalized in to that of facility location, since the facility could include a production operation or service system. The term plant has been traditionally used as synonymous to a factory manufacturing or assembly unit. This could include fertilizer, steel, cement, breweries, refineries, thermal or hydro-electric nuclear power station etc. however, with the enlarged scope of a facility, this term can now be used to refer to banks, hospitals, blood banks, fire stations, police stations, warehouses, recreational centers, central repair workshops etc. We could generally state that a facility could connote almost any physical object relevant to location analysis.

When does a location decision arise?

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

- It may arise when a new facility is to be established.
- In some cases, the facility or plant operations and subsequent expansions are restricted by a poor site, there for necessitating the setting up of the facility at a new site.
- the growing volume of the business makes it advisable to establish additional facilities in new territories
- It could happen that the original advantages of the plant have been outweighed due to new development.
- New economic, social, legal or political factors could suggest a change of location of the existing plant.

- Decentralization and dispersal of industries reflected in the industrial policy resolution so as to achieve an overall development of a developing country would necessitate a location decision at a macro level.

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

Location option

Managers generally consider four options in location planning. One is to expand an existing facility. This option can be attractive if there is adequate room for expansion, especially if the location has desirable features that are not readily available elsewhere. Expansion costs are often less than those of other alternatives.

Another option is to add new location while retaining existing ones, as is done in many retail operations. In such case, it is essential to take in to account what the impact will be on the total system. Adding location can be a defensive strategy designed to maintain a market share or to prevent competitors from entering a market.

A third option is to shut down at one location and move to another. An organization must weigh the cost of a move and the resulting benefit against the costs and benefits of remaining in an existing location. A shift in markets, exhaustion of raw materials, government actions, and the cost of operations often causes firms to consider this options seriously.

Finally, the organizations have the option of doing nothing. If a detailed analysis of potential locations fails to uncover benefits that make one of the previous three alternatives attractive, a firm may decided to maintain the statuesque, at least for the time being.

3.5.2 The location decision hierarchy and factors that affect location decision

There are four location decision hierarchies:

i. ***Global- international***: is the highest level in the location decision hierarchy. Decision makers who are considering expanding in to a new country must consider macroeconomic, demographic, and political issues of long term significance. They must consider international trade issues , such as

- International trade issues (currency exchange risk, balance of trade, quotas, tariffs etc.)
- market access issues(such as free trade agreement, consumer sentiment towards imported goods)
- labor issues(availability, wages , skill and training, and regulations)

- Political concerns (stability of current regime, risk of asset nationalization, local owner ship laws etc.)
- Cultural issues(compatibility of business practices and products with local culture)
- Legal issues(environmental regulations, accounting &reporting requirements etc)

ii. ***Regional considerations***: ones the decision has been made to locate a facility in a particular country, decision makers must choose a region based on regional issues like:

- *Supply issues (availability of material inputs):* select the region endowed with abundant or sufficient inputs.
- *proximity to market*: select the region which is near to the major market if product is perishable, fragile, if the product needs large transportation space, transportation cost is expensive ,and if further processing increases the volume, bulk, fragility and perish ability.
- *proximity to material:* a possible reason to select regions which is near resources includes: when further processing reduces the bulk (e.g. sugar processing), perish ability (e.g., freezing, canning, pasteurizing etc)
- *Transportation facility:* transformation facilities are essential for the economic operations of production systems. Operations manager must study the characteristics of the new materials and finished products in regard to their transportation (water, railroad, road, pipelines, and air line transport) need and search for the location (region) that provides facilities of transportation with a reasonable cost.
- *Climate:* select the region with favorable climate which is important in order to acquire and maintain productive work forces. Certain industries such as agricultural business require specific climatic conditions.

iii. Community considerations: choice of community depends on the following factors:

- *Community attitudes*: in order to ensure the long term existences in that community, it is mandatory to win the interest, enthusiasms, and cooperation of the society. Otherwise, poor relation with community will result in putting the survival of the organization under question mark. So select the community with positive attitudes towards the company.
- *Community government and financial incentives*: it is important to assess the current situation and attempt to predict the future situations in regard to the policies of local government. In general stable, competent, honest, and cooperative government officials

are great asset to a newly located company. Local government may be evaluated in terms of financial incentives they offer, taxation polices, peace and securities etc.

- *Community facilities*: is concerned with the availability of schools, churches, medical facilities, residential housings, recreational opportunities, highways etc.

iv. ***Site considerations*:** after identifying the community in the already selected region, the final step in location selection decision is to screen out the best site out of the possible ones. The followings are the basic factors that influence site selection.

- *Size and cost of the site*: while selecting exact site, consider the size of the site and its cost (building and construction costs). Generally, the size of the site must be large enough to satisfy requirements such as employees parking requirement & future expansion plans and the cost of the land must be reasonable.
- *Drainage and soil condition*: poor drainage leads to accumulations of water around the plant which may be harmful for some organization. Similarly, if the load bearing capacity of the soil is low, it will be difficult to establish sound building foundations.
- *Land development cost:* cost related to excavation, grading, filling, construction of road, sidings, etc must also be taken in to consideration while selecting the site.
- *Utilities:* selection of site is influenced by cost of acquiring and using utilities like electricity, natural gas, water as well as disposal facilities. For example all enterprises need safe and pure water. Some organizations like breweries need water even with some extra ordinary quality. So select the site which is better furnished with utilities.
- *Access concerns*: select the site which is easily accessible for customers, suppliers, utilities and other concerned bodies.

Self check questions

1. List and explain the location decision hierarchy
2. Location decisions a short term decision that can easily be reverted. Do you agree? Justify.
3. Drainage and soil condition are factor to be considered while evaluating region. Do you agree? Justify.

3.5.3 Methods of evaluating potential locations

We have seen that a variety of factors are important to decision makers at each level of the location decision hierarchy. What is their importance, and which factor is most important? The answers to these questions vary from one decision to the next; there may be no precise answer. But, as shown below, there are some methods (both qualitative and quantitative) which are used to evaluate and compare potential site locations.

1. Factor rating method:

is a general approach that is useful for evaluating a given alternative and comparing alternatives. Rating the factors according to their general importance can help decision makers to avoid placing too much emphasis on the wrong factors. Multiple factor rating system can be used to compare the attractiveness of several locations on the basis of more than one criterion. Factor rating system is probably one of the most widely used location selection techniques because they can be combine very diverse issues in to an easy –to-understand format. At the same time, it is important to recognize the fact that although the end result from this type of analysis is a quantitative number, factor rating systems are used to evaluate both qualitative and quantitative factors. Another reason that the factor – rating system approach is so popular is that it is relatively simple to use, requiring only six steps.

- ✓ Identify the specific criteria/factors to be considered in selecting a site.
- ✓ Assign a weight to each factor indicating its importance relative to all of the other factors that are being considered. Typically weight sum to 1
- ✓ select a common scale for rating each factor (for example 1-100)
- ✓ Rate (score) each potential location on each of the factors.
- ✓ Multiply each factor's score by the weight assigned to that factor
- ✓ Sum up the weighted scores for all of the factors and select that location with the highest total score.

Illustration:

To illustrate the factor rating system, consider the following fire extinguisher site selection problem. Three potential sites have been identified. Management has decided to use the following criteria and has assigned the following weights to each of the based up on their relative importance. The three locations are then related on each of these factors and a total score for each location is calculated as follows:

Location rating 1 to 100,

		Where 1 is bad and 100 is good			Weighted score		
Factor/criteria	Weight	Site A	Site B	Site C	Site A	Site B	Site C
Convenience for customer	0.2	60	70	65	12	14	13
Safety	0.1	75	85	60	7.5	8.5	6
Land cost	0.25	50	60	80	12.5	15	20
Availability of workers	0.05	90	70	75	4.5	3.5	3.75
Forecasted sales volume	0.15	80	90	85	-	12	13.5
Crime statistics	0.1	60	50	65	6	5	6.5
Cost of living	0.15	70	55	70	10.5	8.25	10.5
TOTAL	1.00				65.00	67.75	72.5

Site 'C' is better because it has the higher composite score.

2. Location break even analysis

Sometimes, it is useful to draw location break even charts which could aid in deciding which location would be optimal.

Consider the following example:

The location of a tractor factory in site **A** will result in certain annual fixed costs, variable costs and revenue. The figure would be different for site **B** and **C.** The fixed cost, variable cost and price per unit for the three sites are given below. Which location is best?

Site	FC	variable cost/unit
A	10,000	60
B	30,000	40
C	90,000	20

Solution

To solve this problem, we can use graphical method or profit analysis method.

a) graphical method

Compute TC for two different output levels (say 0 units and 5000 units).

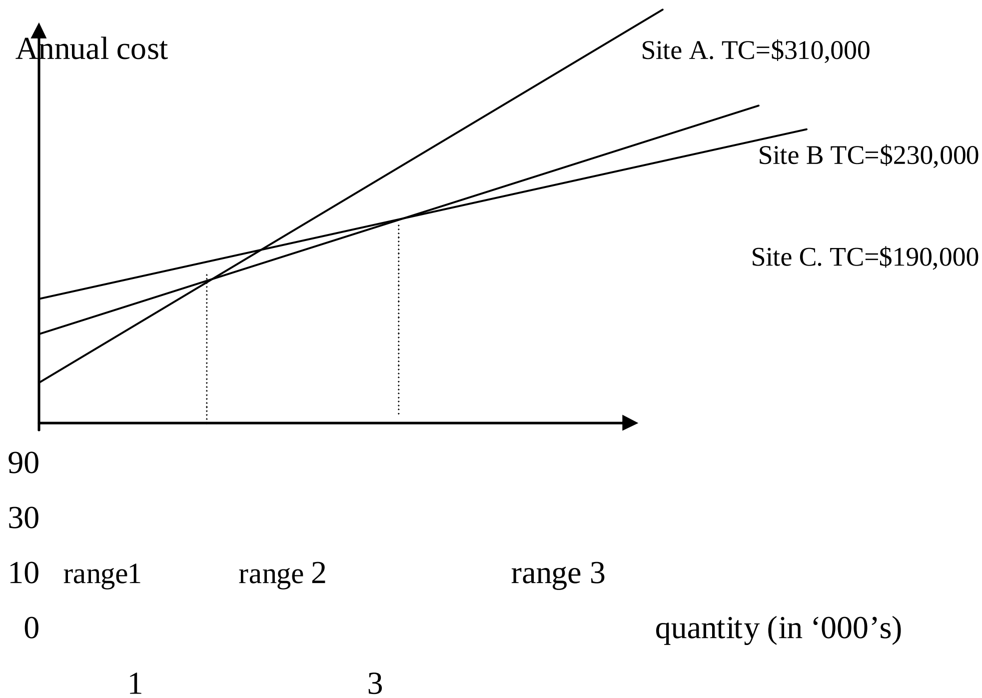
Case1. TC at zero output level

If Q=0, then TC=FC

Case2. TC (in $) at 5000 output level

Site	FC	total variable cost	total cost (FC+TVC)
A	10,000	60X5000=300,000	310,000
B	30,000	40X5000 =200,000	230,000
C	90,000	20X5000=100,000	190,000

After calculating the TC for two different output levels, plot the cost curve for all the communities on a single graph.



Using break even analysis, determine the break even quantity. Break even quantity indicates the relevant range over which each site is feasible.

Range (break even quantity) over which each site provides lowest cost can be calculated as follows:

Range1. Equate the cost equation of site A&B, that is:

10,000+60Q =30,000+40Q, then Q=1000 units

Range 2.Equate the cost equation of site B&C that is:

30,000+40Q = 90,000+20Q, then Q=3000 units

Range3. At range 3, Q> 3000

Thus, if output is less than 1000 unit, location A is best. If output is between 1000 & 3000 units, site B is best. For output level greater than 3000 units, site C is best.

b) Profit analysis method

Given the above example, which site is best for expected demand of 2000 units if price per unit is 75, 68 &80 for site A, B, &C respectively?

Solution

Calculate the total profit for each site at 2000 output level and select the site with the highest profit. Profit = TR-TC. Accordingly,

Profit for site A= (75X2000) - [10,000 + (60X 2000)], Profit = $20,000

Profit for site B= (68X2000) - [30,000 + (40 X 2000)], then profit = $26000

Profit for site C= (80 X 2000) - [90,000 + (20X 2000)], then, profit=$30,000

Thus, site C is the best location.

3. Centre of gravity method

Is a quantitative method for determining the optimal site for a facility based up on minimizing total distribution cost. The first step in the centre of gravity method is to locate each of the existing retail operations on the X and Y coordinate grid map. The purpose of the gird map is to establish relative distance between the sites. The centre of gravity or the site for distribution facility is then found by calculating the X and Y coordinate that result in minimizing the distribution costs among all facilities. To determine the site the following formula can be used.

$$Cx = \frac{\Sigma\, dixVi}{\Sigma Vi} \qquad Cy = \frac{\Sigma diyVi}{\Sigma Vi}$$

Where, Cx is X coordinate of the centre of gravity

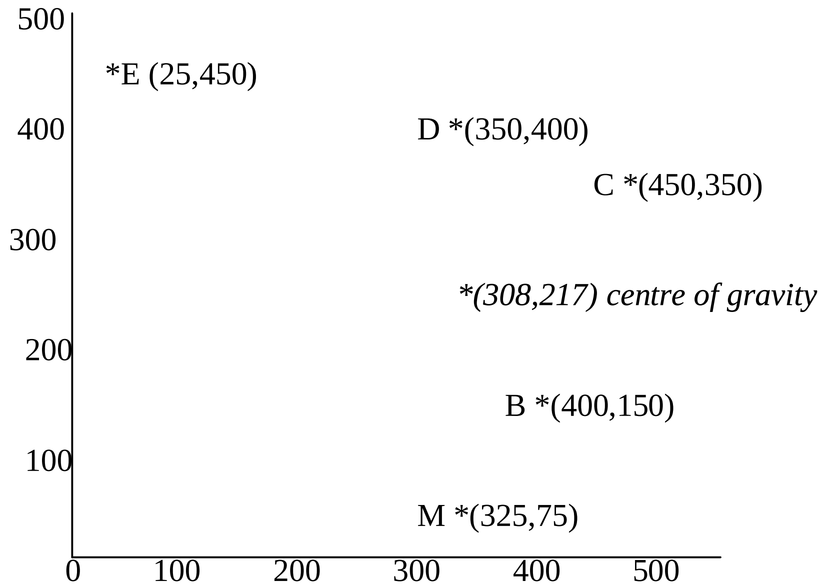
$CY = Y$ coordinate of the centre of gravity

$Dix = X$ Coordinate of the i^{th} location

$Diy = Y$ Coordinates of the i^{th} location

Vi = volume of goods transported to the i^{th} location

Example: A refining company needs to locate an intermediates ware house facilities between its refinery plant in place M and its major distributors B, C, D & E. The following shows the coordinate map for both the plants and distributors.



More over shipping volume from plant M to major distributor are given as follows

Location	M	B	C	D	E
Gallon of gasoline Per month (000,000)	1500	250	450	350	450

Solution

Using the above formula, we can calculate the coordinates of the centre of gravity i.e. the site of the new location.

$$Cx = \frac{(325X1,500) + (400X\ 250) + (450X450) + (350X350) + (25X450)}{1,5000 + 250 + 450 + 350 + 450} = 307.9$$

$$Cy = \frac{(75X\ 1,500) + (150X250) + (350X450) + (\ 400X350) + (450X450)}{1,500 + 250 + 450 + 350 + 450} = 216.7$$

The location of the new facility should be at 308 and 217 i.e. (308,217)

Capacity Planning

What Is Capacity?

A dictionary definition of capacity is 'the ability of hold, receive, store or accommodate'. In a general business sense, it is most frequently viewed as the amount of output that a system is capable of achieving over a specified period of time. Capacity can also be defined as the maximum output that can be produced over a given period of time. In a service setting, this might be the number of customers that can be handled 12 o'clock and 1 o'clock in the afternoon. In, manufacturing this might be the number of automobile that can be produced in a single shift. Generally, capacity is a relative term, and in an operations management context, may be defined as the amount of resource inputs available relative to output requirement over a particular period of time.

Factors Affecting Capacity

Capacity is affected by both internal and external factors. The external factor includes: government regulations (e.g. working hours, safety, pollution etc), union agreement, and suppliers capabilities.

The internal factor includes: product and service design, personnel and jobs(worker training, motivation learning job content and methods), plant lay out and process flow, equipment capabilities and maintenance, materials management, quality control system, product mix decision, and management capabilities.

Capacity Strategy

How much to increase or decrease capacity and when, is a strategic choice. For manufacturing firms, there are three major strategies for adding capacity: proactive, neutral and reactive. Each has its weaknesses and strengths.

i. **Proactive:** with a proactive strategy, management anticipates future growth and builds the facility so that it is up and running when the demand is there. With this strategy, opportunity cost resulting from lost sales due to an inability to meet demand are minimized, although the firm does have to allocate fixed costs over a relatively small volume of units during the plant's initial period of time. In this case there is **capacity cushion** (excess capacity) that is used in many service operations and in the growth stage of the product to ensure that demand can be met from existing resources. Firms that cannot create an inventory or demand back log must have excess capacity in order to deal with the extremes of demand.

ii. **Neutral:** a neutral strategy for adding capacity simply takes middle –of-the –road approach. Additional capacity becomes available when demand is about 50% of total capacity. This is the balanced strategy. Firms that compete in the cyclical industries and firms that are in the maturity stage of the product life cycle are likely to adopt this strategy. Such firms endeavor to match their capacity as closely as possible to near-term demand. Depending on the economic climate, they carry either excess capacity or excess demand. During precession, they will tend to have excess capacity. During economic expansion, they may develop short ages. To such firm, effectively anticipating changes in the economic cycle is very important, as is flexibility in capacity. They may prefer to lease rather than own, relay on temporary employees rather than hire a permanent staff, or find alternative uses for their capacity by developing complementary businesses.

iii. **Reactive:** when a reactive strategy is adopted, the plant capacity is not added until all of the planned output from the facility can be sold. Thus, with this strategy, the plant is not brought on line until demand equals 100%of its capacity. Operating cost is minimized with this approach, as the plant is producing at its desired optimal output, beginning with the first day of operations. This strategy is most conducive to process oriented operations that have very high fixed cost, regardless of the volume produced and low variable cost. E.g. paper mills, breweries and refineries.

Important Capacity Concept

1) BEST OPERATING LEVEL: The best operating level is that capacity for which the average cost is at the minimum. Note that as we move down the unit cost curve for each plant size, we achieve economies of scale until we reach the best operating level and then diseconomies of scale as we exceed this point.

2) ECONOMICS AND DISECONOMIES OF SCALE: The basic notion is well known: as a plant gets larger and volume increases, the average per unit of output drops because each succeeding unit absorbs parts of the fixed costs.

ECONOMICS OF SCALE: is a concept which state that the average unit cost of goods or services can be reduced by increasing its output rate. There are four principal reasons for why economics of scale can drive cost down when output increases:

A. *Fixed costs are spreads over more units:* the fixed cost includes heating cost, debt services, and management salaries. Depreciation of plant and equipment already owned is also a fixed cost in the accounting sense. When the output rate increases. The average unit cost drops because fixed costs are spread over more units.

B. *Construction costs are reduced:* certain activities and expenses are required in building small and large facilities alike: building permits, architects' fees, rental of building equipment, and the like. Industries such as breweries and oil refineries benefits from strong economics of scale because of this phenomenon.

C. *Costs of purchased materials are cut:* higher volume can reduce the cost of purchased materials and services. They give a purchaser a better bargaining position and the opportunity to take advantage of quantity discounts.

D. *Process advantages are found:* high volume production provides many opportunities for cost reduction. At a higher output rate, the process shifts towards a line process, with resources dedicated to individual products. The benefits from dedicating resources to individual products or services may includes spreading up the learning effects, lowering inventory, improving process and job design, and reducing the number of changeovers.

Diseconomies of Scale: At some point a facility can become so large that diseconomies of scale set in; that is, the average cost per unit increases as the facility size increase the reason is that excessive size can bring complexity, loss of focus, and inefficiencies that raise the average unit cost of a product or services. There may be too many layers of employees and bureaucracy, and management loses touch with employees and customers. The organization is less agile and loses the flexibility needed to respond to changing demand. Many large companies become so involved in analysis and planning that they innovate less and avoid risks. The result is that small companies outperform corporate giants in numerous industries.

3) LEARNING (EXPERIENCE) CURVE: Learning (experience) curve theory has a wide range of application in the business world. In manufacturing, it can be used to estimate the capacity requirement and the time for product design. Learning curves can be applied to individuals or organizations. Individual learning is improvement that results when people repeat a process and gain skill or efficiency from their own experience. That is 'practices make perfect'. Organizational learning results from practices as well, but it will also come from changes in administration, equipment, and product design. In organizational settings, we expect to see both kinds of learning occurring simultaneously and often describe the combined effect with the single learning curve. Generally, it is quite possible that initially the operator takes longer time to accomplish the job as compared to the subsequent cycles when he would have acquired the necessary skill and feel in 'learning' the job. Usually, this learning curve is hyperbolic in nature. Though the learning curve concept is important one, it has not been given due consideration. Scholars feel it would be unfair if learning phase is not accounted for while determine capacity requirement and time standard.

4) CAPACITY FOCUS: This means that a firm should not expect to excel in every aspect of manufacturing performance: cost, quality, flexibility, short lead time, and low investment. Rather, it should select a limited set of tasks that contribute the most to corporate objectives.

5) CAPACITY BOTTLENECKS: Is an operation that has the lowest effective capacity of any operation in the process and thus limits the systems output. True expansion of a process's capacity occurs only when bottleneck capacity is increased. The long term capacity bottlenecks can be expanded in various ways. Investment can be made in new equipment; bottleneck's capacity can also be expanded by operating it more hours per week such as going from one shift operation to multiple shifts or going from five work days per week to seven work days per week. Managers also might relieve the bottle neck by redesigning the process.

Long term capacity expansion is not the only way to ease bottlenecks. Overtime, temporary or part-time employees, or temporarily out sourcing or sharing during peak demand period are short term options.

6) CAPACITY FLEXIBILITY: Capacity flexibility means having the ability to rapidly increase or decrease production levels, or to shift production capacity quickly from one product or service to another. Such flexibility is achieved through:

A. FLEXIBLE PLANTS: perhaps the ultimate plant flexibility is the zero-change over time plant. Using movable equipment, knockdown walls, and easily accessible and re routable utilities e.g. tents. Such a plant can adapt to change in real time.

B. FLEXIBLE PROCESS: flexible processes are epitomized by flexible manufacturing systems on the one hand and simple, easily set up equipment on the other hand. Both of these technological approaches permit rapid low cost switching from one product line to the other, enabling what is referred to as economics of scope. By definition, economics of scope exist when; multiple products can be produced at a lower cost in combination than they can separately.

C. FLEXIBLE WORKERS: flexible workers have multiple skills and the ability to switch easily from one kind of task to another. They required broader training than specialized workers and need managers and staff support to facilitate quick changes in their work assignment.

MEASURES OF CAPACITY

No single capacity measure is applicable to all types of situations. For example, a retailer measure capacity as annual sale dollars generated per square foot, a theater measure capacity as number of seats, and a job shop measure capacity as number of machine hour.

Important terms used to measure the capacity:

a. ***Design capacity (peak capacity):*** is the maximum rate of output achieved under *ideal condition*. In other words, it is a planned (engineered) rate of output of goods or services under normal conditions. Peak capacity can be sustained for only a short time, such as few hours in a day or a few days in a month. A process reaches it by using marginal methods of production such as excessive over time, extra shifts, temporality reduced maintenance activities, over staffing, and subcontracting. Although they can help with temporary peaks, these options cannot be sustained for long. Employees do not want to work excessive over time for extended periods, overtime and night –shifts premium drive up costs and quality drops. Generally, overtime soared and exhaustive workers dragged down productivity. Thus, when operating close to peak capacity, a firm can make minimal profits or even lose money, despite high sales levels.

b. ***Effective capacity*:** is the maximum output that a process or firm can economically sustain under normal conditions. It is the greatest level of output the firm can reasonably sustain by using realistic employee work schedules and the equipment currently in place.

   It is the maximum possible given predicted problems such as a product mix, problems in scheduling and balancing operations, machine maintenance, quality factors, and so on. It also includes lunch breaks, and coffee breaks. It is typically less than or equal to the design capacity.

c. ***Output capacity:*** is the actual output of a system at a given point in time. It is even less than effective capacity , for it is affected by unpredicted short range factors such as equipment break down, absenteeism, shortage of raw materials, productivity, and other factors that are outside the control of the operations manager.

d. ***Capacity utilization*:** is the degree to which equipment, space or labor is currently being used. It the ratio of capacity used during a fixed period of time to the available capacity during that same time period.

$$Utilization \ = \ \frac{actual\ capacity\ (or\ capacity\ used)}{\text{Designed capacity}}\ \text{X}\ \ 100\%$$

$$Efficiency \ = \ \frac{actual\ out\ put}{\text{Effective capacity}}\ X\ 100\%$$

e. ***Rated ca*pacity:** when capacity is measured relative to equipment alone, the appropriate measure is rated capacity. It is an engineering assignment of maximum annual output, assuming continuous operations except for an allowance for Norman maintenance, and repair downtime.

$$Rated\ capacity\ =\ design\ capacity\ \boldsymbol{X}\ effective\ capacity\ \boldsymbol{X}\ efficiency$$

Rated capacity will always be less than or equal to effective capacity.

$$Design\ (peak)\ capacity\ >\ effective\ capacity\ >\ rated\ capacity$$

Example 1 If operated around the clock under ideal conditions, the fabrication department of an engine manufacturer can make 100engines per days. Management believe that a maximum output rate of only 45 engines per day can be sustained economically over a long period of time Currently, the department is producing 50 engines per day. What is the utilization of the department related to designed capacity? Efficiency capacity

Soln: $actual\ output = 50, effective\ capacity = 45, \&\ designed\ capacity = 100\ engine$

$$Utilization\ =\ 50/100\ X\ 100\%\ =\ 50\%$$

$$Efficiency\ =\ 50/45\ X\ 100\%\ =\ 111\%$$

Example 2 A call centre might have 1200 work station, but, on a given day, only, have 600 of them staffed with operators. Determine capacity utilization.

Solution: In this case, the call center would be working at $\frac{600\ X\ 100\%}{1200}$ or 50% capacity utilization that day.

Example 3 The Sara James Bakery has a plant for processing breakfast rolls. The facility has an efficiency of 90%, and the effective capacity is 80%. Three process lines are used to produce the rolls. The line operate 7 days a week and three 8 hours shift per day. Each line was designed to process 120 standard rolls per hour. What is designed capacity? Rated capacity?

$$Number\ of\ lines = 3, number\ of\ hours =\ 7 days\ X\ 24\ hrs\ per\ day$$

$$=\ 168\ hrs, number\ of\ rolls/hrs = \mathbf{120}$$

$$Designed\ capacity = number\ of\ lines\ X\ number\ of\ hours\ X\ number\ of\ roles\ per\ hour$$

$$= 3\ X\ 168\ X\ 120$$

$$= \mathbf{60,480\ rolls\ per\ week}.$$

$$Rated\ capacity = 60480\ rolls\ per\ week\ X\ 0.8\ X\ 0.9$$

$$= \mathbf{43546\ rolls\ per\ week}$$

$$\mathbf{Capacity\ cushion} = \frac{\mathbf{designed\ capacity - actual\ capacity}}{\mathbf{Actual\ capacity}} \mathbf{X\ 100\%}$$

Example 3: if the expected annual demand on a facility is birr 10 million worth of products per year and the design capacity is 12 million birr per year, find the capacity cushion.

$$\mathbf{Capacity\ cushion} \frac{\mathbf{=12,000,000-10,000,000}}{\mathbf{10,000,000}} \mathbf{X\ 100\% = 20\%}$$

Time Durations for capacity Planning

Capacity planning is central to long-term success of an organization. Too much capacity can be as agonizing as too little capacity. The objective of capacity planning is to specify which level of capacity will meet market demand in cost efficient way. Capacity planning is generally viewed in three time duration:

A. **LONG RANGE (GREATER THAN ONE YEAR):-** *when* productive resources take a long time to acquire or dispose of. Example: building, equipment or facilities decisions. Long range planning requires top management participation and approval.

B. **INTERMEDIATE RANGE: -** monthly or quarterly plans for the next 6 to 18 months. Here capacity may be varied by such alternatives as hiring part timer, lay off, new tools, minor equipment purchase and sub contracting.

C. **SHORT RANGE: -** less than one month. This is tied into the daily or weekly scheduling process and involves making adjustment to eliminate the variance between planned output and actual output. This includes alternatives such as overtime, personnel transfers, and alternative production routings.

CAPACITY PLANNING DECISION

Although each situation somewhat different, a four step procedure generally can help managers make sound capacity decisions. In describing this procedure, we assume that management has already performed the preliminary step of determining existing capacity.

STEP 1: ESTIMATE FUTURE CAPACITY REQUIREMENTS: The foundation for estimating long term capacity needs is forecasts of demand, productivity, competition, and technological changes that extend well into the future. Unfortunately, the farther ahead you look the more chance you have of making an inaccurate forecast.

The demand forecast has to be converted to a number that can be compared directly with the capacity measure directly used. Suppose that capacity is expressed as the number of available machines at an operation. When just, one product (services) is being processed, the number of machines required, M, is (for single product)

$$\text{No. of machines required} = \frac{\text{processing hours required for year's demand}}{\text{Hours available from one machine per year after deducting desired cushion}}$$

$$M = \frac{Dp}{N\,[1-(c/100)]}$$

$$Where, D = No.\ of\ unit\ (customer)\ forecast\ per\ year$$

$$p = processing\ time\ (in\ hours\ per\ unit/customer)$$

$$N = total\ number\ of\ hours\ per\ year\ during\ which\ the\ process\ operate$$

$$C = desired\ capacity\ cushion$$

If multiple products or services are involved, extra time is needed to change over from one product to the next. Set up time is the time required to change a machine from making one product or service to making another.

$$Total\ setup\ time = D \div (by\ the\ average\ lot\ size)$$

When there are multiple products (services)

$$No.\ of\ machines = processing\ and\ set\ up\ hours\ required\ for\ year's\ demand,$$

Required

$$\frac{Summed\ over\ all\ products}{\text{Hrs available from one machine per year, after deducting desired cushion}}$$

Example: a copy center in an office building prepares bound reports for two clients. The center makes multiple copies (the lot size) of each report. The processing time to run and bind each copy depends on the number of pages. The center operates 250 days per year, with one eight – hours shift. Management believes that a capacity cushion of 15% is best. If currently have three copy machines. Based on the following table of information, determine how many machines are needed at the copy center.

Item	Client X	Client Y
Annual demand (copies)	2,000	6,000
Standard processing time (hrs/copy)	0.5	0.7
Average lot size (copies per report)	20	30
Standard setup time (hours)	0.25	0.40

Solution: $M = \frac{[(2000X0.5) + (2000/20)\ X0.25] \quad + [(6000X0.7) + (6000/30)X0.4]}{[\ (250 \text{ days/year})\ (1 \text{ shift/day})\ (8\text{hrs/shift})]\ (1.0 - 15/100)} = 5{,}305/1700 = 3.12$

Round up to the next integer gives a requirement of 4 machines.

STEP2. IDENTIFY GAPS: A capacity gap is any differences (positive or negatives) between projected demand and current capacity. Identifying gaps requires use of the correct capacity measures. Complications arise when multiple operations and several resource inputs are involved. Expanding the capacity of some operations may increase over all capacity. However if one operation is a bottle neck, capacity can be expanded only if the capacity of the bottlenecked operation is expanded. Bottle neck is any resource whose capacity is less than the demand placed up on it.

Example: grandmother's chicken restaurant is experiencing a boom in business. The owner expects to serve a total of 80,000 meals this year. Although the chicken is operating at 100% capacity, the dining room can handle a total of 105,000 diners per year. Based on the following forecasted demand for the next 5 years, determine the capacity gap.

Year	Meals	Capacity Gap	Demand Capacity
1	90,000	90,000 - 80000=10,000	capacity is positive
2	100,000	100,000 - 80000= 20000	capacity is positive
3	110,000	110,000- 80,000=30,000	110,000- 105,000 =5000
4	120,000	120,000 -80,000 = 40000	120,000-105,000=15,00
5	130,000	130,000-80,000 = 50,000	130,000-105,000 =25,000

NB: The kitchen is currently the bottleneck at 80,000 meals per years. For the first two years the capacity of dining room (105,000) is greater than demand. Capacity gaps exist for the last three years as shown above.

STEP3. DEVELOP ALTERNATIVES: After determining capacity gap, the next logical step is to develop alternative plans to cope with projected gaps. One alternative, called the **base case**, is to do nothing and simply lose orders from any demand that exceeds current capacity. Other alternative are various timing and sizing options for adding new capacity. Additional possibilities includes: expanding at a different locations and using short term options such as overtime, temporary workers, and subcontracting.

STEP4. EVALUATE THE ALTERNATIVES: In this step, the managers evaluate each alternative, both quantitatively and qualitatively.

Qualitative concerns: qualitatively the manager has to look at how each alternative fits the overall capacity strategy and other aspects of the business not covered by the financial analysis. Of particular concerns might be uncertainties about demand, competitive reaction, technological change, and cost estimate. Some of these factors cannot be quantified and has to be assessed on the bases of judgment and experience. Others can be quantified, and the managers can analyze each alternative by using different assumptions about the future. One set of assumption could represent a worst case, where demand is less, competition is greater, and construction costs are higher than expected. Another set of assumption could represent the most optimistic view of the future. These types of what-if analysis allow the manager to get an idea of each alternative's implications before making a final choice.

Quantitative concerns: quantitatively, the manager estimates the changes in cash flows for each alternative over the forecasted time horizon compared top the base case. Cash flow is the different between the flows of funds in to and out of an organizations over a period of time, including revenues, costs, and changes in assets and liabilities.

STEP5.MAKE THE CHOICE: Finally, based on the evaluation results, the manager must make the choice.

TOOLS FOR CAPACITY PLANNING

Long term capacity planning requires demand forecasts for an extended period of time .unfortunately, forecast accuracy declines as the forecasting horizon lengthens. In addition in anticipating what competitors will do increases the uncertainty of demand forecasts. Finally, demand during any period of time is not evenly distributed; peaks and valleys of demand may (and often do) occur within the time period. These realities necessitate the use of capacity cushion. In this section, three types of tools that deal more formally with demand uncertainty and variability are introduced.

1) **WAITING LINE MODELS:** waiting line models often are useful in capacity planning. Waiting line tend to develop in front of a work centre, such as an airport ticket counter, a machine centre , or a central computer. The reason is that the arrival time between jobs or customers vary and the processing time may vary from one customer to the next. Waiting line model use probability distribution to provide estimate average customer delay time, average length of waiting lines, and utilization of the work centre. Managers can use this information to choose the most cost effective capacity, balancing customer services and the cost of adding capacity.
2) **SIMULATION:** more complex waiting line problems must be analyzed with simulation. It can identify the process's bottlenecks and appropriate capacity cushion even for complex process with random demand patterns with predictable suggest in demand during a typical day.
3) **DECISION TREES:** a decision tree can be particularly valuable for evaluating different capacity expansion alternatives when demand is uncertain and sequential decisions are involved. A decision tree is a systematic model of the sequence of steps in a problem and the conditions and consequences of each step.

Chapter Summery

Based on the discussion made so far, we can define Design as: the process of structuring of components parts /activities of products so that as a unit it can provide value for the customer. The product will be designed in terms of size, color, shape, content and other related dimensions. Design greatly affects operation by specifying the products that will be made and it is the prerequisite for operations to occur. The philosophies towards product design are: market pull, technology push and inter functional. Product design must pass through some successive stages such as: idea generation, screening the gathered ideas, initial product design and development, prototype construction, prototype testing, final product and production process design and full scale operations. There are different factors (approaches) that we need to consider while designing the product such as: robust design, concurrent design, group technology, modular design, ergonomics (human engineering) CAD & CAM, Taguchi's approach, consumer quality level, product diversification and simplification. Service design is not identical with product design as service is intangible it is more challenging than product design. Process flow can be classified based on: types of product flow and types of customer order. Types of process, based on product flow includes: continues/line flow, intermittent/job shop flow, and project flow. On the other hand, based on customer order process can be make to stock or make to order.

Facility location decisions are, strategic, long term and non repetitive in nature. When a new facility is to be established, managers generally consider four options in location planning. One is to expand an existing facility, to add new location while retaining existing ones, shut down at one location and move to another, or doing nothing.

There are four location decision hierarchies**:** Global (international), Regional, Community, and Site considerations.

There are some methods which are used to evaluate and compare potential site locations:

Factor rating method, break even analysis method, and centre of gravity method.

Facility layout refers to an optimum arrangement of different facilities including man, machine, equipment, materials, etc. Since a layout once implemented cannot be easily changed and costs of such changes are substantial, the facilities layout is a strategic decision.

The need for layout planning arises both in the process of designing new facilities and in redesigning existing facility. The most common reasons for redesign of lay out include:

- ✓ Inefficient operations, accidents or safety hazards, Changes in the design of products or services, introduction of new products or businesses or changes in the volume of output, changes in methods or equipments, morale problems.

There are three types of lay out decisions: product lay out, process layout and fixed positional layout. Finally, line balancing is a procured that can be used to optimize the assignment of tasks to work centers

Short answer questions

1. What is product design?

2. explain the characteristics of continuous/ line flow

3. explain the characteristics of intermittent flow

Review questions

Multiple choice questions

1. Intends to achieve better performance at lower cost by eliminating hidden, invisible and unnecessary costs without scarifying quality
   - A. Value analysis
   - B. CAD
   - C. Ergonomics
   - D. Taguch approach
2. market pull philosophy of product design focus on:

A. sale what can produced
B. produce what can be soled
C. consider technology before designing
D. all are correct

3. select the correct match
   - A. line----furniture
   - B. intermittent---oil refinery
   - C. shoe factory ----make to order
   - D. job shop----hotel
4. Which one is correct?
   - A. high flexibility leads to product standardization
   - B. high standardization leads to better customization
   - C. flexibility is more simple in manufacturing than service
   - D. highly flexible process is difficult automate
5. the process design tools that uses symbol to denotes what happens to the product as it progress productive facilities is
   - A. assembly drawing
   - B. flow process chart
   - C. assembly chart
   - D. route sheet
6. Which one represent the process of deciding on the best physical arrangement of all resources that consume space within plant?
   - A. Location decision
   - B. Product design
   - C. Reverse engineering
   - D. Layout decision
   - E. Manufacturing
7. The amount of time with in which each work stations has to complete its set of tasks before the product moves to the next station is
   - A. Precedence relationship
   - B. Operating cycle
   - C. Cycle time
   - D. Idle time
   - E. None

8. All are among the advantages of 'U' shaped layout over the straight line, except:
   A. Increasing communication among workers
   B. Increasing flexibility of work assignments
   C. Facilitating teamwork
   D. Used when raw materials & finished goods enter & leave at different points
   E. None
9. The apportionment of sequential work activities into work stations so that each work station has approximately equal time groups represents:
   A. Layout decision
   B. Location decision
   C. Line balancing
   D. Demand management
10. All of the following can be reasons for facility layout & re-layout analysis except:
    A. New plant location
    B. Change in the level of demand
    C. Change in the design of existing product
    D. High efficiency in current space utilization
    E. None
11. What is the efficiency of a line with a balance delay of 20%?
    A. 60%
    B. 100%
    C. 80%
    D. 120%
    E. 40%
12. Which of the following location options is the best?
    A. add new location while retaining the existing one
    B. expanding the existing location
    C. doing nothing
    D. shut down one location and moving to another
13. Which one is **false** about process layout?
    A. Less time is lost because workers do not move from one station to the other
    B. Individual based incentive system can be used
    C. Possible to isolate machine that create interferences
    D. It is more flexible & less vulnerable to change
    E. None of the above

14. What is the center of gravity method?

A. A method that determines the location of a facility closest to the main supplier

B. A method that determines the location of a facility that will minimize shipping cost and travel time to various destinations.

C. A method that determines the location of a facility in the middle-point of all suppliers.

D. A method that determines the location of a facility closest to the most number of consumers.

E. None

Consider the following 'factor rating' method and answer the following three questions

ABC Company wants to establish a new branch. Four potential sites have been identified. Management has decided to use the following criteria and has assigned the following weights to each based up on their

		site			
		Score out of 100			
Criteria	weight	Kenya	Ethiopia	Sudan	Uganda
Labor	0.2	69	55	59	60
Crime statistics	0.3	80	40	63	78
Land cost	0.04	90	85	95	75
RM availability	0.4	70	60	50	40
Cost of living	0.06	60	70	90	80

15. Which criterion is more relevant for the company?

A. Labor
B. Land cost
C. Raw material
D. Crime statistics
E. Cost of living
F. All are equally important

16. According to this data, land is expensive in

A. Kenya
B. Ethiopia
C. Sudan
D. Uganda
E. Cannot determined

17. Cheap labor is easily available in

A. Kenya
B. Ethiopia
C. Sudan
D. Uganda
E. Cannot be determined

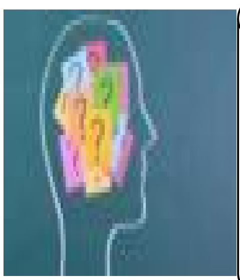
CHAPTER -FOUR

OPERATIONS PLANNING AND CONTROL

Objectives:

On successful completion of this section, you should be able to**:**

- Define the term scheduling
- Appreciate the importance and benefits of scheduling
- Understand the priority rules to assign jobs to machines
- Explain the performance measures of job shop scheduling
- Understand the concepts of Scheduling n jobs on one machine and Scheduling n jobs on two machine
- Define aggregate planning
- Identify optional strategies for developing an aggregate plan
- Understand the strategies required during aggregate planning
- Solve an aggregate plan via the transportation method of linear programming



Key Brain Storming questions

- Define the aggregate plan.
- Explain why we use an aggregate or a composite product when developing the aggregate plan.
- Compare and contrast the level and the chase aggregate plans.

4.1 AGGREGATE PLANNING

4.1.1 The Role of Aggregate Planning

Aggregate planning is an integral part of the business planning process. This process begins when your company's top management gathers input from finance, marketing, operations, and engineering to develop a strategic business plan. The strategic business plan, with its long-term focus, provides your company's direction and objectives for the next 2 to 10 years. The strategic business plan is normally updated and reevaluated annually. The strategic business plan is also the starting point for sales and operations planning. It states the company's objectives for profitability, growth rate, and return on investment.

A. **Marketing Plan:** The marketing plan is intended to meet the objectives of the strategic business plan. The marketing plan identifies the sales needed to achieve the profitability level, the growth rate, and the return on investment stated in the strategic business plan.

B. **Aggregate or Production Plan:** The aggregate plan, also called the ***production plan***, identifies the resources needed by the operations group during the next 6 to 18 months to support the marketing plan. The aggregate plan details the aggregate production rate and the size of the work-force, which enables planners to determine the amount of inventory to be held; the amount of overtime or under time authorized; any authorized subcontracting, hiring, or firing of employees; and back-ordering of customer orders. The aggregate plan is usually updated and reevaluated monthly by the operations group.

C. **Financial and Engineering Plans:** The ***financial plan*** indicates the sources and uses of funds, expected cash flows, anticipated profits, and projected budgets. The ***engineering plan*** supports the research and development of new products introduced in the marketing plan and subsequently planned for in the aggregate plan.

D. **Master Production Schedule:** The sales and operations plan is evaluated and updated monthly. The master production schedule and the detailed sales plan are reviewed weekly or even daily. The master production schedule is an anticipated production schedule and is typically stated as specific finished goods.

Aggregate plan: statement of a company's *production rates, workforce levels, and inventory holding* based estimates of customer requirements and capacity limitations.

Production plan: a manufacturing firm's aggregate plan, which generally focuses on production rate and inventory holdings.

It determines the *quantity and timing* of production for the immediate future. *Aggregate planning is an intermediate term planning decision.* It is the process of planning the quantity and timing of output over the intermediate time horizon (3 months to one year). Within this range, the physical facilities are assumed to be fixed for the planning period. Therefore, fluctuations in demand must be met by varying labor and inventory schedule. Aggregate planning seeks the best combination to minimize costs.

4.1.2 Typical Objectives of Aggregate Planning

The many functional areas in an organization that give input to the aggregate plan typically have conflicting objective for the use of the organization's resources. Six objectives usually are considered during development of a production or staffing plan, and conflicts among them may have to resolve:

1. **Minimize cost/maximize profit:** if customer demand is not affected by the plan, minimizing cost will also maximize profit.
2. **Maximize customer service:** improving delivery time and on time delivery may require additional workforce machine capacity or inventory resources.
3. **Minimize inventory investment:** inventory accommodations are expensive because the money could be used for more productive investments.
4. **Minimize changes in production rate:** frequent change in production rates can cause difficulties in coordinating the supplying of materials and required production line rebalancing.
5. **Minimize changes in workforce levels:** fluctuating workforce levels may cause lower productivity because new employees typically need time to fully productive.
6. **Maximize utilization of plant and equipment:** process based on a line flow strategy requires uniformly high utilization of plant and equipment.

4.1.3 Aggregate Planning Strategies

The variables of the production system are labor, materials and capital. More labor effort is required to generate higher volume of output. Hence, the employment and use of overtime (OT) are the two relevant variables. Materials help to regulate output. The alternatives available to the company are inventories, back ordering or subcontracting of items. These controllable variables constitute pure strategies by which fluctuations in demand and uncertainties in production activities can be accommodated by using the following steps:

- *Vary the size of the workforce*: Output is controlled by hiring or laying off workers in proportion to changes in demand.

- *Vary the hours worked*: Maintain the stable workforce, but permit idle time when there is a slack and permit overtime (OT) when demand is peak.
- *Vary inventory levels*: Demand fluctuations can be met by large amount of inventory.
- *Subcontract*: Upward shift in demand from low level. Constant production rates can be met by using subcontractors to provide extra capacity.
- *Change prices* or other factors to influence demand
- Backlogs , backorder and stocks:

4.1.4 Types Of Aggregate Planning Strategies

Managers often combine ***reactive*** (workforce adjustment, anticipation of inventory, workforce utilization, vacation schedules, subcontractors and Backlogs, backorder and stocks) and ***aggressive*** (complementary products, and creative pricing) alternatives in various ways to arrive at an acceptable aggregate plan.

Level strategy: a strategy that maintains a constant workforce level or constant output rate during the planning horizon. When a level strategy used the first method, marinating a constant workforce level, it might consist of not hiring or laying off workers (except at the beginning of the planning horizon), building up anticipation inventories to absorb seasonal demand fluctuations, using under-time in slack periods and overtime up to contracted limits for peak periods. When level strategy uses the second method, maintaining a constant output rate, it allows hiring and layoffs in addition to other alternatives of first level strategy. The key to identifying a level strategy is whether the workforce or output rate is constant.

Chase strategy: a strategy that matches demand during the planning horizon by varying either the workforce level or the output rate. When a chase strategy uses the first method, varying the workforce level to match demand, it relies on just one reactive alternative-workforce variation. This chase strategy has the advantage of no inventory investment, overtime, or under-time. However it has some drawback, including the expense of continually adjusting workforce levels, the potential alienation of the workforce, and the loss of productivity and quality because of constant change in the workforce.

The second chase strategy, varying the output rate to match demand, opens up additional reactive alternatives beyond changing the workforce level. Sometimes called the *utilization strategy*, the extent and timing of the workforce's utilization is changed through overtime, under- time and vacation are taken. Subcontracting, including temporary help during the peak season, is another way of matching demand.

Mixed strategy: Strategies that consider and implements a full range of receive alternatives and goes beyond a "Pure" chase or level strategy. Whether management chooses a pure strategy or some mix the strategy should reflect the organizations environment and planning objectives.

4.1.5 Developing the aggregate plan

Here are the steps in developing an aggregate plan:

Step 1 Identify the aggregate plan that matches your company's objectives: level, chase, or hybrid.

Step 2 Based on the aggregate plan, determine the aggregate production rate: If you use the level plan with inventories and back orders, the aggregate production rate is set equal to average demand. In addition, if you allow no back orders, the size of the workforce is changed initially so that all demand is met on time.

If you use the chase aggregate plan, calculate how much output capacity you need each period. Calculate how many units will be produced on regular time and overtime and how many units will be subcontracted.

Step 3 Calculate the size of the workforce: If you use the level aggregate plan, calculate how many workers you need to achieve the average production rate needed.

If you change capacity each period with hires and fires, calculate how many workers you need each period and make the necessary change in the workforce.

If you change capacity through a variety of options, calculate how much of a particular option you need each period.

Step 4 Test the aggregate plan: Using the production rate and initial workforce size, calculate your inventory levels (excesses and shortages), any shortages you face, expected number of employees hired and fired, and when you will need overtime.

Calculate the total costs for your plan.

Step 5 Evaluate the plan's performance in terms of cost, customer service, human resources, and operations.

After you develop a plan, it is critical to evaluate it in terms of cost, customer service, operations, and human resources. Cost comparisons are simple if you are comparing similar ending positions—that is, plans with the same ending inventory level or producing the same number of units.

The comparisons are less clear when plans produce different quantities and leave different ending inventories. In this case, you can use a per unit cost comparison. To do this for customer service, measure how many back orders were placed during each period and throughout the duration of the plan. Decide whether this is an acceptable level of customer service to satisfy marketing's objectives. Assess the plan first in terms of operations, then in terms of human resources. Are the workers putting in excessive overtime one month and doing little the next? How does this plan affect the workforce? Does it lower morale or does it provide stability for the workers? When you evaluate the plan from several perspectives, you can decide how it can best satisfy your company's objectives.

Example: BLUE RAIDERS Computer, a new PC mail order company, is in need of an aggregate planning for the next five months. The company has gathered the following data:

Demand Forecast:

Month 1	Month 2	Month 3	Month 4	Month 5
700	800	400	400	600

Costs:

Inventory holding cost	$25/PC/month
Stock out cost	$100/PC
Subcontracting (marginal cost above in-house production)	$200/PC
Regular time labor cost	$10/hr
Overtime labor cost	$15/hr
Hiring cost	$500/worker
Layoff cost	$1000/worker

Other Data:

Beginning Inventory	100
Ending Inventory	200

Current Work Force	10
Labor Hours/PC	4 hrs
Workdays/month	20 days
Hours/day	8 hrs

Determine and evaluate production, work force, and inventory levels for the company for each month by using following strategies:

1. Level Strategy: Maintains a constant production rate or work-force level over the planning horizon. Assuming no overtime and subcontracting.

Regular labor cost/worker/month = $10 * 8 *20 = $1600

Adjusted demand for month 1 and month 5:

Production = Average demand / month = [(700+800+400+400+600)+(200-100)]/5= 3,000/5 = 600

Production/month/worker = (8*20)/4= 40

Work force level = 600/40 = 15 workers

Month	Production	Demand	Beginning Inventory	Ending Inventory	Stock Out
1	600	700	100	0	0
2	600	800	0	0	200
3	600	400	0	0	0
4	600	400	0	200	0
5	600	600	200	200	0

Cost Evaluation:

	$25 * (50+0+0+100+200) = $8750
Lost sale cost	= $100 * 200 = $2,000
Regular labor cost	$1,600 * 15 *5 = $120,000
Hiring/firing cost	$500 * 5 = $2,500
Total cost	$133,250

2. Chase Strategy: Adjust production rate or work force levels (by hiring and layoffs) to match

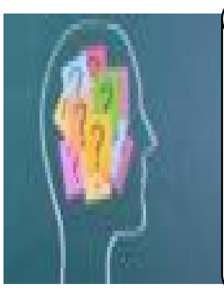
Inventory holding cost

the demand requirements over the planning horizon. Assuming no overtime and subcontracting.

Month	Demand (adjusted)	# workers needed	Hire	fire	Beginning Inventory	Ending Inventory
1	600	15	5		100	0
2	800	20	5		0	0
3	400	10		10	0	0
4	400	10			0	0
5	800	20	10		0	200

Cost Evaluation:

Hiring cost	$500 * (5+5+10) = $10,000
Firing cost	$1000 *10=$10,000
Regular labor cost	$1,600*(15+20+10+10+20) = $120,000
Inventory Cost	$25 * (50 + 100) =3,750
Total cost	$143,750



Key Brain Storming questions

- Explain how finite loading is done.
- Explain the benefits of finite loading.
- Describe forward scheduling.
- Describe backward scheduling.

4.2 OPERATIONS SHEDULING

Concepts of scheduling

What is scheduling?

Scheduling is the processes of determining the starting and completion times to jobs. It is the determination of when labor, equipment and facilities are needed to produce a product or provide a service. Scheduling is a time table for: performing activities, using resources, or allocating facilities. Generally, a schedule specifies the timing and sequence of production.

Schedule must be realistic; that is they must be capable of being achieved within the capacity limitations of the manufacturing facilities.

Scheduling should be clearly differentiated from aggregate planning. The purpose of scheduling is to ensure that available capacity is efficiently and effectively used to achieve the organization's objectives. The purpose of aggregate planning is to determine the resources (labor, equipment, space etc.) that should be acquired for scheduling.

Often several jobs might be processed at one or more work stations. Typically a variety of tasks can be performed at each work station which make effective scheduling a must rather than an alternative. Sequencing & loading should be considered during scheduling activity.

Sequencing: sequencing is concerned with developing an exact order (or sequence) of job processing. It is the determination of the order in which jobs are processed. One of the oldest sequencing methods is the Gant chart. Gant chart is a bar chart that shows a job's progress graphically or compares actual against planed performance.

Loading: is the assignment of work to specific resources/ machines. It is simply the process of assigning work to individual workers or machine. Loading can be: finite loading, infinite loading, back ward loading and forewarned loading.

1. *Finite loading*: refers to loading activities with regard to capacity. Tasks are never loaded beyond capacity.
2. *Infinite loading*: loading activity without regard to capacity.
3. *Back ward loading* begins with the due date for each job and loads the processing time requirements against each work centre by proceeding back ward in time. The

purpose of back ward loading is to calculate the capacity required in each work centre for each time period.

4. *Forewarned loading* begins with the present date and loads jobs forwards in time. The processing time is accumulated against each work centre, assuming infinite capacity. The purpose of forewarned loading is to determine the approximate completion date of each job and the capacity required in each time period.

Objectives of scheduling

The objectives of scheduling includes minimizing: job lateness, response time, completion time, overtime, idle time, work in process inventory, and maximizing machine and labor utilization.

Self check questions

1. Explain the concept of sequencing and loading
2. Explain the types of loading

**** Scheduling is common for manufacturing as well as service sectors.

4.2.1 Scheduling in manufacturing

Scheduling in manufacturing is the process of assigning priorities to manufacturing orders and allocating workloads to a specific work centers. Scheduling is challenging if the task variety is high. This is a case particularly for the job shop scheduling. In the following discussion, we will concentrate on scheduling issues for job shop production.

Job shop scheduling

For job shop production scheduling decision can be quite complex**.** What makes Scheduling so difficult in a job shop is the variety of jobs (customer orders) that are processed, each with distinctive routing & processing requirement. In a pure job shop, there are several jobs to be processed, each of which may have different routing among department or machines in the shop. In designing a scheduling and control system for a high variety of activities, sequencing and prioritizing should be emphasized.

Priority rules for allocating jobs to machine- sequencing

As discussed above, sequencing is prioritizing jobs that have been assigned to limited resources. Sequencing is simple if work centers are lightly loaded and need the same processing time. But if work centers are heavily loaded there will be longer waiting time and idle time. In this case to minimize the waiting and idle time, we must prioritize the tasks by using priority rules.

Priority rules are the criteria by which the sequence of jobs is determined. The process of determine which job is started first on a particular machine or work centre is known as priority sequencing. Some of the more common priority rules for sequencing jobs are:

- *First come, first serve (FCFS):* orders are run in the order that they arrive in the department i.e. the oldest first rule.
- *Shortest processing time (SPT):* run the job with the shortest completion time first i.e. shortest operating time first.
- *Earliest due date first (due date*): run the job with earliest due date first. Thus, a job that is due tomorrow has a higher priority than the job that is due next week or next month.
- *Critical ratio (CR):* this is calculated as the difference between the due date and the current date divided by the work remaining. Orders with the smallest CR are run first. In the CR rule, jobs are sequenced from lowest CR to highest CR. Those with a CR less than one are considered behind schedule and need to be expedited. And CR greater than one implies that the job is ahead schedule and can be de-expedite.

$$CR = \frac{\text{due date – today's date}}{\text{Total shop time remaining}} = \frac{\text{time remaining}}{\text{lead time remaining}}$$

- *Last come first serve (LCFS):* this rule occurs frequently by default. As orders arrive they are placed on the top of the stack and the operator usually picks up the order on top to run first.
- *Random order* – whim: the supervisors or the operators usually select which ever job they feel like running.
- Slack time remaining per operation(STR/OP):

$$STR/OP = \frac{\text{time remaining before due date – remaining processing time}}{\text{Number of remaining operations}}$$

Self check questions

1. List and explain the priority rules to assign the task to work centre
2. How can we find the CR?
3. Which method is best to prioritizes task assignment?

Measuring effectiveness of priority rules

The effectiveness of any given sequence is frequently judged in terms of one or more performance measures. The most frequently used performance measures are:

1. **Job flow time:** This is the length of time a job is at a particular workstation or work center. It includes not only actual processing time but also any time waiting to be processed, transportation time between operations, and any waiting time related to equipment breakdowns, unavailable parts, quality problems, and so on: Job flow time is the length of time that begins when a job arrives at the shop, workstation, or work center, and ends when it leaves the shop, workstation, or work center. The average flow time for a group of jobs is equal to the total flow time for the jobs divided by the number of jobs.
2. **Job lateness:** This is the length of time the job completion date is expected to exceed the date the job was due or promised to a customer. It is the difference between the actual completion time and the due date. If we only record differences for jobs with completion times that exceed due dates, and assign zeros to jobs that are early, the term we use to refer to that is job tardiness.
3. **Make span**: Make span is the total time needed to complete a group of jobs. It is the length of time between the start of the first job in the group and the completion of the last job in the group
4. **Average number of jobs:** Jobs that are in a shop are considered to be work-in-process inventory. The average work-in-process for a group of jobs can be computed using the following formula:

Average number of jobs = Total flow time/Make span Time

If the jobs represent equal amounts of inventory, the average number of jobs will also reflect the average work-in-process inventory.

Example1: Mesfin industrial engineering has engaged in assembling different model cars. Assume six 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, the fifth order model type E and the six order model F. Further assume that all order requires the use of only one machine which forces the company to decide on the processing sequence for the six orders. The following is the time (in days) required to complete the job on in the machine. Determine the sequence of jobs, the average flow time, average days late, and average number of jobs at the work center, for each of these rules:

A. FCFS(*First come, first serve)*
B. SPT(*Shortest processing time)*
C. EDD(*Earliest due date first)*
D. CR(*Critical ratio)*

Orders	Processing time (in days)	Due date (in days)
Model A	2	7
Model B	8	16
Model C	4	4
Model D	10	17
Model E	5	15
Model F	12	18

Assume orders arrived in the order shown.

A. The FCFS sequence is simple A-B-C-D-E-F.

Job sequence	Processing time (1)	Flow time (2)	Due date (3)	Days late (2)-(3) {0 if negative}
Model A	2	2	7	0
Model B	8	10	16	0
Model C	4	14	4	10
Model D	10	24	17	7
Model E	5	29	15	14
Model F	12	41	18	23
	41	120		54

- Total flow time: 120 days
- Average flow time: 120/6 = 20 days.
- Total tardiness(lateness)=54 days
- Average tardiness: 54/6 = 9 days
- The make span is 41 days.
- Average number of jobs at the work center: 120/41 =2.93.

The flow time column indicates cumulative processing time, so summing these times and dividing by the total number of jobs processed indicates the average time each job spends at the work center. Similarly, find the average number of jobs at the center by summing the flow times and dividing by the total processing time.

B. Using the SPT rule, the job sequence is A-C-E-B-D-F (see the following table).

Job sequence	Processing time (1)	Flow time (2)	Due date (3)	Days late (2)-(3) {0 if negative}
Model A	2	2	7	0
Model C	4	6	4	2
Model E	5	11	15	0
Model B	8	19	16	3
Model D	10	29	17	12
Model F	12	41	18	23
	41	108		40

- Total flow time: 108 days
- Average flow time: 108/6 = 18 days.
- Total tardiness(lateness)=40 days
- Average tardiness: 40/6 = 6.67 days
- The make span is 41 days.
- Average number of jobs at the work center: 108/41 =2.63

C. Using earliest due date as the selection criterion, the job sequence is C-A-E-B-D-F.

Job sequence	Processing time (1)	Flow time (2)	Due date (3)	Days late (2)-(3) {0 if negative}
Model C	4	4	4	0
Model A	2	6	7	0
Model E	5	11	15	0
Model B	8	19	16	3
Model D	10	29	17	12
Model F	12	41	18	23
	41	110		38

- Total flow time:110 days
- Average flow time: 110/6 = 18.33 days.
- Total tardness:38
- Average tardiness: 38/6 = 6.33 days.
- Make span time:41 days
- Average number of jobs at the work center: 110/41 = 2.68

D. Using the critical ratio(CR) we find:

Job sequence	Processing time	Due date	Critical ratio calculation
Model A	2	7	(7-0)/2=3.5
Model B	8	16	(16-0)/8=2
Model C	4	4	(4-0)/4=1(lowest)
Model D	10	17	(17-0)/10=1.7
Model E	5	15	(15-0)/5=3
Model F	12	18	(18-0)/12=1.5

At the day 4(C completed), the critical ratios are:

Job sequence	Processing time	Due date	Critical ratio calculation
Model A	2	7	(7-4)/2=1.5
Model B	8	16	(16-4)/8=1.5
Model C	-	-	-
Model D	10	17	(17-4)/10=1.3
Model E	5	15	(15-4)/5=2.2
Model F	12	18	(18-4)/12=1.17(lowest)

At the day 16(C and F are completed), the critical ratios are:

Job sequence	Processing time	Due date	Critical ratio calculation
Model A	-	7	(7-16)/2=-4.5(lowest)
Model B	8	16	(16-16)/8=0
Model C	-	-	-
Model D	10	17	(17-16)/10=0.1
Model E	5	15	(15-16)/5=-0.2
Model F	-	18	-

At the day 18(C, F and A are completed), the critical ratios are:

Job sequence	Processing time	Due date	Critical ratio calculation
Model A	-	-	-
Model B	8	16	(16-18)/8=-0.25
Model C	-	-	-
Model D	10	17	(17-18)/10=-0.10
Model E	5	15	(15-18)/5=-0.60(lowest)
Model F	-	-	-

At day 23 (C, F, A and E completed)

Job sequence	Processing time	Due date	Critical ratio calculation
Model A	-	-	-
Model B	8	16	(16-23)/8=-0.875
Model C	-	-	-
Model D	10	17	(17-23)/10=-0.60
Model E	-	-	-
Model F	-	-	-

The job sequence is C,F, A,E,B and D

Job sequence	Processing time (1)	Flow time (2)	Due date (3)	Days late (2)-(3) {0 if negative}
Model C	4	4	4	0
Model F	12	16	18	0
Model A	2	18	7	11
Model E	5	23	15	8
Model B	8	31	16	15
Model D	10	41	17	24
	41	133		58

- Total flow time:133 days
- Average flow time: 133/6 = 22.17 days.
- Total tardness:58 days
- Average tardiness: 58/6 = 9.67 days.
- Make span time:41 days
- Average number of jobs at the work center: 133/41 = 3.24

Comparison of four rules

Rule	Average flow times (days)	Average tardiness(days)	Average numbers o f jobs at the work center
FCFS	20	9	2.93
SPT	18	6.67	2.63
EDD	18.33	6.33	2.68
CR	22.17	9.67	3.24

In this example, the SPT rule was the best according to two of the measures of effectiveness and a little worse than the EDD rule on average tardiness. The CR rule was the worst in every case. For a different set of numbers, the EDD rule (or perhaps another rule not mentioned here) might prove superior to SPT in terms of average job tardiness or some other measure of effectiveness. However, SPT is always superior in terms of minimizing flow time and, hence, in terms of minimizing the average number of jobs at the work center and completion time. It is best for each shop or organization to consider carefully its own circumstances and the measures of effectiveness it feels are important, when selecting a rule to use.

Generally speaking, the FCFS rule and the CR rule turn out to be the least effective of the rules. The primary limitation of the FCFS rule is that long jobs will tend to delay other jobs. If a process consists of work on a number of machines, machine idle time for downstream workstations will increase. However, for service systems in which customers are directly involved, the FCFS rule is by far the dominant priority rule, mainly because of the inherent fairness but also because of the inability to obtain realistic estimates of processing time for individual jobs. The FCFS rule also has the advantage of simplicity. If other measures are important when there is high customer contact, companies may adopt the strategy of moving processing to the "backroom" so they don't necessarily have to follow FCFS.

Because the SPT rule always results in the lowest (i.e., optimal) average completion (flow) time, it can result in lower in-process inventories. And because it often provides the lowest (optimal) average tardiness, it can result in better customer service levels.

Finally, since it always involves a lower average number of jobs at the work center, there tends to be less congestion in the work area. SPT also minimizes downstream idle time. However, due dates are often uppermost in managers' minds, so they may not use SPT because it doesn't incorporate due dates.

The major disadvantage of the SPT rule is that it tends to make long jobs wait, perhaps for rather long times (especially if new, shorter jobs are continually added to the system). Various modifications may be used in an effort to avoid this. For example, after waiting for a given time period, any remaining jobs are automatically moved to the head of the line. This is known as the truncated SPT rule.

The EDD rule directly addresses due dates and usually minimizes lateness. Although it has intuitive appeal, its main limitation is that it does not take processing time into account. One possible consequence is that it can result in some jobs waiting a long time, which adds to both in-process inventories and shop congestion.

The CR rule is easy to use and has intuitive appeal. Although it had the poorest showing in Example 1 for all three measures, it usually does quite well in terms of minimizing job tardiness. Therefore, if job tardiness is important, the CR rule might be the best choice among the rules.

Example 2: Use the S/O rule to schedule the following jobs. Note that processing time includes the time remaining for the current and subsequent operations. In addition, you will need to know the number of operations remaining, including the current one.

Job	Remaining processing time	Due date	Remaining number of operation
A	4	14	3
B	16	32	6
C	8	8	5
D	20	34	2
E	10	30	4
F	18	30	2

Solution:

Determine the difference between the due date and the processing time for each operation. Divide the amount by the number of remaining operations, and rank them from low to high. This yields the sequence of jobs:

Job	Remaining processing time(1)	Due date(2)	Slack(2)-(1)	Remaining number of operation (4)	Ratio :slack/(4)	Rank
A	4	14	10	3	3.33	3
B	16	32	16	6	2.67	2
C	8	8	0	5	0	1
D	20	34	14	2	7	6
E	10	30	20	4	5	5
F	18	30	12	2	6	4

The indicated sequence is C-B-A-E-F-D.

Using the S/O rule, the designated job sequence may change after any given operation, so it is important to reevaluate the sequence after each operation. Note that any of the previously mentioned priority rules could be used on a station-by-station basis for this situation; the only difference is that the S/O approach incorporates downstream information in arriving at a job sequence.

In reality, many priority rules are available to sequence jobs, and some other rule might provide superior results for a given set of circumstances. The purpose in examining these few rules is to provide insight into the nature of sequencing rules. The following section describes a special-purpose algorithm that can be used to sequence a set of jobs that must all be processed at the same two machines or work centers.

Sequencing jobs through two machines

Johnson's rule is a technique that managers can use to minimize the make span for a group of jobs to be processed on two machines or at two successive work centers (some-times referred to as a two-machine flow shop). It also minimizes the total idle time at the work centers. For the technique to work, several conditions must be satisfied:

Assumptions

1. The processing time on different machine are exactly known and are independent of the order of the jobs in which they are to be processed
2. The time taken by the job in moving from one machine to another is negligible
3. Once a job has begun on a machine, it must be completed before another job can begin on the same machine
4. All jobs are known and are ready for processing before the period under consideration begins
5. Machines are to be used are of different types
6. The order of completion of the job are independent of the sequence of the jobs

Let there be n jobs, each of which is to be processed through two machines, M1 and M2 in the order M1M2, i.e., each job has to be pass through the same sequence of operations. In other words, a job is assigned on machine M1 first and after it has been completely processed on machine M1, it is assigned to machine M2. If machine M2 is not free at the moment for processing the same job, then the job has to wait in a waiting line for it turn on machine M2,i.e,passing is not allowed.

Since passing is not allowed, therefore, machine M1 will remain busy in processing all the n jobs one by one while machine M2 may remain idle time of the second machine. This can be achieved only by determining sequence of n jobs which are to be processed on two machines M1 and M2. The procedure suggested by Johnson for determing the optimal sequence can be summarized as follows:

Step 1: list the jobs along with their processing times in table as shown below:

Processing time on machine	Job number			
	1	2	3	………..n
M1	t_{11}	t_{12}	t_{13}	………. t_{1n}
M2	t_{21}	t_{22}	t_{23}	……… t_{2n}

Step 2: examine the columns for processing times on machine M1 and find the smallest processing time in each column, i.e. find out, min(t_{1j},t_{2j}) for all j

Step 3(a) if the smallest processing time is for the first machine M1, then place the corresponding job in the first available position in the sequence. If it is for the second machine, then place the corresponding job in the last available position in the sequence.
(b) If there is a tie in selecting the minimum of all the processing times, then there may be three situations:

I. Minimum among all the processing times is the same for the machine, i.e. min $(t_{1j},t_{2j}) = t_{1k}=t_{2k}$, then process the kth job first and the rth job last.
II. If the tie for the minimum occurs among processing times t_{1j} on machine M1 only, then select the job corresponding to the smallest job subscript frist.
III. If the tie for the minimum occur among processing times t_{2j} on M2, then select the job corresponding to the largest job corresponding to the largest job subscript last

Step 4: Remove the assigned jobs from the table. If the table is empty, stop and go to step 5. Otherwise, go to step 2

Step 5: calculate idle time for machine M1 and M2

A. Idle time for machine M1=(total elapsed time)-(time when the last job in a sequence finishes on machine M1)
B. Idle time for machine M2= time at which the first job in a sequence finishes on machine M1+$\sum_{j=2}^{n}$ { (time when the jth job in a sequence starts on machine M2)-(time when the (j-1) th job in a sequence finishes on machine M2)}

Step 6: the total elapsed time to process all jobs through two machines is given by
Total elapsed time=time when the nth job in a sequence finishes on machine M2.
$=\sum_{j=1}^{n} m_{2j} + \sum_{j=1}^{n} i_{2j}$

Where : m_{2j}= time required for processing jth job on machine M2

m_{2j}=time for which machine M2 remains idle after processing (j-1)th job and before starting work in the jth job

Example: find the sequence that minimizes the total elapsed time required to complete the tasks on two machines

Task	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**
Machine I	2	5	4	9	6	8	7	5	4
Machine II	6	8	7	4	3	9	3	8	11

Solution:

The smallest processing time between the two machine is 2 which corresponds to task A on machine I. this, task A will be processed first as shown below:

A								

After the task A has been set for processing first, we are left with 8 tasks and their processing times are given below:

Task	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**
Machine I	5	4	9	6	8	7	5	4
Machine II	8	7	4	3	9	3	8	11

The minimum processing time in this reduced problem is 3 which corresponds to task E and G both on machine II. Since the corresponding processing time on of task E on machine I is less than the corresponding processing time of task G on machine I, therefore, task E will be processed in the last and task G shall be processed before it. Task E and G will not be considered further. Thus, current partial assignment becomes:

A							G	E

The set of processing times now gets reduced to :

Task	**B**	**C**	**D**	**F**	**H**	**I**
Machine I	5	4	9	8	5	4
Machine II	8	7	4	9	8	11

The smallest processing time in this reduced problem is 4, which corresponds to task C and I on machine I and to task D on machine II. Thus task C will be replaced in the second sequence cell and task I in the third sequence cell and task D in the sequence cell before task G. the entries of the partial sequence are now:

A	C	I				D	G	E

The set of processing time now gets reduced as follows:

Task	**B**	**F**	**H**
Machine I	5	8	5
Machine II	8	9	8

The smallest processing time in this reduced problem is 5, which corresponds to task B and H both on machine I. since the corresponding processing times of B and H on machine II is same, therefore, either of these two tasks can be placed in fourth and fifth sequence cells. Thus, it indicates an alternative optimal sequence. The optimal sequences are, therefore given below:

A	C	I	B	H	F	D	G	E
A	C	I	H	B	F	D	G	E

Minimum elapsed time

Sequence	Machine I		Machine II	
	Time in	Time out	Time in	Time out
A	0	2	2	8
C	2	6	8	15
I	6	10	15	26
B	10	15	26	34
H	15	20	34	42
F	20	28	42	51
D	28	37	51	55
G	37	44	55	58
E	44	50	58	61

The minimum elapsed time, i.e. time from start of task A to completion of last task E is 61 hours. During this time the machine I remain idle for 61-50=11 hours. The idle time for machine II is equal to the time at which the first task A in the sequence finishes on machine I plus the last task E in the sequence starts on machine II minus the last but one task G finishes on machine II, i.e. 2+58-58=2 hours.

Self check question

1. Which one of the following is / are **not** the assumption Johnson rule

   B. The processing time on different machine are exactly known and are independent of the order of the jobs in which they are to be processed

   C. The time taken by the job in moving from one machine to another is negligible

   D. Once a job has begun on a machine, it must be not completed before another job can begin on the same machine

   E. All jobs are known and are ready for processing before the period under consideration begins

   F. Machines are to be used are of different types

   G. None of the above

1. Which one of the following is / are **correct** regarding Johnson rule

   A. if the smallest processing time is for the first machine M1, then place the corresponding job in the first available position in the sequence

   B. If the smallest processing time is for machine M2, then place the corresponding job in the last available position in the sequence

   C. If there is a tie in selecting the minimum among all the processing times is the same for the machine, i.e. min (t_{1j},t_{2j}) = t_{1k}=t_{2k}, then process the kth job first and the rth job last.

   D. If the tie for the minimum occurs among processing times t_{1j} on machine M1 only, then select the job corresponding to the smallest job subscript frist.

   E. All of the above

   F. All except “B” and “D

4.2.2 Scheduling in services

Scheduling is also important in service organizations. For example nurses must be scheduled in hospital, and truck must be scheduled for deliveries for furniture distributors. One important distinction between manufacturing and services that affects scheduling is that service operations cannot create inventories to buffer demand uncertainties. A second distinction is that in service operations demand often is less predictable; customers may decide on the spur of the moment that they need a hamburger, a hair cut or a plumbing repair. Thus capacity, often in the form of employees is crucial for service providers. In this section we discuss various ways in which schedule systems can facilitate the capacity management of service providers.

Scheduling customer demand

One way to manage capacity is to schedule customers for arrival times and definite periods of service time. With this approach, capacity remains fixed and demand is leveled to provide timely service and utilize capacity. Three methods are commonly used: appointment, reservation and backlog.

Appointment: an appointment system assigns specific times for services to customers. The advantages of this method are timely customer service and high utilization of servers. Doctors, dentists, lawyers, and automobile repair shops are examples of service providers that use appointment systems. Doctors can use the system to schedule parts of their days to visits hospital patients and lawyers can set aside time to prepare cases. If timely service is to be provided, however, care must be taken to tailor the length of appointment to individual customer needs rather than merely scheduling customers at equal time interval.

Reservation: reservation system, although quite similar to appointment systems, are used when the customer actually occupies or uses facilities associated with the service. For example, customer reserve hotel rooms, automobiles, airline seats, and concert seats. The major advantage of reservation system is the lead time they give service managers to plan the efficient use of facilities. Often, reservation requires require some form of down payment to reduce the problem of no-shows

Backlog: a less precise way to schedule customers is to allow backlogs to develop; that is customers never know exactly when service will commence. They present service request to an order taker, who adds it to the waiting line of orders already in the system. TV repair shops, restaurants, banks, grocery stores, and barber shops are examples of the many types of business that uses this system. Various priority rules can be used to determine which order to process next. The usual rule is first come, first served, but if the order involves rework on a previous order, it may get a higher priority.

Scheduling the worker:

Another way to manage capacity with a schedule system is to specify the on duty and off duty periods for each employee over a certain time period as in assigning postal clerks, nurses, pilots, attendants, or police officers to specific work days and shifts. This approach is used when customers demand quick response and total demand can be forecasted with reasonable accuracy. In this instant capacity is adjusted to meet the expected loads on the service system. The work force capacity available each day must meet or exceed daily work force requirements. If it does not, the scheduler must try to rearrange days off until the requirements are met. If no such scheduling can be found, management might have to change the staffing plan and authorize more employees, over time hours or large backlogs.

Managers usually use rotating schedule than fixed schedule to assign workers on their duty. In rotating schedule rotate employees through a series of work days or hours. Thus over a period of time, each person has the same opportunity to have weekends and holidays off and to work days, as well as evening and nights. A rotating schedule gives each employee the next employee‘s schedule the following week. In contrast, a fixed schedule calls for each employee to work the same days and hours each week.

Self check questions

1. Johnson`s rule is used to assign n jobs to one machines. Is it correct? Justify
2. Explain the performance measure of job shop scheduling
3. All scheduling activities are carried out at the top level. Do you agree? Justify.
4. What we are scheduling in the service sector?

Summary

Scheduling is the allocation of starts and finish time to each particular order. Therefore scheduling can bring productivity in shop floor by providing a calendar for processing a set of jobs. The single machine-scheduling problem consists of *n* jobs with the same single operation on each of the jobs, while the flow shop-scheduling problem consists of *n* jobs with *m* operations on each of the jobs. In this problem, all the jobs will have the same process sequences. The job shop scheduling problem contains *n* jobs with *m* operations on each of the jobs; but, in this case, the process sequences of the jobs will be different from each other.

4.3 Self - assessment questions

I. Multiple choice questions

A manufacturing facility has five jobs to be scheduled in to production. The following table gives the processing times plus the necessary wait times and the jobs are due on the dates shown:

Jobs (in order of arrival)	*processing time (in days)*	*due date (days hence)*
A	3	5
B	4	6
C	2	7
D	6	9
E	1	2

Consider the above data and answer questions 1 up to 7.

1. Based on FCFS priority rule, the number of jobs in the system and utilization respectively are:

   a) 3.125 and 32% b) 2.315 and 43% c) 5.32 and 22%
   d) 4.5 and 50% e) 6 and 16% f) none

2. Based on EDD priority rule, the sequence of the job will be:

   A. D—C—B—E—A d) D—B—A—C—E
   B. C—B—E—A—D e) A—B—C—D—E
   C. E—A—B—C—D f) none

3. Based on shorter processing time priority rule, the sequence of the activity can be:

   A. D—A—E—C—B d) C—B—D—E—A
   B. D—B—A—C—E e) A—B—E—D—C
   C. E—C—A—B—D f) none

4. Based on FCFS priority rules, job **D** will began after:

a) 7 days   b) 9 days   c) 15 days

d) 3 days   e) 5 days   f) none

5. Based on FCFS priority rule, the total flow time and the make span time respectively are:

a) 16 and 50   b**)** 50 and 16   **c)** 10 and 32

d) 32 and 10   e**)** 40 and 60   **f)** none

6. Based on FCFS priority rule ,the average job lateness will be:

a) 4.6 days   b) 6.4 days   c) 6.3 days

d) 3.6 days   e) 6 days   f) none

7. Based on **CR** priority rule, the activity performed last should be:

a) D   d) C

B) E   e) B

c) A   f) none

8. The assignment of work to specific machine is:

A. Sequencing   d) cycle time

B. Loading   e) bottle neck

C. make span time   f) none

Based on the data below, answer questions that follow:

ABC Garment business has received five orders. There is only one work center that all kinds of jobs are to be performed in. The time required (in days) to complete each job and days till due are;

Job Order	**Processing time**	**Number of days till due**
Coat (C)	7	8
Underwear (U)	2	3
Shirt (S)	5	7
Trouser (T)	3	9
Jacket (J)	6	6

1. Based on EDD (Earliest Due Date) rule, the order of the activities will be:
   A. U-J-S-C-T
   B. J-S-U-T-C
   C. S-J-T-U-C
   D. C-J-U-T-S
   E. T-C-U-J-S
2. The make span time will be:
   A. 32
   B. 28
   C. 45
   D. 30
   E. None
3. Based on FCFS rule, total flow time of the orders will be:
   A. 80
   B. 70
   C. 60
   D. 50
   E. None
4. Based on the Shortest processing time, the order of the activities will be:
   A. T-C-U-J-S
   B. U-T-S-J-C
   C. J-T-S-U-C
   D. S-T-J-C-U

II. **Solve the following questions**

1. Consider the following single machining scheduling problem:

Job (j)	1	2	3	4	5	6
Processing time (t_j)	10	8	8	7	12	15
Due date (d_j)	15	10	12	11	18	25

Determine the sequence which will minimize the maximum lateness using EDD.

2. Consider the following information and answer the questions that follow

Today is day 21 on the XYZ company schedule. Three jobs are on order shown as follows:

Job	A	B	C
Demand	30	28	27
Work days required	4	5	2

Required:

a) schedule (prioritize) the activity
b) Which activity needs to be expedited, and which activity has some slack? Why?

Hint: first find the due date

3. The following is the time in hours required to compute the jobs in two work centers.

Job order	chair	table	shelf	door	board
Assembly (in hrs)	4	3	4	6	5
Finishing (in hrs)	2	8	1	3	9

Required:

a) schedule the work using Johnson rule
b) Determine the make span time, total flow time and total idle time

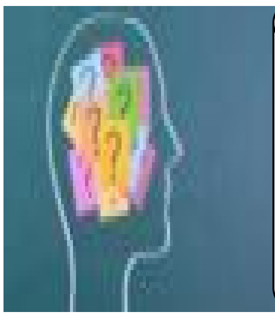
CHAPTER FIVE

QUALITY MANAGEMENT AND CONTROL

Objectives:

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

- Define the term quality
- Explain the concept of TQM
- Understand the cost of quality
- Apply statistical quality control to keep the quality requirement under control



Key Brain Storming questions

- Defining Quality
- Cost of Quality
- The Evolution of Total Quality Management (TQM)
- What Is Statistical Quality Control?
- Sources of Variation: Common and Assignable Causes

5.1 Over view of quality

5.1.1 What is quality?

While quality management is cross functional in nature and involves the entire organization, operations have 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 can be defined in a number of different ways.

In an article entitled “what does product quality really mean?” David Garvin, discuss five approaches to define quality:

- He state that a common notion of quality is that it is synonymous with ‘*superiority*’ *or* ‘*innate excellence*’. From this view point, quality cannot be precisely defined but can only be recognized through experience.
- A second view point is that quality is precise and measurable concept and that *differences in quality* reflect differences in quantity of some *product attributes.*

For instance, high quality ice cream has high butterfat content. According to this approach, quality can be ranked based on the amounts of the desired attributes they possess. (It is Product based view)

- The third view is that quality is determined by what a customer wants and is willing to pay. According to this view the goods and services that *best satisfy* individual consumer's unique needs or wants are regarded as having the highest quality. Thus quality can be defined as *fitness for intended use*, or in other words, how well the product performs its intended functions.(user based view)
- A fourth definition of quality arises from the unique perspective of manufacturing operations. In this setting quality is associated with engineering and manufacturing practices; hence, the perspective of quality is synonymous with *conformance to specification*. Quality conformance can be defined as, how well manufacturing is able to meet design specification.(manufacturing view)
- Finally the value based approach to quality defines it in terms of *cost and price*. In this sense, a quality product is one that provides a predetermined level of performance at an acceptable price or provide conformance to design specification at an acceptable cost. (Value based approach)

In considering all these approaches to quality, it is clear that the meaning of quality depends on one's view point and places in the organization. Thus different definitions are needed. More over it is necessary to shift one's perspective of quality as products move from their design stage to market. All of the viewpoints just presented are necessary in order to result in an overall quality product.

5.1.2 Dimension of quality

The common dimension of quality includes:

Performance: is a measure of product's primary operating characteristics. Within an automobile, for example, performance characteristics would include how fast it can accelerate from 0 to 60 mph and its fuel efficiency in terms of miles per gallon. For personal computer, performance characteristics would include speed and random accessory memory (RAM).

Feature**:** are the 'belts and whistles' that are offered with the product. While features are not the primary operating characteristics of a product, nonetheless, be very important to the customer. For example, a moon roof and stereo system may be the designing factors for a new car buyer while a specific type of refrigerator may appeal to a customer because it offers an icemaker and water dispenser.

Reliability: The reliability of a product relates to the probability that the product will fail within a specified time. High product reliability is important in such product as airplanes, computers and coping machines. It also refers consistency of performance.

***Durability*:** relates to the expected operational life of the product. In some instance, as with a light bulb, the filament eventually burns out and the entire product must be replaced. In other case, such as within an automobile, the consumer must evaluate the tradeoff between replacing the product entirely versus spending money on repair for the existing one. It simply means, 'useful life' of the product.

***Serviceability*:** concerned with how readily the product can be repaired and the response (i.e. speed, competence, and courtesy) associated with that repair. It simply refers 'easy of repair'

***Aesthetic*:** is also a dimension of quality for wish there is a high degree of individual judgment and that is also *highly subjective*. In fact in terms of aesthetics, good quality to one group of customers might even be perceived as poor quality to another group. Companies, there for, have an opportunity with this quality dimension to seek out a very specific market niche. It refers to sensory characteristics (sound, feel, look etc).

***Perceived quality*:** is directly related to the reputation of the firm that manufactures the product. Often total information about the various quality aspects of a product is not available, especially when the product is new. Consequently, customers relay heavily on the past performance and reputation of the firm making the product.

5.1.3 Differences between Manufacturing and Service Organizations

Defining quality in manufacturing organizations is often different from that of services. Manufacturing organizations produce a tangible product that can be seen, touched, and directly measured. Examples include cars, CD players, clothes, computers, and food items. Therefore, quality definitions in manufacturing usually focus on tangible product features.

The most common quality definition in manufacturing is conformance**,** which is the degree to which a product characteristic meets preset standards. Other common definitions of quality in manufacturing include ***performance*—**such as acceleration of a vehicle; ***reliability*—**that the product will function as expected without failure; ***features*—**the extras that are included beyond the basic characteristics; **durability—**expected operational life of the product; and ***serviceability*—**how readily a product can be repaired. The relative importance of these definitions is based on the preferences of each individual customer. It is easy to see how different customers can have different definitions in mind when they speak of high product quality.

In contrast to manufacturing, service organizations produce a product that is intangible. Usually, the complete product cannot be seen or touched. Rather, it is experienced. Examples include delivery of health care, experience of staying at a vacation resort, and learning at a university. The intangible nature of the product makes definitions quality difficult. Also, since a service is experienced, perceptions can be highly subjective. In addition to tangible factors, quality of services is often definitions by perceptual factors. These include ***responsivenes***s to customer needs, ***courtesy*** and ***friendliness*** of staff, ***promptness*** in resolving complaints, and ***atmosphere***. Other definitions of quality in services include time—the amount of time a customer has to wait for the service; and consistency—the degree to which the service is the same each time. For these reasons, Defining quality in services can be especially challenging.

Self check questions

1. The meaning of quality depends on one's view point. Explain.
2. Today, in the organizational structure, quality is under the manufacturing department. Do you agree? Justify your answer.
3. What are the common dimensions of quality?

5.1.4 Cost of quality

The reason quality has gained such prominence is that organizations have gained an understanding of the high cost of poor quality. Quality affects all aspects of the organization and has dramatic cost implications. The most obvious consequence occurs when poor quality creates dissatisfied customers and eventually leads to loss of business. However, quality has many other costs, which can be divided into two categories. The first category consists of costs necessary for achieving high quality, which are called quality control costs. These are of two types: prevention costs and appraisal costs. The second category consists of the cost consequences of poor quality, which are called quality failure costs. These include external failure costs and internal failure costs.

The prevention cost

Prevention costs are costs associated with preventing defects before they happen. Such costs include:

- Cost of providing quality engineering, and quality planning services for: ensuring correct specifications of materials, use of right methods and process, preparing company standards, preparing sampling procedures, preparing test schedules arranging training of personnel, planning process control etc. cost of inspection so as to keep the production going (not to sort out good from bad items) such as inspection of patterns, , tools, gauges, dies, jigs and fixtures, ;inspection of production equipments etc.

- Cost involved with training and retraining of operators, supervisors and other staffs.
- Cost of research and development efforts, so as to maintain high quality products.
- The cost of redesigning the process to remove the cause of poor quality.
- Cost incurred in the organization of quality circles and other techniques with the objectives of creating interests and involvements of workers and staffs in their work motivate them and high quality of work life. These activities occur prior to production and are aimed at preventing defects before they occur.

The appraisal (inspection)

Appraisal costs are costs incurred in assessing the level of quality attended by the operating system. Appraisal helps management identify quality problem. Such costs include:

- Cost of testing or inspecting incoming raw materials, including the cost of their movement for the purpose of inspection testing at regular interval
- Cost of providing and maintaining laboratory services for the purpose of inspection
- Cost of process control test or stage inspection.
- Cost of product inspection, such as mechanical testing, non destructive testing cost of carrying out field trials etc.
- Cost of maintenance and calibration of test and inspection equipment and apparatus at regular interval.
- Expenditure incurred in vendor rating when any of the materials required for the product are procured from outside sources.

The failure costs are incurred either during the production process (internal) or after the production is shipped (external).

The internal failure

Internal failure costs result from defects that are discovered during the production of a product or services. Such costs include***:***

- Cost of scrap or rejections produced which cannot be passed on to, or which will not be accepted by the customer and which becomes a total cost. It will include the cost of power and various in process materials spent in producing the rejection.

- cost of rework or corrective operations , in case of such items which have not been passed during inspection but which can be made acceptable after certain rework or repair such as welding, brazing, pressing , filling, re-heat treatment rough machining etc.
- Cost involved in fault investigation, trouble –shootings, defect analysis. It may also entail cost of re-examination, and testing, test methods, change of material specification or method of production etc.
- Loss in capacity of production because of the rejection produced.

The external failure cost

External failure costs arise when a defect is discovered after the customer has received defective products or services. Such costs include product:

- Loss of future orders to the company owing to loss in its prestige caused by high rejection or poor performance in services. The customer may even withhold payments and the relation may be impaired which may be difficult to improve again. The customers may permanently with draw placing order.
- Cost involved in attending to customers complaints and providing customer services, including warranty charges (the cost of refund, repair, or replace), returned merchandises (cost related to returning goods to sellers including transportation), losses of taxes and duties, allowance (cost of concession), complaints (the cost of setting customer complaints) and the like.
- Litigation costs which include not only legal fees but also the time and effort of employees who must appear for the company in court.

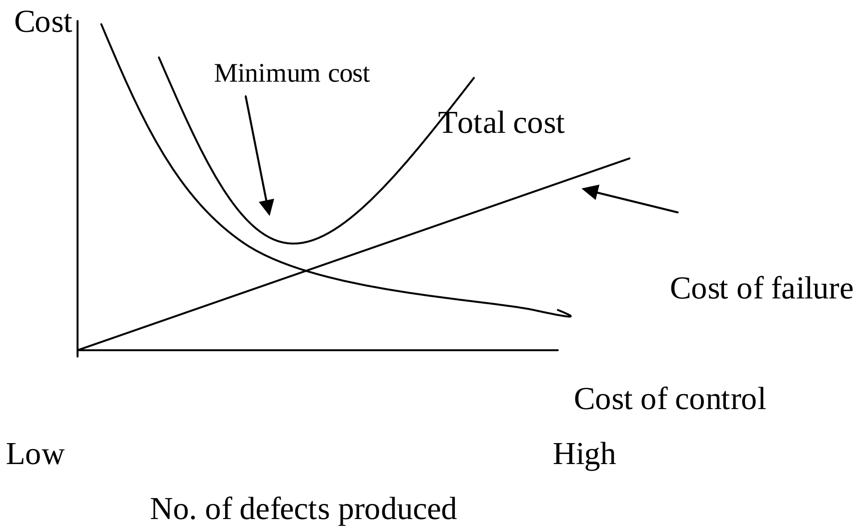
The total cost of quality can thus be expressed as the sum of the following cost:

$Total\ cost\ =\ control\ cost\ +failure\ cost$, that is

$$(Prevention\ cost\ +appraisal\ cost)\ +\ (internal\ failure\ cost+\ external\ failure\ cost)$$

The total cost of quality can be minimized by observing the relationship between the cost of quality and degree of conformance. When the degree of conformance is very high (low defects) the cost of failure are low but the cost of control are quite high. When the degree of conformance is low (high defect) the opposite situation exist. Thus there is, between the two extremes, an optimal level of conformance where total quality costs are minimized.

Good quality management also requires the proper balance between appraisal and prevention costs, so that total control costs are at the minimum.



Self check question
1. What are the costs of quality?
2. Preventive cost of quality is the cost incurred because of producing defective product. Do you agree? Explain.
3. External failure cost is insignificant and must be ignored. Do you agree?

5.2 The philosophy of total quality management(TQM)

What characterizes TQM is the focus on identifying root causes of quality problems and correcting them at the source, as opposed to inspecting the product after it has been made. Not only does TQM encompass the entire organization, but it stresses that quality is customer driven. TQM attempts to embed quality in every aspect of the organization. It is concerned with technical aspects of quality as well as the involvement of people in quality, such as customers, company employees, and suppliers. Here we look at the specific concepts that make up the philosophy of TQM.

1. Customer Focus

The first, and overriding, feature of TQM is the company's focus on its customers. Quality is defined as meeting or exceeding customer expectations. The goal is to first identify and then meet customer needs. TQM recognizes that a perfectly produced product has little value if it is not what the customer wants. Therefore, we can say that quality is customer driven. However, it is not always easy to determine what the customer wants, because tastes and preferences change. Also, customer expectations often vary from one customer to the next

2. Continuous Improvement

Another concept of the TQM philosophy is the focus on continuous improvement. Traditional systems operated on the assumption that once a company achieved a certain level of quality, it was successful and needed no further improvements. We tend to think of improvement in terms of plateaus that are to be achieved, such as passing a certification test or reducing the number of defects to a certain level. Traditionally, change for American managers involves large magnitudes, such as major organizational restructuring. The Japanese, on the other hand, believe that the best and most lasting changes come from gradual improvements. To use an analogy, they believe that it is better to take frequent small doses of medicine than to take one large dose. Continuous improvement, called kaizen by the Japanese, requires that the company continually strive to be better through learning and problem solving. Because we can never achieve perfection, we must always evaluate our performance and take measures to improve it.

3. Employee Empowerment

Part of the TQM philosophy is to empower all employees to seek out quality problems and correct them. With the old concept of quality, employees were afraid to identify problems for fear that they would be reprimanded. Often poor quality was passed on to someone else, in order to make it “someone else’s problem.” The new concept of quality, TQM, provides incentives for employees to identify quality problems. Employees are rewarded for uncovering quality problems, not punished.

In TQM, the role of employees is very different from what it was in traditional systems. Workers are empowered to make decisions relative to quality in the production process. They are considered a vital element of the effort to achieve high quality. Their contributions are highly valued, and their suggestions are implemented. In order to perform this function, employees are given continual and extensive training in quality measurement tools.

4. Process Management

According to TQM a quality product comes from a quality process. This means that quality should be built into the process. Quality at the source is the belief that it is far better to uncover the source of quality problems and correct it than to discard defective items after production. If the source of the problem is not corrected, the problem will continue. For example, if you are baking cookies you might find that some of the cookies are burned. Simply throwing away the burned cookies will not correct the problem. You will continue to have burned cookies and will lose money when you throw them away. It will be far more effective to see where the problem is and correct it. For example, the temperature setting may be too high; the pan may be curved, placing some cookies closer to the heating element; or the oven may not be distributing heat evenly.

Quality at the source exemplifies the difference between the old and new concepts of quality. The old concept focused on inspecting goods after they were produced or after a particular stage of production. If an inspection revealed defects, the defective products were either discarded or sent back for reworking. All this cost the company money, and these costs were passed on to the customer. The new concept of quality focuses on identifying quality problems at the source and correcting them.

5. Use of QFD technique for designing product

A critical aspect of building quality into a product is to ensure that the product design meets customer expectations. This typically is not as easy as it seems. Customers often speak in everyday language. For example, a product can be described as “attractive,” “strong,” or “safe.” However, these terms can have very different meaning to different customers. What one person considers to be strong, another may not. To produce a product that customers want, we need to translate customers’ everyday language into specific technical requirements. However, this can often be difficult. A useful tool for translating the voice of the customer into specific technical requirements is quality function deployment (QFD). Quality function deployment is also useful in enhancing communication between different functions, such as marketing, operations, and engineering.

6. Use of Quality Tools

You can see that TQM places a great deal of responsibility on all workers. If employees are to identify and correct quality problems, they need proper training. They need to understand how to assess quality by using a variety of quality control tools, how to interpret findings, and how to correct problems. In this section we look at seven different quality tools. These are often called the seven tools of quality control

A. ***Cause-and-Effect Diagrams***: Cause-and-effect diagrams are charts that identify potential causes for particular quality problems. They are often called fishbone diagrams because they look like the bones of a fish.

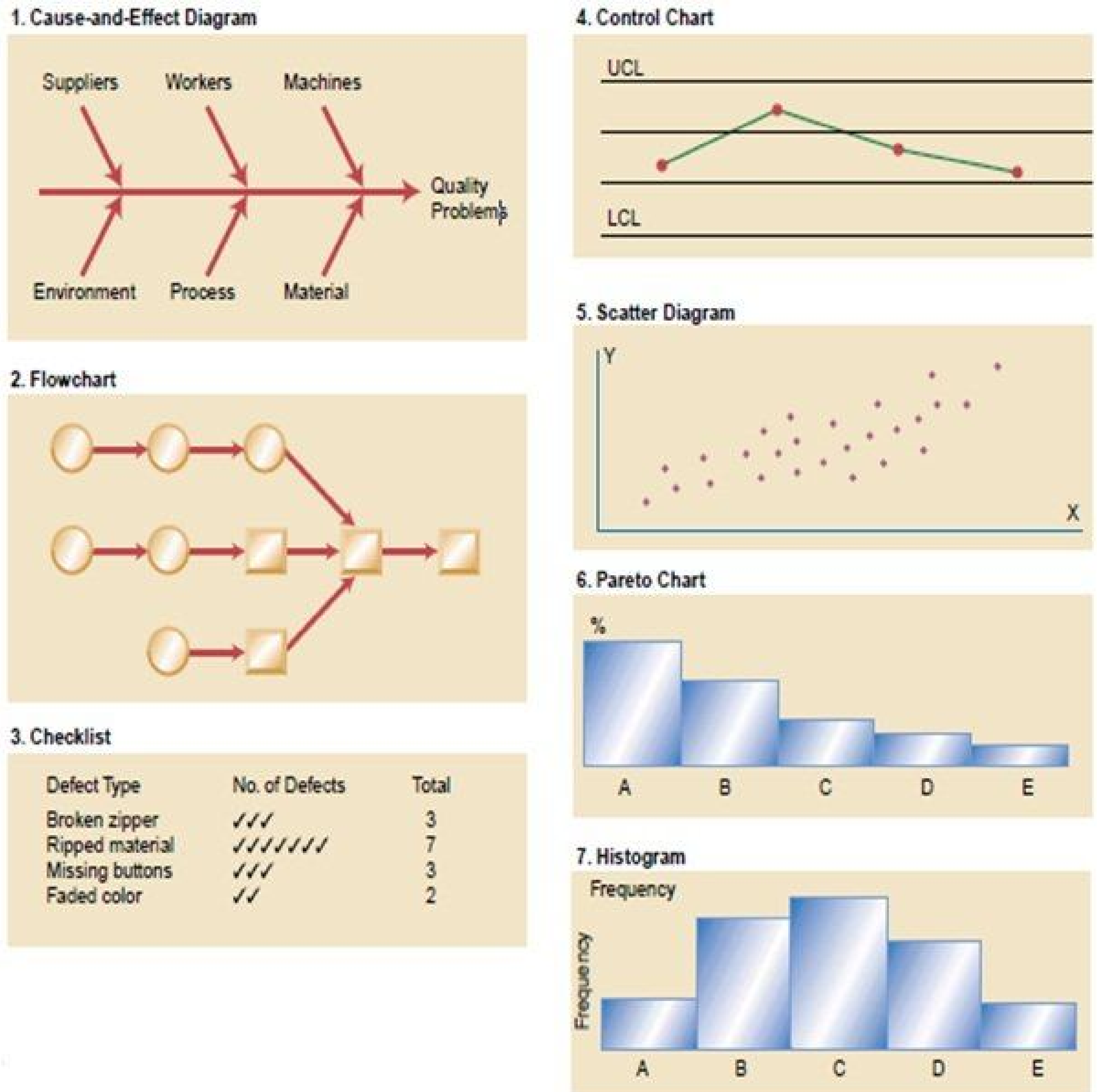
B. ***Flowcharts:*** A flowchart is a schematic diagram of the sequence of steps involved in an operation or process. It provides a visual tool that is easy to use and understand. By seeing the steps involved in an operation or process, everyone develops a clear picture of how the operation works and where problems could arise.

C. ***Checklists;*** A checklist is a list of common defects and the number of observed occurrences of these defects. It is a simple yet effective fact- finding tool that allows the worker to collect specific information regarding the defects observed.

D. ***Control Charts;*** Control charts are a very important quality control tool. We will study the use of control charts at great length in the next section on stastical quality control. These charts are used to evaluate whether a process is operating within expectations relative to some measured value such as weight, width, or volume. For example, we could measure the weight of a sack of flour, the width of a tire, or the volume of a bottle of soft drink. When the production process is operating within expectations, we say that it is "in control."

E. ***Histograms:*** A histogram is a chart that shows the frequency distribution of observed values of a variable. We can see from the plot what type of distribution a particular variable displays, such as whether it has a normal distribution and whether the distribution is symmetrical.

F. **Par*eto Analysis;*** Pareto analysis is a technique used to identify quality problems based on their degree of importance. The logic behind Pareto analysis is that only a few quality problems are important, whereas many others are not critical. The technique was named after Vilfredo Pareto, a nineteenth-century Italian economist who determined that only a small percentage of people controlled most of the wealth. This concept has often been called the 80–20 rule and has been extended to many areas. In quality management the logic behind Pareto's principle is that most quality problems are a result of only a few causes. The trick is to identify these causes.



7. Managing Supplier Quality

TQM extends the concept of quality to a company's suppliers. Traditionally, companies tended to have numerous suppliers that engaged in competitive price bidding. When materials arrived, an inspection was performed to check their quality. TQM views this practice as contributing to poor quality and wasted time and cost. The philosophy of TQM extends the concept of quality to suppliers and ensures that they engage in the same quality practices. If suppliers meet preset quality standards, materials do not have to be inspected upon arrival. Today, many companies have a representative residing at their supplier's location, thereby involving the supplier in every stage from product design to final production.

Self check questions

1. Pick correctly matched one
   - A. A flow chart: : chart which shows frequency distribution of observed values of variables
   - B. Scattered diagram : a chart that identifies potential cause for particular quality problem
   - C. Fishbone diagram: a technique used to identify quality problem based on their degree of importance
   - D. Histogram: shows how two variables are related to one another
   - E. All except “B”
   - F. None of the above
2. According to TQM philosophy employees are
   - A. Less empowered to seek out quality problems
   - B. Reprimanded for detecting defective product
   - C. punished for uncovering quality problems
   - D. given continual and extensive training in quality measurement tools
   - E. all except A
   - F. none of the above
3. Which one of the following statement clearly depict the difference between traditional approach and new approach (TQM)
   - A. The TQM focused on inspecting goods after they were produced or after a particular stage of production whereas the traditional approach focuses on identifying quality problems at the source
   - B. TQM extends the concept of quality to suppliers and ensures that they engage in the same quality practices where as a old approach heavily depend up on companies tended to have numerous suppliers that engaged in competitive price bidding
   - C. In traditional approach all employees are empowered to seek out quality problems and correct them while in TQM approach, employees were afraid to identify Problems for fear that they would be reprimanded
   - D. “B” and “C” are correct answer
   - E. All except “C”
   - F. None of the above

5.4. Statistical quality controls

One of the cornerstones of quality control is the use of statistical methods to determine how much inspection to use. In many case a great deal can be saved by taking a sample rather than making 100 percent inspection. In other cases there is no alternative but to take a sample .e.g. destructive testing. Two distinct types of statistical methods are available: acceptance sampling and process control. Consider each in the following discussion.

5.4.1. Acceptance sampling

Applies to lot inspection where a decision to accept or reject a lot of materials is made on the basis of random sample drawn from the lot. This type of inspection is frequently used for incoming raw materials or for finished goods prior to shipment.

Generally it can be defined as taking one or more samples at random from a lot of items, inspecting each of the items in the sample (s) and deciding – on the basis of inspection result- whether to accept or reject the entire lot. This type of inspection can be used by the customers to ensure that quality standards are met prior to shipments. Acceptance sampling is used in preference to 100% inspection where ever the cost of inspection is high in relation to the cost of passing defective items to the customer.

In a single acceptance sampling, one sample is taken from a lot and the decision whether to accept or reject the lot is made after the sample is inspected and compared with standards.

Formally, we let:

n= sample size

c= acceptance number

x= number of defective units found in the sample.

For single sampling, the decision rule whether to accept or reject the lot after inspecting the sample is as follows:

If $x \le c$, accept the lot

If $x > c$, reject the lot

For example, suppose we have a lot of 10,000 items and we decided to take a random sample of 100 items (n=100). We inspect the 100 items and find 3 defectives(x=3). Assume the acceptance number in this case is 2(c=2). Since the number of defective units in the sample exceeds the acceptance number, the lot of 10,000 units will be rejected. Note that very good lots or very bad lots will usually require only one sample and lots of medium quality may require two or more samples to reach a decision.

5.4.2. Process quality control system

No two products or services are exactly alike because the processes used to produce them contain many sources of variation, even if the processes are working as intended. For example, the time required to process a credit card application varies because of the load on the credit department, the financial background of the applicant, and the skill & attitude of the employees. Nothing can be done to eliminate variation in process output completely, but management can investigate the cause of variation. Generally, the source of variation can be:

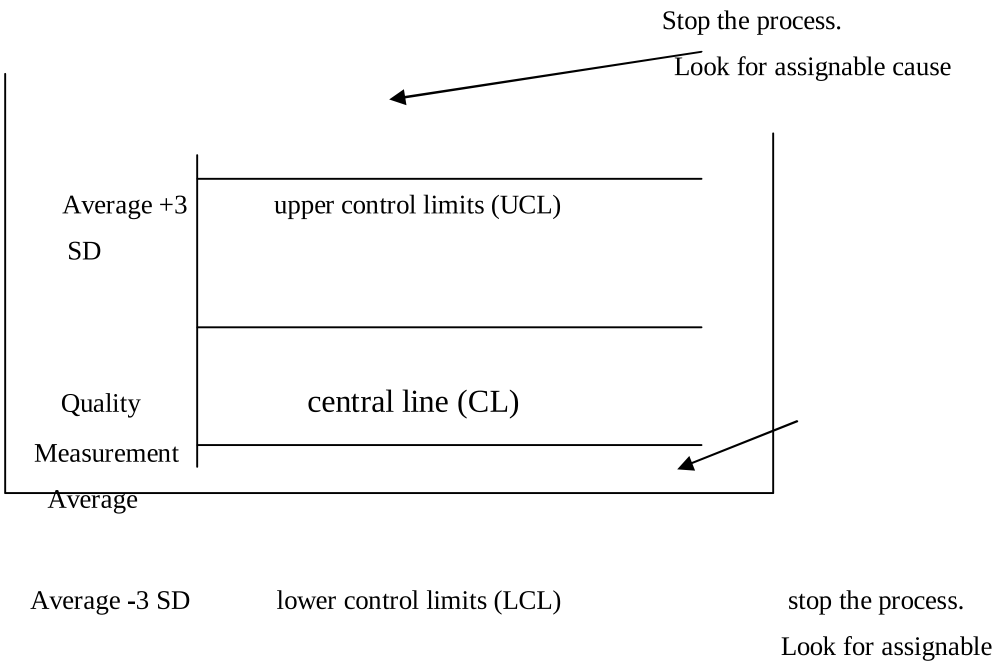
i. *Common causes of variation*: which are purely random, unidentifiable sources of variation that are unavoidable with the current process. No matter how perfectly the process is designed, there will be some variability in quality characteristics from one unit to the next. For example, a machine filling cereal boxes will not deposit exactly the same weight in each boxes; the amount filled will vary around some average figure. The aim of process control is to find the range of *natural variation* of the process and to then ensure that production stays within this range. Natural variation is usually under the state of control.

ii. *Assignable causes:* The second category of variation is assignable sources of variation also called special cases includes any abnormal variations which are not usually found in a state of control. Assignable causes of variation are any variation causing factor that can be identified and eliminated. Assignable causes that results abnormal variation may include: lax (careless) procedures, untrained operators, improper machine maintenance. The first job of process control manager is to seek out these sources of unnecessary variation and bring the process under statistical control, where the remaining variation is due to random causes.

A process 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 chart or control chart.

In the control chart shown below the Y axis represents the quality characteristics which is being controlled while the X axis represent time or particular sample taken from the process. The center line of the chart is the average quality characteristic being measured. The upper control limit represents the maximum acceptable random variations and the lower control limit indicates the minimum acceptable random variation when a state of control exists. Generally speaking, the upper and lower control limits are set at +- three standard deviations from the mean. If normal probability distribution is assumed, these control limits will include 99.7 % of the random variations observed.

Process control chart



After a process has been brought to steady –state operation, periodic samples are taken and plotted on the control chart. When the measurement falls within the control limits, the process is continued. If the measurement falls outside the control limits, the process is stopped and a search is made for an assignable causes. Through this procedure, the process is maintained in a constant state of statistical control and there is only natural variation in the processes output.

Quality measures: to detect abnormal variation, inspectors must be able to measure quality characteristics. Quality can be evaluated in two ways. One way is to measure variables i.e. product or service characteristics such as weight, length, volume or time that can be measured. Another way to evaluate quality is to measure attributes- i.e. product or service characteristics that can be quickly counted for acceptable quality.

Generally as discussed below, quality can be measured for control charts by attributes or by variables.

i. Process control with attribute measures: p and c chart

Control charts for attributes are used when the process characteristic is counted rather than measured. For example, the number of defective items in a sample is counted, whereas the length of each item is measured. There are two types of attribute control charts, one for the fraction of defective items in a sample (a p-chart) and one for the number of defects per unit (a c-chart). A p-chart is appropriate when the data consist of two categories of items. For instance, if glass bottles are inspected for chipping and cracking, both the good bottles and the defective ones can be counted. However, one can count the number of accidents that occur during a given period of time but not the number of accidents that did not occur. Similarly, one can count the number of scratches on a polished surface, the number of bacteria's presented in a water sample, and the number of crimes committed during a month of august, but cannot count a number of non-occurrences. In such cases, C- chart is appropriate.

P chart or C chart

The following tips should help you to select the type of control chart, a P- chart or a C- chart, that is appropriate for particular applications.

Use a P-chart

1. When observations can be placed into one of two categories. Example include items (observations) that can be classified as:
   A. Good or bad
   B. Pass or fail
   C. Operate or not operate
2. When the data consist of multiple samples of n observations each (e.g., 15 samples of n=20 observations each)

Use a C- chart

When only a number of occurrences per units of measure can be counted; nonoccurrence's cannot be counted. Examples of occurrences and units of measure include

A. Scratches, chips, dents or errors per item
B. Cracks or faults per unit of distance (e.g., meters, miles)
C. Bacteria or pollutants per unit of volume (e.g., gallon)
D. Calls, complaints, failures, equipment breakdowns etc

P- chart: a P chart is used to monitor the proportion of defective items generated by the process. The theoretical basis for the p- chart is binomial distribution, although for a large sample size, the normal distribution provides a good approximation to it. Conceptually, a p- chart is constructed and used in such the same way as a mean chart.

The center line on p-chart is the average fraction defective in population, P. the standard deviation of sampling distribution when p is known is

$$\square p=\sqrt{\frac{p(1-p)}{n}}$$

Control limits are computed using the formulas:

UCLp=P+zδp

LCLp= P-zδp

If P is unknown, it can be estimated from samples

Note: because the formula is approximation, it sometimes happens that the computed LCL is negative. In those instances, zero is used as a lower limit.

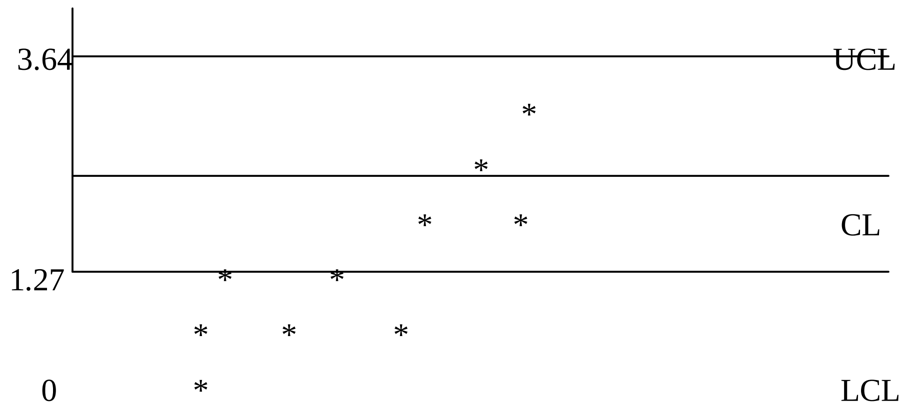
Example: suppose samples of 200 cards are taken from a key punch operation at 2 hours interval to control the keypunch process. The percentage of cards in error for the past 10 samples is found to be 0.7, 1.2, 1.6, 2.0, 1.0, 0.8, 1.8, 1.5, 0.9, and 1.2 percent is the process out of control?

The average of these sample percentages yields a –p=1.27 percent or 0.0127 (sum of all samples divided by sample number i.e.10) which is the centre line of the control chart. The upper and lower control limits are:

$$UCL = 0.0127 + 3\sqrt{\frac{0.0127(1-0.0127)}{200}} = 0.0364$$

$$LCL = 0.0127 - 3\sqrt{\frac{0.0127(1-0.0127)}{200}} = -0.0110$$

When the LCL is negative, it is rounded up to 0 because a negative percentage is impossible. Thus we have the following charts.



Since all sample points are found to be in the control, these 10 samples can be used to establish the centre line and control limits.

Example 2: an inspector counted the number of defective monthly billing statements of a company telephone in each of 20 samples. Using the following information, construct a control chart that will describe 99.74% of the chance variation in the process when the process is in control. Each sample contained 100 statements

Sample	Defectives	Sample	defectives
1	4	11	8
2	10	12	12
3	12	13	9
4	3	14	10
5	9	15	21
6	11	16	10
7	10	17	8
8	22	18	12
9	13	19	10
10	10	20	16
		Total	220

Z For 99.74% is 3

P= $\frac{total\ number\ of\ defective}{total\ number\ of\ observations}$=$\frac{220}{20*100}$=0.11

□p=$\sqrt{\frac{p(1-p)}{n}}$=$\sqrt{\frac{0.10(1-0.11)}{100}}$=0.03

Control limits are:

UCLp=P+z□p=0.11+3(0.03) =0.20

LCLp= P-z□p=0.11-3(0.03) =0.02

Plotting the control limits and the sample fraction defective, you can see that the process is not in control; sample 8(22/100=0.22) and sample 15(21/100=0.21) are above the upper control limit.

C-chart: when the goal is to control the number of occurrences (e.g., defects) per unit, a C-chart is used. Units might be automobiles, hotel rooms, typed pages or rolls of carpet. The underlying sampling distribution is the poisson distribution. Use of the poison distribution assumes that defects occur over some continuous region and that the probability of more than one defect at any particular spot is negligible. The mean number of defects per unit is C and the standard deviation is $\sqrt{c}$. For practical reasons, normal approximate to the poison is used. The control limits are:

UCLc=c+z$\sqrt{c}$

LCLc= c-z$\sqrt{c}$

If the value of c is unknown, as is generally the case, the sample estimate, c is used in place of c. if the process is unknown, it can be estimated from sample data, using c =number of defectives/number of samples. When the computed lower control limit is negative, the effective lower limit is zero. The calculation sometimes produces a negative lower limit due to the use of normal distribution to approximate the poisson distribution. The normal is symmetrical, where as the poison is not symmetrical when c is close to zero.

Example : roll of coined wire are monitored using c-chart eighteen rolls have been examined, and the number of defects per roll has been recorded in the following table. Is the process in control? Plot the values on a control chart using 3 standard deviation control limits.

Sample	Number of defective	Sample	Number of defective
1	3	10	1
2	2	11	3
3	4	12	4
4	5	13	2
5	1	14	4
6	2	15	2
7	4	16	1
8	1	17	3
9	2	18	1
		Total	45

$\bar{c}$ =45/18=2.5

UCLc= c +3$\sqrt{c}$=2.5+3$\sqrt{2.5}$ =7.24

LCLc= c-3$\sqrt{c}$=2.5-3$\sqrt{2.5}$ =-0.66=0

iii. Process control with variable measures: using $\bar{X}$ and R charts

Control charts are also used for measurements of variables. In this case a measurement of 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 or mean) and a measure of variability (the range or standard deviation). With these values, control charts are developed for both the central tendency (-x charts) and the variability of the process(R charts). When the process is found to be out of control on either of these values it is stopped and a search for an assignable cause is made.

R-charts: A range chart, or R-chart is used to monitor process variability. To calculate the range of a set of sample data, the analysts subtract the smallest from the largest measurement in each sample. If any of the data fall outside the control limits, the process availability is not in control.

The control limits for the R-chart are

UCL= D4 $\bar{R}$ and LCL= D3 $\bar{R}$ & $\bar{R} = \frac{\Sigma \text{Sample range}}{\text{no. of sample}}$

Where, R= average ranges and is the central limit of the control chart

D3 & D4 = constant that provide 3 standard deviation limits for a given sample.

Values for D3 & D4 are contained in the quality control table and change as a function of the sample changes. Note that the spread between the controls limits narrows as the sample size increases. This change is a consequence of having more information on which to base an estimate for the process range.

Example: twenty five samples of n=10 observation have been taken from a milling process. The average sample range was 0.01 cm. determine upper and lower control limits for sample ranges.

$\overline{R}$=0.01cm, n=10

From table, for n=10, D4=1.78 and D3 =0.22

UCL=1.78(0.01) =0.0178 or 0.018

LCL=0.22(0.01) =0.0022 or 0.002

In example above, a sample range of 0.018 cm or more would suggest that the process variability has increased. A sample range of 0.002 or less would imply that the process variability had decreased. In the former case, this means that the process was producing too much variation; we would want to investigate this in order to remove the cause of variation. In the latter case, even though decreased variability is desirable, we would want to determine what was causing it: Perhaps an improved method has been used, in which case we would want to identify it. Possibly the improved quality has come at the expense of productivity, or this was only a random occurrence. Hence, it can be beneficial to investigate points beyond the lower limit as well as points beyond the upper limit in a range chart

$\overline{X}$ – Charts: an $\overline{X}$ charts (read 'X' -bar chart) is used to measure the mean or average. When the assignable causes of process variability have been identified and the process variability is in statistical control, the analyst can construct an X bar chart to control the process average. The control limits for the x bar chart are:

$$UCL = \overline{\overline{X}} + A2\ \overline{R} \quad \text{and} \quad LCL = \overline{\overline{X}} - A2\ \overline{R} \qquad \overline{\overline{X}} = \frac{\Sigma \text{sample mean}}{\text{no. of sample}}$$

A2 is constant to provide three sigma limits for the sample mean and changes as sample size changes.

Consider the following example.

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

Solution

The data are shown in the following table.

Data for the $\bar{X}$ and R charts: observation of screw diameters (in inch)

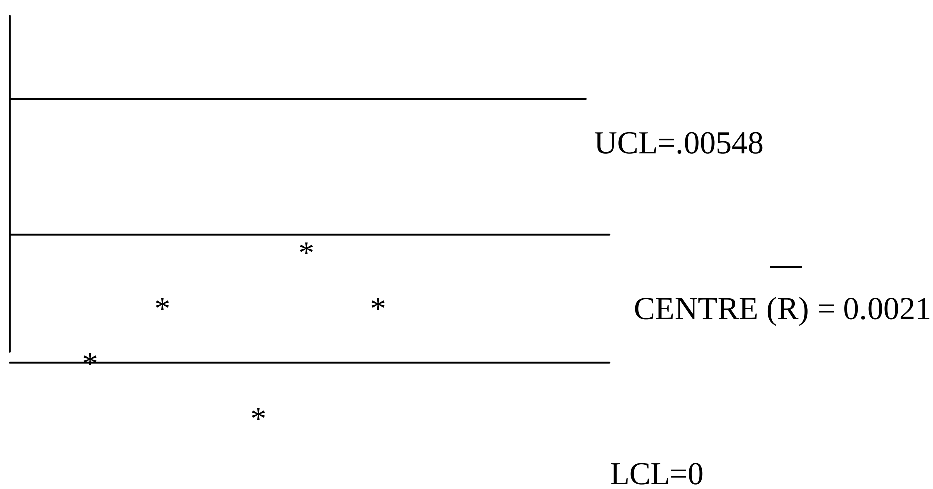
	Observation					
Sample no.	1	2	3	4	R	$\bar{X}$
1	.5014	.5022	.5009	.5027	.0018	.5018
2	. 5021	.5041	.5024	.5020	.0021	.5027
3	.5018	.5026	.5035	.5023	.0017	.5026
4	.5008	.5034	.5024	.5015	.0026	.5020
5	.5041	.5056	.5034	.5047	.0022	.5045
				Average	.0021	.5027

Step1. Compute the range for each sample by subtracting the lowest value from the height value. For example, in sample 1 the range is .5027-, 5009 =.0018. Similarly the range for sample 2, 3, 4, &5 are 0.0021, 0.0017, 0.0026, and 0.0022 respectively. As shown the average range is .0021.

Step2. To constructs the R chart, select the appropriate constant from the table for sample size 4(D4=2.58 &D3=0) .The control limits are:

UCL= 2.58(.0021) =0.005418 inches & LCL = 0(0.0021)=0 inch.

Step3. Plot the range on the R charts as shown below. None of the *sample ranges* fall outside the control limits. Consequently, the process variability is in statistical control. If any of the sample ranges had fallen outside of the limits, or an unusual pattern had appeared, we would have had to search for the causes of the excessive variability, correct them and repeat step 1.



Step4. Compute the mean for each sample. For example, the mean for sample 1 is

$$\frac{0.5014+.5022+.5009+.5027}{4} = 0.5018 \text{ inch}$$

Similarly the means of samples 2, 3, 4, and 5 are 0.5027, 0.5026, 0.5020, & 0.5045 respectively. As shown in the table the grand mean is 0.5027.

Ste 5. Now construct the X chart for the process average. The average screw diameter is 0.5027 inches. The average range ~~is~~ 0.0021. , so use the grand mean 0.5027, $\overline{R}$ =0.0021 and A2 from the table for sample size 4 to construct the control limits.

$UCL = X + A2\,R$ = 0.5027 + .73(.0021) = .5042 *inches* and

LCL= $\overline{\overline{X}} - A2\,\overline{R}$ = .5027-.729(.0021) =.5011.

Step6. Plot the sample means on the control chart as shown above for R chart.

In this case the mean of sample 5 falls above the upper control limit, indicating that the process average is out of control and that assignable cause must be explored.

Self check questions

1. What is a control chart that monitors changes in the dispersion or variability of a process?
   A. X chart
   B. R chart
   C. C chart
   D. P chart
2. P-charts are used to measure:
   A. continuous variation
   B. intermittent random variation
   C. proportion of items in a sample that are defective
   D. the count of defective parts
   E. proportion of items in a sample that are good
   F. None of the above
3. which one of the following statement is/are **correct** regarding variation
   A. All processes that provide a good or a service exhibit a certain amount of natural variation in their output
   B. The amount of inherent variability differs from process to process
   C. Unlike natural variation, the main sources of assignable variation can usually be identified (assigned to a specific cause) and eliminated.
   D. All of the above
   E. All except “B”

5 .5 Quality awards and standards

5.5.1 The Malcolm Baldrige National Quality Award (MBNQA)

The Malcolm Baldrige National Quality Award was established in 1987, when Congress passed the Malcolm Baldrige National Quality Improvement Act. The award is named after the former Secretary of Commerce,Malcolm Baldrige, and is intended to reward and stimulate quality initiatives. It is designed to recognize companies that establish and demonstrate high quality standards. The award is given to no more than two companies in each of three categories: manufacturing, service, and small business. Past winners include Motorola Corporation, Xerox, FedEx, 3M, IBM, and the Ritz-Carlton.

To compete for the Baldrige Award, companies must submit a lengthy application, which is followed by an initial screening. Companies that pass this screening move to the next step, in which they undergo a rigorous evaluation process, conducted by certified Baldrige examiners. The examiners conduct site visits and examine numerous company documents. They base their evaluation on seven categories, which are shown in table below.

Categories	**Points**
Leadership	120
Strategic planning	85
Customer and market focus	85
Information and analysis	90
Human resource focus	85
Process management	85
Business result	400
Total point	1000

5.5.2 The Deming Prize

The Deming Prize is a Japanese award given to companies to recognize their efforts in quality improvement. The award is named after W. Edwards Deming, who visited Japan after World War II upon the request of Japanese industrial leaders and engineers. While there, he gave a series of lectures on quality. The Japanese considered him such an important quality guru that they named the quality award after him. The award has been given by the Union of Japanese Scientists and Engineers (JUSE) since 1951. Competition for the Deming Prize was opened to foreign companies in 1984. In 1989 Florida Power & Light was the first U.S. Company to receive the award.

5.5.3 ISO 9000 Standards

Increases in international trade during the 1980s created a need for the development of universal standards of quality. Universal standards were seen as necessary in order for companies to be able to objectively document their quality practices around the world. Then in 1987 the International Organization for Standardization (ISO) published its first set of standards for quality management called ISO 9000. The International Organization for Standardization (ISO) is an international organization whose purpose is to establish agreement on international quality standards. It currently has members from 91 countries, including the United States. To develop and promote international quality standards, ISO 9000 has been created. ISO 9000 consists of a set of standards and a certification process for companies. By receiving ISO 9000 certification, companies demonstrate that they have met the standards specified by the ISO. The standards are applicable to all types of companies and have gained global acceptance. In many industries ISO certification has become a requirement for doing business. Also, ISO 9000 standards have been adopted by the European Community as a standard for companies doing business in Europe.

In December 2000 the first major changes to ISO 9000 were made, introducing the following three new standards:

- ISO 9000:2000–Quality Management Systems–Fundamentals and Standards: Provides the terminology and definitions used in the standards. It is the starting point for understanding the system of standards.
- ISO 9001:2000–Quality Management Systems–Requirements: This is the standard used for the certification of a firm's quality management system. It is used to demonstrate the conformity of quality management systems to meet customer requirements.
- ISO 9004:2000–Quality Management Systems–Guidelines for Performance: Provides guidelines for establishing a quality management system. It focuses not only on meeting customer requirements but also on improving performance.

These three standards are the most widely used and apply to the majority of companies. However, ten more published standards and guidelines exist as part of the ISO 9000 family of standards.

To receive ISO certification, a company must provide extensive documentation of its quality processes. This includes methods used to monitor quality, methods and frequency of worker training, job descriptions, inspection programs, and statistical process-control tools used. High-quality documentation of all processes is critical. The company is then audited by an ISO 9000 registrar who visits the facility to make sure the company has a well-documented quality management system and that the process meets the standards. If the registrar finds that all is in order, certification is received. Once a company is certified, it is registered in an ISO directory that lists certified companies. The entire process can take 18 to 24 months and can cost anywhere from $10,000 to $30,000. Companies have to be re-certified by ISO every three years.

One of the shortcomings of ISO certification is that it focuses only on the process used and conformance to specification. In contrast to the Baldrige criteria, ISO certification does not address questions about the product itself and whether it meets customer and market requirements. Today there are over 40,000 companies that are ISO certified. infact, certification has become a requirement for conducting business in many industries.

5.5.4 ISO 14000 Standards

The need for standardization of quality created an impetus for the development of other standards. In 1996 the International Standards Organization introduced standards for evaluating a company's environmental responsibility. These standards, termed ISO 14000, focus on three major areas:

- Management systems standards measure systems development and integration of environmental responsibility into the overall business.
- Operations standards include the measurement of consumption of natural resources and energy.
- Environmental systems standards measure emissions, effluents, and other waste systems. With greater interest in green manufacturing and more awareness of environmental concerns, ISO 14000 may become an important set of standards for promoting environmental responsibility.

Self check questions

1. What is the Malcolm Baldrige National Quality Award? Why is this award important, and what companies have received it in the past?
2. What are ISO 9000 standards? Who were they set by and why? Can you describe other certifications based on the ISO 9000 certification?
3. ISO 14000 standards focuses on
   A. Systems development and integration of environmental responsibility into the overall business
   B. The measurement of consumption of natural resources and energy
   C. The measurement of emissions, effluents, and other waste systems.
   D. Continuous improvement programs, employee training, and functioning of teams
   E. All of the above
   F. All except "B"

Summary

- Quality can be defined in a number of different ways. Some of the common definitions are stated as follows:
  - ✓ Quality is synonymous with '*superiority' or 'innate excellence*'. From this view point, quality cannot be precisely defined but can only be recognized through experience.
  - ✓ A second view point is that quality is precise and measurable concept and that *differences in quality* reflect differences in quantity of some *product attributes*.
  - ✓ Quality can be defined as *fitness for intended use*, or in other words, how well the product performs its intended functions.(user based view)
  - ✓ Quality is *conformance to specification*. Quality conformance can be defined as, how well manufacturing is able to meet design specification.(manufacturing view)
- Quality can be evaluated in two ways. One way is to measure variables i.e. product or service characteristics such as weight, length, volume or time that can be measured. Another way to evaluate quality is to measure attributes- i.e. product or service characteristics that can be quickly counted for acceptable quality.
- There are four categories of quality costs. The first two are prevention and appraisal costs, which are incurred by a company in attempting to improve quality. The last two costs are internal and external failure costs, which are the costs of quality failures that the company wishes to prevent.

- Total quality management (TQM) is different from the old concept of quality because its focus is on serving customers, identifying the causes of quality problems, and building quality into the production process.
- Seven features of TQM combine to create the TQM philosophy: customer focus, continuous improvement, employee empowerment, use of quality tools, product design, process management, and managing supplier quality.
- Quality function deployment (QFD) is a tool used to translate customer needs into specific engineering requirements. Seven problem-solving tools are used in managing quality. Often called the seven tools of quality control, they are cause-and-effect diagrams, flowcharts, checklists, scatter diagrams, Pareto analysis, control charts, and histograms.
- The Malcolm Baldrige Award is given to companies to recognize excellence in quality management. Companies are evaluated in seven areas, including quality leadership and performance results. These criteria have become a standard for many companies that seek to improve quality. ISO 9000 is a certification based on a set of quality standards established by the International Organization for Standardization. Its goal is to ensure that quality is built into production processes. ISO 9000 focuses mainly on quality of conformance.

Self assessment questions

I. Multiple choice questions

1. from the following alternatives, which one of the following is **not** the costs of poor quality under preventive
   A. Design cost
   B. Training cost
   C. Planning cost
   D. Rework cost
   E. Information cost
2. Of the following which one is true about total quality management(TQM)
   A. Firms must inspect quality in to product to weed out defective product
   B. Managers should fix any quality related problem to the quality department
   C. It focuses on spending more time on inspection than planning
   D. In the organization quality must be everybody responsibility
   E. Unlike top managers, lower level managers are not responsible for quality

Work out

1. A Production manager for a tire company has inspected the number of defective tires in five random samples with 20 tires in each sample with 3sigma limit. The table below shows the number of defective tires in each sample of 20 tires. Calculate for upper and lower control limits.

Sample	Number of Defective Tires	Number of Tires in each Sample	Proportion Defective
1	3	20	**.15**
2	2	20	**.10**
3	1	20	**.05**
4	2	20	**.10**
5	2	20	**.05**
Total	9	100	**.09**

2. Processing new account at Dashen Bank is intended to average 10 minutes each. Five samples of four observations each have been taken. Use the sample data to construct upper and lower control limits for both mean chart and range chart. Does the result suggest that the process is in control?(4 mark)

	Sample 1	**Sample 2**	**Sample 3**	**Sample 4**	**Sample 5**
	10.2	*10.3*	*9.7*	*9.9*	*9.8*
	9.9	*9.8*	*9.9*	*10.3*	*10.2*
	9.8	*9.9*	*9.9*	*10.1*	*10.3*
	10.1	*10.4*	*10.1*	*10.5*	*9.7*
Total	**40**	**40.4**	**39.6**	**40.8**	**40**

APPENDIX

Number of observations in sub group ,n	**Factor for X-chart,A2**	**Lower control limit,D3**	**Upper control limit,D4**
2	*1.88*	*0*	*3.27*
3	*1.02*	*0*	*2.57*
4	*0.73*	*0*	*2.58*
5	*0.58*	*0*	*2.11*
6	*0.48*	*0*	*2.00*
7	*0.42*	*0.08*	*1.92*
8	*0.37*	*0.14*	*1.86*
9	*0.34*	*0.18*	*1.82*
10	*0.31*	*0.22*	*1.78*
11	*0.29*	*0.26*	*1.74*
12	*0.27*	*0.28*	*1.72*
13	*0.25*	*0.31*	*1.69*
14	*0.24*	*0.33*	*1.67*
15	*0.22*	*0.35*	*1.65*
16	*0.21*	*0.36*	*1.64*
17	*0.20*	*0.38*	*1.62*
18	*0.19*	*0.39*	*1.61*
19	*0.19*	*0.40*	*1.60*
20	*0.18*	*0.41*	*1.59*