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**PRODUCTION AND
OPERATIONS MANAGEMENT**

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LESSON 1

INTRODUCTION

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STRUCTURE

- 1.1 Learning Objectives
- 1.2 Introduction to Production and Operations Management
- 1.3 Evolution of Production and Operations Management
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- 1.9 Glossary
- 1.10 Answers to In-text Questions
- 1.11 Self-Assessment Questions
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1.1 LEARNING OBJECTIVES

The objective of the lesson is to create an understanding of the theoretical and practical aspects of production and operations management and also to impart the understanding of the:

- Meaning and nature of Production and Operations Management
- Evolution and Scope of Production and Operations Management
- Emerging Trends in Operation Management.
- Operations Strategy and Its linkages with competitive strategy.
- The formulation of the Operations Strategy



1.2 INTRODUCTION

Production and operations management is a critical management role in the regulated transformation of raw materials into goods and services with an added value per the organisation's policies. Although production and operations management concepts and techniques have been developed throughout time owing to global competitiveness, these concepts and methods are supplemented by newer/modified concepts and designs to fit the evolving needs of business houses.

As businesses operate in an environment where they have to offer goods, services or ideas to potential customers to earn revenue for their shareholders and also in order to expand, diversify, grow and create goodwill for themselves, they have to undertake operations with the resources that they have. The primary function of any business is the objective for which the industry has been set up. For example, for a company who sells cold drinks, operations will include all the necessary steps that are important to produce and store and finally sell the cold drinks bottles to the end customer in such a way that it ensures utmost efficiency.

Production and Operations Management involved two distinct ideas: "Production" and "Operations". Operations management, in particular, became a popular field in academics only after the services became a matter of mass production in the new industrial revolution. When the show became intangible along with the conventional tangible, to fill this gap and to broaden the understanding of the field of production management in the services sector, the advent of operation management began.

Meaning of Production Management:

Production management deals with how the management activities are arranged in an organisation concerning the designing, controlling, operating and updating of the production and its ancillary systems. It is also noted that the production management processes must be dealt with keeping in mind the utmost efficiency and effectiveness of the management system. Production management is often misunderstood as a separate function of management. It is a function which relates to planning and coordinating the resources that are required for the production of goods in a tangible business organisation and the production of services in an intangible form of business organisation (Intangible form may be understood as a business with virtual existence).

In the words of **E.S. Buffa**, "*Production management deals with decision making related to production processes so that the resulting goods or services are produced according to specifications, in the amount and by the schedule demanded and out of minimum cost.*"



Therefore, production management focuses on both goals which are maximisation of customer satisfaction and benefits and, on the other hand, optimal utilisation of resources so that losses and wastage are minimised.

IN-TEXT QUESTIONS

1. Plant layout is a structure of how the physical components of a _____ unit are _____.
2. Production management is a newer concept as compared to operations management (True / False)
3. Production is the process of converting _____ into _____
4. The production process of a car manufacturer and sweet shop owners are both divided into _____.

1.3 EVOLUTION OF PRODUCTION AND OPERATIONS

The Great Wall of China, the Egyptian pyramids, and the archaeological remains of once-thriving cities of Asia, North Africa, Europe, and the Americas are all examples of early production systems that may be found today. It was obvious that decisions about the layout of the facilities, the scheduling of the workforce, and the procurement of supplies needed to be made. Ancient cultures were aware of and used contemporary operations management ideas. For instance, in ancient Greece, the specialisation of work was pretty frequent.

With rare exceptions, most things were manufactured by artisans working alone or as part of a small business until the seventeenth century. Labour specialisation was used on occasion, although the overall size of activities was often modest and labour-intensive. A typical manufacturing plant featured a few apprentice employees the owner-master craftsman oversaw. Rather than equipment, its technology was manifested in brains and hands. Product design and manufacturing were unified in the person of the owner; quality control, labour scheduling, and material management were done by experiences using basic principles; markets were tiny, and distribution was easy.

1.3.1 The Industrial Revolution

The Industrial Revolution ushered forth modern operations management. Technological improvements in eighteenth-century England resulted in massive changes in how things were



manufactured, the scope of operations, the size of markets, and the organisational structure of staff. The textile sector was the first to see considerable technical advances.

Spinning and weaving technologies were noteworthy because they marked a big step toward replacing human labour with other sources of power (mainly water and mule energy). They represented competence and technology in machines rather than humans. Machines enabled unskilled people to produce fabric of higher quality than expert weavers could produce by hand. Around this period, the machine tool industry in England and America began to emerge. Until then, wooden components were extensively employed in machines because they could be fashioned with more accuracy than metal parts, but they were not wear-resistant. By 1825, the Industrial Revolution was well underway in England. Many industries have factories that use steam-powered machinery. As a result of improved productivity, goods production grew significantly, and prices typically declined. Change, like other revolutions, created issues. Machines have displaced workers. Wages were low, workplaces were drab and unsanitary, 14-16-hour work days were frequent, and women and even young kids were virtually entirely exploited as labour in numerous sectors. Because these conditions were so repressive and prevalent, the British Parliament created a continual stream of laws granting employees more rights and protection.

Soon after the American Revolutionary War, the Industrial Revolution extended to the United States. Operations became so enormous that firm owners were no longer able to closely monitor all elements of their businesses. As capital requirements grew, new types of ownership emerged, including multimember partnerships and public stock ownership. The manufacturing process was broken down into discrete components, allowing specialised equipment to be created to do each stage of the process and employees to become more efficient at completing a restricted range of tasks-labourspecialisation. Each of these components is required to be overseen and coordinated with the rest of the organisation's components. A group of expert managers was quickly required to create, plan, and monitor the company's activities.

1.3.2 Scientific Management

As the management class rose, so did interest in how to manage operations. Scientific discoveries in astronomy, chemistry, physics, and biology throughout the second half of the nineteenth century led to the notion that the universe was regulated by natural laws. The structure of scientific inquiry served as the foundation for what became known as scientific management. The assumption that there were rules guiding industrial systems, just as there were laws governing natural systems, served as the foundation for scientific management. If



such rules could be established, they might be utilised to determine the optimal method to do any work or manufacture a product.' Natural system scientific laws were found via observation and experimentation.

Frederick W. Taylor (1856-1915) was known as the "Father of Scientific Management." Taylor's theory was founded on four guiding principles:

1. Work is governed by basic scientific rules. Management may utilise scientific approaches to understand what these principles are and then use them to build the optimal strategy to complete any assignment.
2. Every individual is unique, and these differences may be utilised in production management by matching the appropriate person to the correct task and teaching workers to fully develop and utilise their abilities. Through observation and experimentation, this matching and training should be done scientifically.
3. To increase productivity, use employee self-interest. Suppose management communicates the reasons for the job design to employees and provides them with suitable incentives. In that case, it will be in the employees' best interests to complete their jobs as planned. As a result, Taylor devised salary incentive systems that rewarded workers for exceeding some (scientifically determined) norm while punishing those who fell short.
4. Responsibility should be divided between floor employees and management. Taylor suggested that staff groups be formed that specialise in devising production processes, designing jobs and work techniques, establishing salary incentive programmes, choosing and training people, and planning and coordinating operations. These staff groups and line supervisors would then educate the floor employees on what to do, how to do it, and when. This concept caught on, and these employees became known as industrial engineers.

1.3.3 The Human Relation Movement

The goal of scientific management was to improve job design, teach employees, and give financial incentives to boost worker productivity. Other than financial self-interest, the social and psychological components of labour were deemed insignificant. In the 1920s, a branch of psychology emerged that held that other variables, such as work environment, social group pressure, and employee-management relationships, had a significant impact on productivity. The research that sparked this trend began in 1927 at Western Electric Company's Hawthorne factory and is now known as the Hawthorne Studies.



The Hawthorne studies investigated the effects of illumination, work breaks, and monetary incentives. They also incorporated a comprehensive interviewing procedure in which employees may express their criticisms and concerns. Several productivity studies and worker groups were included in the Hawthorne studies. When the Hawthorne experiments concluded in 1932, almost 20,000 employees had taken part in some form. After a few years, the researchers decided that the employees were responding to the attention they got rather than the illumination; by being chosen and placed in different rooms, the workers felt important and performed harder.

1.3.4 Operation Research/ Management Science

During WWII, the British government established multidisciplinary scientific teams to do research on military operations such as shipping logistics, search and detection (including radar development), and aircraft design and vulnerability. This effort was labelled as "operational research." The governments of the United States and Canada established comparable "activities research" teams to analyse their own military operations. Much of the early operations research work relied heavily on mathematical models and analysis to solve issues. This work was so effective that similar ideas were used to solve operational difficulties in industry and government after the war. (This industrial work was also known as management science at times.) Nowadays, the phrases operations research and management science are sometimes used interchangeably)

1.3.5 Computers in Operation Management

Computers have had a significant influence on industrial production system management, as well as the areas of operations research and industrial engineering. Computers' speed and data-handling skills enable engineers and scientists to create bigger, more realistic models of structured systems and to get meaningful answers to those models using simulation approaches. Computers are utilised to regulate machine motions, as well as to monitor tool settings, equipment or material temperatures, and fluid flow rates, as well as to make continual changes to rollers, valves, or heaters. One of the most significant applications of computers in operations management is to improve information flow. This information can be readily maintained and updated, and it can be instantly communicated with those who require it, such as department heads, machine operators, and production workers.

1.3.6 The Japanese Production System

Japanese manufacturing techniques originated as an area of significant practises and ideologies in the post-World War II era and peaked in the 1980s. The Toyota Production



System (TPS), based on just-in-time (JIT) production or so-called lean manufacturing, is perhaps the most well-known collection of Japanese manufacturing practices. Taiichi Ohno, a former Toyota executive, and Shigeo Shingo, a distinguished engineer and consultant, were the forerunners of these procedures. The achievement has prompted operations managers all across the world to investigate how Japanese businesses achieved such production supremacy.

- **Quality comes first in the Japanese manufacturing system:**

"The basic purpose of the firm is to put the quality of the product ahead of all other considerations." The following are the ways how excellence is ensured:

- (a) Creating higher-quality items
- (b) Making sure that everyone is responsible for the quality of the products rather than just inspectors
- (c) Ensuring that the product is accurate from the start to prevent rework or complete rejections.
- (d) Employing statistical quality control techniques as necessary.

- **Improve the Product and Process Continuously:**

Most process technology gains are the product of numerous minor improvements over time. The Japanese manufacturing system encourages employees and managers to submit cost-cutting and quality-improving modifications.

- **Eliminate all sorts of waste**

The Japanese manufacturing system focuses on detecting and eliminating all sources of waste. Any action or substance that is expensive but adds no value to the product is removed. This concept gave rise to inventory-reduction techniques such as JIT.

1.3.7 Operation Management Today

An intriguing element of operations management is that most of the critical issues that existed a century ago are still relevant today. For many years, basic ideas and ways for solving them have existed. However, we now have greater tools and knowledge to carry them out.



1.3.8 Difference between Production management and Production & Operation management

Criteria	Production Management	Production and Operations Management
Scope	Limited to managing the production process only	Broader scope that includes managing the entire operations process
Focus	Emphasizes on manufacturing goods and meeting production targets	Focuses on overall operations management, including supply chain, inventory, quality, and customer satisfaction
Objectives	Main objective is to ensure efficient and effective production processes	Aims to improve the overall business performance through efficient operations management
Key activities	Planning, organizing, directing, and controlling the production process	Coordination of all activities involved in producing goods and services, including planning, scheduling, inventory management, quality control, and supply chain management
Responsibility	The production manager is responsible for managing the production process	Production and operations managers are responsible for managing the overall operations process
Application	Primarily applied in manufacturing industries	Applicable to both manufacturing and service industries



1.3.9 Similarities between Production management and Production & Operation management

Criteria	Similarity
Goal	Both aim to ensure that production processes are efficient and effective
Focus	Both emphasize the importance of planning, organizing, and controlling operations
Key activities	Both involve planning, scheduling, quality control, and inventory management
Importance	Both are critical to the success of manufacturing and service organizations

IN-TEXT QUESTIONS

5. Japanese production system eliminates all kinds of _____.
6. Human relations movement is an outcome of Hawthorne studies (True / False)
7. Scientific Management principles were developed in the 1920s by Elton Mayo and Henri Fayol. (True/False)
8. The Modern operations problems have to deal with using _____

1.4 SCOPE OF PRODUCTION AND OPERATIONS MANAGEMENT

The conversion of input raw material into finished final goods using tools and methods, which also ensures efficiency is what production and operations management are concerned with. It is different from other activities as it focuses only on "conversion through employing physical resources," as opposed to other functions like people, logistics, trade etc. The following activities (but are not limited to) come under the scope:

- Deciding the location of its manufacturing plants and storage facilities.
- Deciding the layout of the production plant



- Decision on how the product will look (Product design)
- Decision on how the process will be undertaken
- How procurement of raw materials will be done
- How production will take place
- How quality standards must be ensured.
- Decision on Inventory management
- Decision on production and plant capacity planning
- Decision on Maintenance and Repair
- Decision on supply chain management

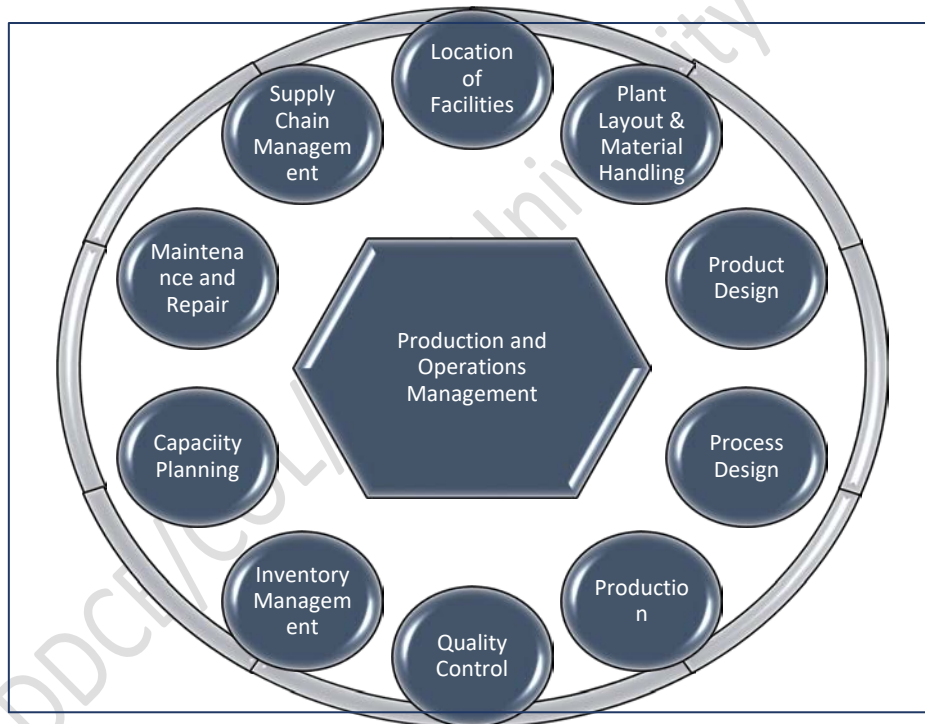


Fig 1.1: Scope of Production and Operations Management

1.4.1 Location of Facilities:

Location decision is one of the most important decisions of production and operations management. The decision about where the plant facility will be established concerns the location decision. For example, the idea of setting up a manufacturing plant in an industrial



town of Haryana will majorly be based on several factors, including the availability of raw material, labour, ancillary activities, the customer's geographic location etc., in no particular order.

The decision concerning the location of the facilities is typically a key decision because it has a long-term impact on the firm. Once set up, it takes much work for the firms to step back from the decision.

1.4.2 Plant Layout & Material Handling

The layout is the structure in which the physical components of any production facility are arranged. A production facility typically has various centres of production where each centre has a different role to play in the production process. Think of a car manufacturing plant at Manesar, Haryana. They do not just let the steel sheets, Tires, Paint cans, electrical wiring, Glass, Fibre panels, screws and bolts into the building from one side and get the final finished car out from the other. Rather there are dedicated facilities for every operation.

For metal fabrication, there is a separate setup, another set-up for the engine, another for paint etc. Similarly, each set-up requires different kinds of inputs and materials also. Sometimes the material has to be taken from one place to another. All these decisions regarding the handling of material and setting up of the physical arrangement of the plant have to be taken keeping in mind the required quality that is to be achieved with minimum wastage and costs. Thus, Plant layout and material handling are crucial decisions under production and operations management.

1.4.3 Product Design

Bringing ideas into reality is what product design is all about. In a strategy for growth and expansion, every corporate organisation must create, refine, and launch new goods. The largest problem firms confront creating new items and introducing them to the market. The business's success entirely depends on the success of its products in the market. Whether or not the customers like what they pay for is the crucial factor that can lead a business towards newer heights and ruins. Here, Product design plays an important role.

1.4.4 Process Design

Process design refers to a decision made on the process path for converting inputs into finished goods. The technique to employ, the technology to employ, the study of the process flow, and the design of the facility. Thus, the analysis of the workflow for turning raw materials into completed goods and the choice of workstation for each step in the workflow are crucial considerations in process design.



1.4.5 Production

The actual initiation of converting inputs to outputs is known as production. Usually, the process of production is divided into various steps; whether it is a manufacturing plant at Manesar that we talked about earlier or a small sweet shop in a nearby locality, almost every production process is a step-by-step conversion of raw materials into finished products.

1.4.6 Quality Control

A method used to maintain a standard of quality for goods and services can be termed quality control. It involves systematically overhauling several elements that have an impact on the product's quality. Quality control also uses an efficient feedback system and corrective action mechanism to avoid faults at their source.

1.4.7 Inventory Management

One of the critical responsibilities of a production and operations manager is to ensure that the organization maintains adequate inventory levels to meet customer demands. Inventory management decisions include determining the optimal quantity to order, when to place an order, and how much safety stock to maintain. A manager must strike a balance between maintaining adequate inventory levels to meet demand and minimizing the costs associated with holding inventory.

1.4.8 Capacity Planning

Capacity planning refers to the process of determining the optimal level of production that a company can achieve over a specific period. Production and operations managers must make decisions about how much capacity they need to meet customer demands while taking into account factors such as labor availability, equipment, and material resources. They also need to consider potential changes in demand and how to adjust capacity accordingly.

1.4.9 Maintenance and Repair

Production and operations managers are responsible for ensuring that equipment and machinery are in good working condition to maintain the production process. This requires a plan for maintenance and repair to minimize downtime and avoid costly repairs. Decisions related to maintenance and repair include choosing the best equipment maintenance strategy, scheduling maintenance and repair work, and identifying the right suppliers to provide the necessary equipment parts and services.

1.4.10 Supply Chain Management

Supply chain management involves overseeing the flow of goods, services, and information from suppliers to customers. Production and operations managers must make decisions about



supplier selection, lead times, transportation, and distribution. They also need to ensure that the supply chain is efficient and cost-effective, while maintaining high levels of quality and customer satisfaction. Effective supply chain management can improve customer satisfaction, reduce costs, and enhance the organization's competitiveness.

ACTIVITY

Choose a multinational company of your choice that operates in India. Out of the list of global trends in production and operation management, how many can you observe in the workings of this company. Write 500-600 words on your observation. Also try to find some trends that the company does but that is not present in the study material.

1.5 EMERGING TRENDS IN OPERATION MANAGEMENT

From labour division to scientific management and mass manufacturing. Operation attempts to synchronise with the requirements of businesses by improving and innovating constantly.

1.5.1 Computer-Aided Design and Manufacturing

The next significant development came after the automation and Scientific Management trends. The designing and manufacturing are carried out using computers thanks to these computer-assisted procedures, considerably enhancing the processes' efficiency. The creation of new products and the redesign of processes were both greatly aided by these technologies.

In 1996, General Motors encountered computer-aided systems for the first time and used them to save time and money. It facilitated the company's introduction of new automobiles more smoothly and expeditiously.

1.5.2 Product life cycle shortening

When a product was first created, its life cycle used to be somewhat longer, and it often remained on the market for a longer amount of time. Product life cycles are now shorter due to the rapid advancement of technology. Companies are compelled to launch new items quickly while fostering innovation as a result of this. This has presented a fresh problem and necessitates a speedier operation overhaul.



1.5.3 Supply Chain Management

Due to shorter product life cycles, demanding consumers, and quick changes in technology, materials, and processes, supply chain partners are needed to be more responsive to end-user expectations. Additionally, managers are now getting the work done from other third parties in the chain with specialised knowledge.

1.5.4 Mass Personalisation

Large-scale, standardised mass manufacturing was once used in order to achieve economies of scale. Businesses must now adjust to the increased flexibility and competitiveness of the market with creative product designs and adaptable production processes that satisfy the individual needs of consumers. Currently, the tendency is shifting toward the manufacture of commodities on demand, wherever and whenever it is needed. This has caused the way operations were previously planned to shift, resulting in improved and more effective procedures.

1.5.5 Employee Participation

Employee complaints were typically disregarded in the past since workers were seen as simply input items in production. More competency is needed in the workplace as a result of the knowledge explosion and increasingly technological workplace.

In response, operations managers are now delegating more decision-making to specific employees. With the growth of HRM, businesses now frequently place a greater emphasis on employee empowerment and upliftment.

1.5.6 Green Manufacturing

In the past, manufacturing was centred on getting resources for the least amount of money while neglecting environmental impact. Managers of operations are currently becoming more and more concerned with designing goods and processes that are environmentally sustainable. This is creating items and their packaging in a way that uses the fewest resources possible and is recyclable, biodegradable, and generally ecologically friendly.

In other terms, the contemporary trend in operations management towards ecological sustainability has been dubbed "Green manufacturing."

1.5.7 Operations convert to Lean



It's interesting how the "Lean" philosophy can be used to explain all of the patterns mentioned above. Sustainability and mass personalisation are two distinct facets of lean operations, respectively. Businesses can only achieve effective Sustainable Management by adhering to the continual improvement principle of the lean mindset. In reality, JIT alone has made mass personalisation feasible since it enables personalisation in accordance with client wants or wishes without raising prices or lengthening production times.

JIT is an operational concept that aims to instantly meet consumer demand while maintaining faultless quality and zero waste. It is a method of planning and managing. The previous techniques of mass manufacturing, which involved selling large quantities of created items in batches to achieve economies of scale, have been replaced by the lean operations concept. In the current era of operations management, this has changed to JIT production, where goods are manufactured immediately upon customer orders with adaptations, resulting in a significant decrease in product cost.

CASE STUDY

Designing the production process: A case of ABV Infra works

ABV Infra works is a real estate company which builds residential and commercial properties that are both affordable and sustainable to the environment. For ensuring the affordability of the property, the co. tries to minimize the labour cost involved in the construction. Since the state laws are as such that labour has to be paid on a time-wage system, so ABV focuses on minimizing the time it takes for construction. Mr. Lokesh, who is the construction supervisor estimated that a lot of time that is wasted is attributed to ordering and procuring the raw material. So, he ordered all the required raw material in one go. Now since every type of construction material is on the locations, the production process is not being done one step at a time, which is causing further delays and wastages. Assist Mr. Lokesh in taking the right decision in the given set of constraints with respect to the scope of production and operation management.

1.6 OPERATION STRATEGY AND ITS LINKAGES WITH THE COMPETITIVE STRATEGIES



While an operations plan is one side of a company's strategy, it is crucial for success and competitiveness. Companies without such plans lag behind more strategic competitors and cannot change with the times. When it comes to operations planning, both large and small firms have struggled, usually lagging behind more technologically savvy competitors. For instance, Amazon has eliminated a large number of brick-and-mortar businesses despite continually developing technology, such as drones for delivery.

For a firm to be successful and competitive, all of its parts must work together. Every department has to have a plan that advances the overall corporate/business strategy and advances the organisation's goal.

One classification for core strategies would be:

1. **Corporate:** overall business strategy, directing the business objective, and associated divisions
2. **Customer-Driven:** operational strategies to satisfy a certain consumer segment's demands
3. **Core Competencies:** How to enhance the main assets and strengths
4. **Competitive Priorities:** How to set the business apart within the marketplace to better supply a desired good or service
5. **Product or Service Development:** Techniques for product innovation, value, and design

The key success factors of a firm, such as its characteristics, assets, capacities, and competencies, are related to competitiveness. A business may concentrate on the most critical items by identifying these and measuring them with key performance indicators. These "distinctive" capabilities are a further method to frame strategic positions: Price, quality, functionality, features, appearance, durability, service, adaptability and tradeoff.

Order Qualifiers and Order Winners

These terms are used to describe the factors that are critical to meeting customer requirements and gaining a competitive advantage in the marketplace.

An order qualifier is a characteristic or feature that a product or service must possess to be considered by a customer as a potential purchase. These are the minimum standards that a product or service must meet to be considered for purchase. For example, a customer may require a product to be delivered within a certain timeframe or meet certain quality standards



before considering it as an option. Meeting order qualifiers is necessary for a company to stay in the competition, but it is not enough to create a competitive advantage.

An order winner is a characteristic or feature that differentiates a product or service from its competitors and leads customers to choose it over other options. Order winners provide a competitive advantage by meeting or exceeding customer expectations and creating a unique selling proposition. For example, a product that has better quality, more features, or faster delivery time than its competitors can be an order winner. Companies that excel at providing order winners gain a competitive advantage and can increase their market share.

It is important for production and operations managers to understand the difference between order qualifiers and order winners, as this knowledge can help them focus on areas where they can differentiate themselves and gain a competitive advantage in the marketplace. By identifying the order qualifiers and order winners of their products or services, managers can develop strategies that leverage their strengths and address their weaknesses.

1.6.1 Competitive Priorities

The methods through which the Operations Management function concentrates on affordability, excellence, flexibility, and timeliness are competing priorities. The emphasis placed on each of the competition criteria will depend on the corporation's clients.

- **Affordability:** Companies with customers that place a high value on pricing will be very interested in creating procedures that allow them to keep their prices competitive. These companies typically pay close attention to where the waste is located and how to get rid of it. They will save money by reducing errors. These companies will monitor their productivity closely and take steps to boost it. Utilising resources efficiently is essential.
- **Excellence:** Businesses that cater to customers that place a high value on quality and perfection focus on designing effective products and processes. Together, marketing and engineering develop products that meet customer demands. Manufacturing must ensure that the operation can produce the products flawlessly. Outstanding design quality and process quality are the two ways a business may ensure that customers' needs will be satisfied.
- **Flexibility:** Companies with diverse clientele must place a high emphasis on their ability to adapt quickly. Businesses that place a strong focus on flexibility usually achieve this by carefully choosing equipment that is multipurpose and all-purpose. They typically try to hold onto a small amount of additional capacity. Employees with



a wide range of abilities who can work across divisions or with various technologies are in great demand. These companies want to be able to quickly introduce new products and move from producing one thing to another. Maintaining rapid equipment setups is an essential strategy for achieving this. Additionally, they aim to be able to modify the output volume fast should the need or opportunity arise.

- **Timeliness:** Corporations that want to speed up distribution must become highly efficient in delivering their goods and services. Amazon and McDonald's are two instances of this.

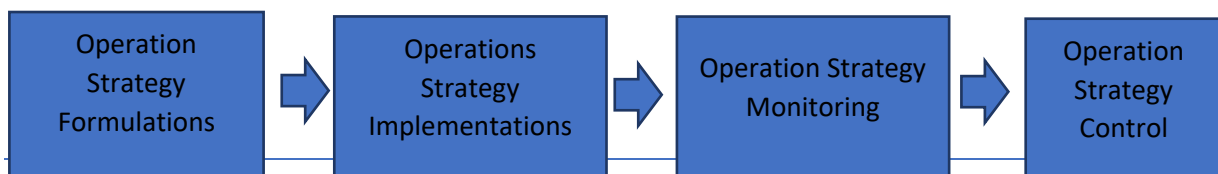
Since it is unrealistic for any one company to excel on all of the competing goals at once, it has long been accepted that every significant choice that must be taken within an organisation's operations will include a trade-off. A manufacturer that competes on price is one example. They can decide to swap out one of their input components with one of higher quality in order to decrease faults. However, this will raise their expenses. Trade-offs between price and quality are typical. Speed and flexibility are also viewed as trade-offs. Operational complexity is increased when firms provide more choices and variety. They will operate more slowly as a result.

IN-TEXT QUESTIONS

9. Excellence is not one of the competitive priorities. (True/False)
10. Competitive advantage can be achieved if we have _____ advantage.
11. There is no relationship between competitive strategy and operational strategy. (True / False)

1.7 OPERATION STRATEGY AND ITS LINKAGES WITH THE COMPETITIVE STRATEGIES

Many businesses have mission statements that outline their objectives as an organisation, the products they provide, and the target market they are striving for. Corporations continuously assess their internal processes and resources that create these commodities using the strategic management process. Each strategy must go through four fundamental stages, and decision-makers must be informed of the objectives of each stage.





1.7.1 Formulations of operation Strategy:

The process of describing the different goals and choices that comprise the strategy is known as the formulation of operations strategy.

- The main focus is various approaches to coordinating activities, plans, and goals.
- Its is a unique task with its own existence in the plans. There have been several elaborate formulation models created.

It is the process of selecting the most effective plan of action. During this time, objectives are created, and plans for achieving them are made. A SWOT analysis is done for bringing up the required changes.

Think about a company's intention to boost internet sales. If research indicates that competitors in that market do not see a return on their investment, business decision-makers may consider some other possibilities. On the other hand, if competitors are claiming better sales, the business may decide to launch an online store and start a social media marketing campaign to increase website traffic.

1.7.2 Operation Strategy Implementations

Carrying out activities to their operational stage is known as implementation. Each employee has to be aware of their responsibilities if the company is to prosper. Measures of appropriate activity offer crucial feedback by supplying data that pinpoints both successful outcomes and areas in need of improvement.

1.7.3 Implementation and Monitoring

By assessing the tactics used during the implementation phase, performance feedback is offered. Some companies use a gap analysis to evaluate their performance against predetermined targets. If new products or upgrades to existing ones are required, it may be determined by comparing the current condition to the anticipated future state.

Tracking performance, scanning the surroundings, evaluating the data it gathers, and taking the required action is all part of monitoring and control.

1.7.4 Controlling and Modifications



Risk can be managed through three approaches: prevention, mitigation, and recovery. To correct any defects or problems found during evaluation, it is essential to go through the modification stage. Applications in other sectors might be made using the strengths found.

1.8 SUMMARY

The lesson focuses on understanding a foundational base of production and operational management. How the discipline has evolved over the years in sync with the industrial revolution, and how its dimensions are changing over time. The new trends in the discipline are extremely crucial to understand as it sets the stage for the type of jobs that the industry requires. From labour-centric production processes to the new-age methods where computers do all the jobs, people are either spectators or supervisors of the process. The lesson also talks about how the various competitive strategic parameters can be achieved via operation strategies.

1.9 GLOSSARY

Just-In-Time Inventory: A procurement system where goods are procured only when required.

Mass personalisation: A type of production strategy where the needs of each customer are fulfilled along with achieving the mass production goal.

Lean: A process where wastages are minimised and resource utilisation is made optimum.

SWOT: Strength, Weakness, Opportunity, Threat.

1.10 ANSWERS TO IN-TEXT QUESTIONS

1. Manufacturing, Arranged	8. Modern Tools
2. False	9. False
3. Input, Output	10. Operational
4. Steps	11. False
5. Wastage	
6. True	



7. False	
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1.11 SELF-ASSESSMENT QUESTIONS

1. Explain the scope of Production and Operations Management. Discuss various components of production and Operation Management.
2. How is Production Management different from Operations Management? What are the factors that are present in operation management and not in production management?
3. What is the Impact of the Japanese style of production on the effectiveness of the Japanese MNCs? Explain.
4. The evolution of Production and Operations Management is in tandem with the industrial revolution. Discuss.
5. How is Mass Personalisation changing the landscape of the business environment?

1.12 SUGGESTED READINGS

Martinich, Joseph S. (2009). Production and Operations Management An Applied Modern Approach. *John Wiley and Sons*.

Panneerselvam, R. (2012). Production and Operations Management (Third Edition). *PHI Learning Private Limited*.

Kumar, A., Suresh, N. (2009). Production and Operations Management (With Skill Development, Caselets and Cases). *New Age International Publishers*.

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LESSON 2

FACILITIES LOCATION AND ITS LINKAGE WITH SUPPLY CHAIN

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STRUCTURE

- 2.1 Learning Objectives
- 2.2 Introduction to Facility Location
- 2.3 Facility Location
- 2.4 Supply Chain Network
- 2.5 Summary
- 2.6 Glossary
- 2.7 Answers to In-text Questions
- 2.8 Self-Assessment Questions
- 2.9 References
- 2.10 Suggested Readings

2.1 LEARNING OBJECTIVES

The objectives of the lesson will help readers to understand the role of facility location and how it is important for deciding the supply chain network design. The chapter is written in a way to achieve the following sub-objectives:

- To understand the concept of facility location
- To study how facility decisions are important in global operations
- To explore the factors affecting the facility location decisions
- To learn the various location planning methods
- To understand the concept of supply chain management and learn about various trends
- To understand the linkages between facility location and supply chain network design



2.2 INTRODUCTION TO FACILITIES LOCATION

Facility location plays an important role in operations management. Every business has some kind of facilities, operating space, and storage space for machinery, bulk stock, types of equipment, etc., to perform their day-to-day operations smoothly. So, they require adequate space to run the business operations without compromising on time, and money and use their resources to their full potential.

Facility location is a strategic decision for the business to decide and assess whether a particular location will reduce the operating economy and increase operating efficiency by computing and controlling operational cost and labor availability, and ensuring easy arrival of raw material and distribution of the final product. While there are several mathematically derived methods to determine the optimum facility location, the business owner should also assess the qualitative aspects, i.e., that are not measurable in numbers, to ensure the best possible site location for the optimum day-to-day operations of the business. For example, a location that is far from a major city may face higher transportation costs, unavailability of unskilled and skilled labor, and delayed supply of raw materials. Therefore, after a critical analysis of both quantitative and qualitative factors, the best possible facility location is selected. The various factors affecting the choice of location have been discussed in the following section.

Facility location is also an important concept for supply chain management (Melo, Nickel, & Saldanha-da-Gama, 2009). The efficiency of the distribution system and the logistic system, and the ability to fulfill the order requirements on time are the key components of the supply chain which are heavily dependent on where the facility is located. Therefore, the facility should be located in the proximity of other suppliers as well as retailers. The emergence of technology in terms of artificial intelligence (AI) and the internet of things (IoT), as well as the growing awareness of various stakeholders about environment-friendly practices, have also impacted supply chain decisions. Therefore, the facility location and the operations in the facility location should adopt technological changes for efficient operations as well as ensure environmental sustainability. This has also led to the concept of green supply chain management. The linkage between facility location and supply chain network design is crucial (Petrisor & Cozmiuc, 2017) and it has been discussed later in this chapter.

2.3 FACILITIES LOCATION

The basic production, distribution, and feedback (PDF) model is explained in Figure 1.1. The key elements of any such production and distribution network include raw material supplier, factory or production unit, warehouse or storage unit, wholesaler, retail store, and customers.



There is also a reverse process resulting in providing information, requirement, and feedback. The raw material supplier will ensure the availability and transportation of raw materials to the factory or production unit for further processing. The factory or production unit will process that raw material into the finished goods and will send it to the warehouse or storage unit. The warehouse or storage unit will preserve the finished goods and ensure their safety. Upon the order requirement received from the wholesaler, the warehouse manager will prepare the consignment ready to be delivered to the wholesalers' location. Now it is the job of the marketing manager as well as the wholesaler to provide the finished goods to a preferred chain of retail stores. These retail stores are selected strategically to ensure maximum coverage of the target customers and be available at locations where the customers are shopping. And lastly, a feedback mechanism works in the background where all the involved elements will provide information, requirement, and appropriate feedback.

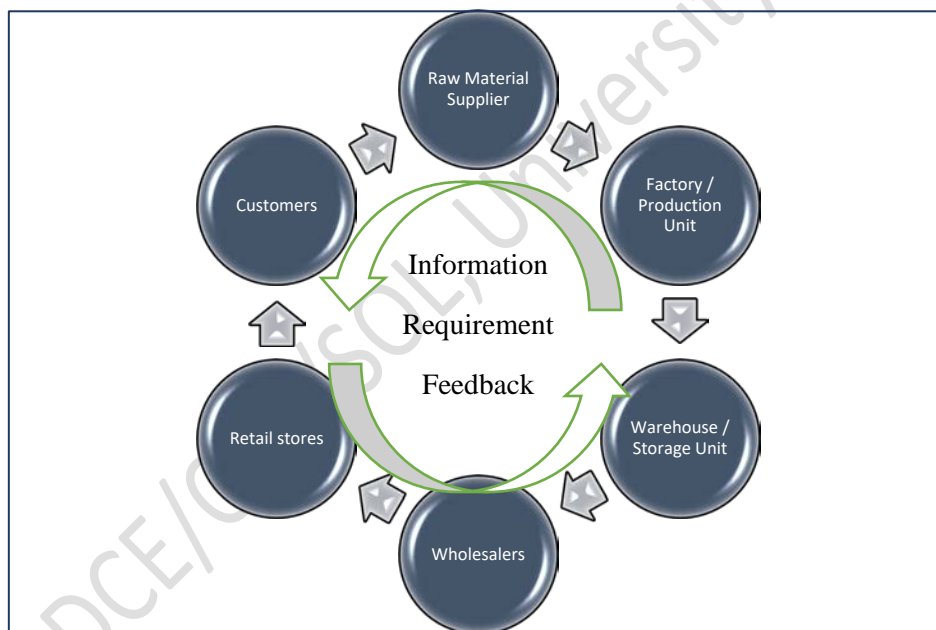


Fig 2.1: Flow of production, distribution, and feedback(*Source: Author's compilation*)

The facility location decisions will ensure that the above production and distribution model works seamlessly. Therefore, it is very crucial to decide upon the facility location strategically after considering all the elements discussed above. The facility location or the production unit should be accessible to suppliers as well as wholesalers. As the volume of business operations increases, the businesses tend to keep the production unit and the warehouses at the same location in close proximity to wholesalers and retailers.



Big businesses move a step ahead with the help of a strategic decision to adopt either forward integration or backward integration or both. In forward integration, they acquire their suppliers and become their own retailers by opening their own branded stores. For example, exclusive stores of Nike, Reliance, etc. In the case of backward integration, the manufacturer acquires their supplier of raw materials to save cost and time. In both strategies, the business is trying to have more control over the production and distribution network. For example, China is known for its world-class manufacturing unit, wherein they invite small suppliers of raw material by giving them space in the production unit itself and also have their warehouses situated at the same location and the manufacturing unit is the size of a small city. This is one of the reasons why China is famous around the world for its production infrastructure and for producing goods at the cheapest possible cost.

There could be various circumstances under which a business decides to explore a new location for its operations. Some of the common reasons are:

- Opening a new segment of the business
- Expansion of existing manufacturing operations
 - To cater to the increased demand
 - For increasing presence in a new region or covering a new territory
- To strategically reduce costs of the existing business operations
- Due to the uncontrollable external factors in the socio-cultural, regulatory, or legal environment

It is recommended that a business should be flexible enough to adapt to any unforeseen external changes and have a provision for shifting to an alternate location, beforehand. Many large businesses share the same facility location to manufacture different segments of goods in order to save costs and reach economies of scale.

2.3.1 Globalization of operations

Due to the globalization and opening of the economy, customers have easy access to global products and global markets. When a business goes global by launching its operations around the world, they face a very diverse set of geo-political challenges. In order to tackle these challenges and the competition in global markets for providing world-class quality, businesses have spread their operations in various cost-effective manufacturing hubs around the world. It is also called the expansion of manufacturing hubs and can be seen as a growth strategy of a business. Not only does the global presence help in catering to a different set of



customers, but it also helps in lowering the overall operating costs by reducing the cost of various factors. The main reasons are:

- a. **Reduced labor costs:** Manufacturing of certain goods is cheaper in some of the South Asian and South American countries than manufacturing in Europe or America. This is due to the wage rates and currency differences, which the businesses take advantage of and set up their facility at a location with cheaper labor and operating costs.
- b. **Reduced raw material costs:** For providing the finished goods effectively and efficiently, and maintaining the promised quality standards, the businesses try to open their facility at a location where they can find the raw material at a cheaper rate as compared to their home country. Raw material costs are one of the major determinants of total costs. If the home country has higher raw material costs and lower transportation costs, and the target country has lower raw material costs and higher transportation costs, then the total costs should be computed to compare the total costs in both scenarios and decide whether to manufacture at home country or move to a target country with cheaper raw material costs.
- c. **Easy access to buyer markets:** It is a strategic decision to decide upon the location of the manufacturing unit. Sometimes the location is decided in closer proximity to the buyers and to have easy access to neighboring countries. For example, it is preferable for a car manufacturer to start its operations in any Eastern European country to operate at lower labor and raw material costs as well as have access to the maximum countries in the whole of Europe.
- d. **Tax rebates:** There are certain countries and islands with lower tax rates and some are even tax-free. Such places are very popular for setting up a manufacturing unit.
- e. **Trade agreements and benefits from government:** Sometimes to promote trade and business between countries. Trade agreements are signed to promote trade in terms of import and export. But sometimes countries launch a special campaign to promote manufacturing. One of the examples is the “Make in India” campaign launched by the Indian Government to invite companies around the world to start their manufacturing unit in India. The idea is to increase production and investments, and take benefit from technology transfer. For businesses, it is lucrative to open their manufacturing operations in a country, where the government is supportive while drafting their regulatory policies, provides any kind of rebates, follows a decentralized approach, and listens to the industry’s voice.



ACTIVITY

Identify a globally renowned company. Try to find out the following:

- Where it acquires its raw material from?
- Where is its manufacturing unit located?
- Where the company is selling its products?

Now, assume an arbitrary cost of raw material, transportation cost, manufacturing cost, labor cost, and distribution cost. Calculate the total cost for one product. As a manager, critically evaluate and show how you can further lower the total cost.

2.3.2 Factors affecting location decisions

It must be now clear why facility location is so important, as it affects the whole supply chain network. But still, there is no clear-cut shortcut to estimate the best possible location. As discussed earlier, a wise decision-making manager should consider both qualitative and quantitative factors. The qualitative factors will include land acquisition, construction and building, transportation, electricity, and other utility costs. The quantitative factors on the other hand will include the supply and demand of labor, climate conditions, regulations of the state, legal requirements, environment-related laws, and the political and cultural environment. For example, in the year 2008, while manufacturing the Nano car, Tata had to move its existing manufacturing plant location from West Bengal due to political disturbance in the state. This caused delays and an increase in the cost of production for Tata. A list of factors is compiled and given in Table 1.1:

Table 2.1: Factors affecting location decisions (source: Author’s compilation)

Operational Factors	Labor Factors	Logistic Factors	Socio-cultural, Political and Climatic conditions
<ul style="list-style-type: none"> • Electricity • Water supply • Waste management • Resource availability and costs 	<ul style="list-style-type: none"> • Availability of competent labor (skilled or unskilled) • Labor costs • Concerns of unions 	<ul style="list-style-type: none"> • Carrying Costs • Mode of transportation • Transportation regulations • Closeness to others 	<ul style="list-style-type: none"> • Weather conditions • Society’s acceptability • Religious concerns • Government regulations • Tax policies, rebates and duties



- a. **Operational Factors:** The factors which are directly incurred due to the manufacturing processes at the unit. This includes electricity consumption charges, water charges, fuel consumption charges, etc. Another concern is to manage the waste generation due to the production process. Therefore, waste management also generates some charges to responsibly decompose and dispose of the waste. Availability of resources and costs related is also an important issue for the management when deciding on a facility location.
- b. **Labor Factors:** These factors are related to the human capital resources required for production. It is important for a facility to be located in such a location where there is an abundance of labor that can be employed. Whether the requirement is for skilled labor or unskilled labor should be also considered. The cost associated with labor will also vary accordingly. Also, another major issue is labor unions. While labor unions are formed to protect the rights of the labor, there could be instances where labor unions may dominate the business or go on strike to halt production due to various reasons. So, the political conditions of labor in a particular region should also be considered.
- c. **Logistic Factors:** Before deciding upon any location, the rough estimation of raw material and inventory carrying cost should be considered. The close proximity to the suppliers and wholesalers will result in lower carrying costs. The transportation mode is also a major factor that changes the cost drastically. While some modes such as air transportation are used for faster transportation, but they can be expensive. Similarly, transportation by road can help in last-mile connectivity but it can take much time to deliver. Apart from that, the regulations such as restricting commercial vehicles to enter the city during night time lead to delayed delivery.
- d. **Socio-cultural, Regulatory and Climatic conditions:** Places like Leh& Ladakh in India, where the road connectivity is only limited for 6 months due to heavy snowfall, may not be ideal locations for manufacturing. Similarly, places with heavy rainfall may also create delays in transportation. The people living around the facility location also influence the manufacturing operations due to potential health and environmental hazards. Violation of their religious traditions can also affect the sentiments of the community around the facility location. Apart from that, compliance with government regulations should be also considered. “Ease of doing business” is the ranking concept to measure how easy it is to start a business in a particular location in terms of regulations and protection of the businesses. Tax structure and rebates also influence the strategic decision of selecting a facility location.



2.3.3 Location planning methods:

As discussed above, there are various qualitative factors affecting the decision about facility location. However, there are some quantitative measures to guestimate the operating cost. Various options for facility location can be assessed based on certain benchmarks and the best performer in those ranking or ratings or scores can be selected.

Some of the conventional methods to assess the operating cost at different facility locations are:

- a. **Location-based Break-Even Analysis:** It is a very popular and logical method to assess the cost of different facility locations and compare the available location options. Only two factors are considered to find out the break-even point, i.e, revenue and total cost. Total cost comprises fixed cost and variable cost. The steps to determine the break-even point (B.E.P) are:
 - i. Finding out all direct and indirect costs involved.
 - ii. Segment the costs into two categories: fixed costs (FC) and variable costs (VC).
 - iii. Prepare a graph with the x-axis showing production volume and the y-axis showing total cost.
 - iv. Find out the intersection point after which total cost is equal to total revenue, after which the business should start making profits.

$$B.E.P = \frac{\text{Fixed Costs}}{\text{Revenue per unit} - \text{Variable Cost per unit}}$$

- b. **Weighted score method:** In this method, the weights are assigned to a set of identified factors based on their importance between 0 to 5, where 0 being least important and 5 being most important, and scores are given to individual facility locations between 0 to 10, where 0 is the least and 10 is the highest score. Then the weighted score is calculated by multiplying each weight by the score obtained by each facility location. Based on the total weighted score, the best facility location can be identified. In Table 1.2, the best facility location is FL1 with the highest weighted score of 78.



Table 2.2: Weighted scores

Factors	Weights (W)	Scores (S)			Weighted Scores (WS)		
		FL1	FL2	FL3	FL1	FL2	FL3
Operational	5	7	4	10	35	20	50
Labor	3	9	5	4	27	15	12
Logistic	2	8	7	6	16	14	12
Total weighted score					78	49	74

c. **Total operating cost method:** In this method, the preference of the facility location can be decided on the basis of the total operating costs involved for a particular facility location. The facility location will be selected after identifying the facility location which has the lowest cost. In Table 1.3, by observing the total operating cost under FL1, FL2 and FL3, one can easily conclude that FL3 has the lowest operating cost at 16,10,000. Therefore, FL3 should be selected, if total operating cost is the main parameter for deciding the facility location.

Table 2.3: Total operating cost of facility locations

Factors	FL1	FL2	FL3
1. Cost for land acquisition	10,00,000	15,00,000	7,00,000
2. Construction of Factory/Production Unit	5,00,000	6,00,000	7,00,000
3. Labor wages	50,000	30,000	40,000



4. Electricity & Water charges	15,000	12,000	10,000
5. Cost for acquiring raw material (Carrying cost)	2,00,000	1,50,000	1,00,000
6. Cost for sending goods to warehouse/wholesaler (transportation cost)	1,50,000	1,00,000	50,000
7. Taxes	1,00,000	50,000	10,000
Total operating cost	20,15,000	24,42,000	16,10,000

d. **Factor rating method:** It is a popular technique used in determining the best location for a new facility, such as a manufacturing plant or distribution center. It is a quantitative approach that considers a range of factors and assigns weights to each factor to calculate an overall score for each potential location.

The basic steps involved in the Factor Rating method are as follows:

1. Identify the factors that are important in the location decision. These factors can include things like labor availability and cost, transportation infrastructure, proximity to suppliers and customers, taxes and regulations, and quality of life factors.
2. Assign weights to each factor based on their relative importance. For example, labor availability and cost may be assigned a higher weight if the facility is heavily reliant on labor, while proximity to suppliers and customers may be more important if the facility needs to be responsive to market demands.



3. Score each potential location on each factor, using a rating scale from 1 to 10 or 1 to 100, depending on the level of detail required. For example, a location with a large pool of available labor at a relatively low cost may be given a higher score for the labor availability and cost factor than a location with a smaller labor pool at a higher cost.
4. Multiply the scores for each factor by their respective weights and add them up to get an overall score for each potential location.
5. Choose the location with the highest overall score.

The Factor Rating method is a useful tool for making location decisions, as it provides a systematic and objective way to evaluate potential locations. However, it is important to ensure that the factors and weights used are appropriate for the specific situation, and that the scores assigned to each location are based on accurate and reliable data.

Let's say that a company is trying to decide where to build a new manufacturing facility. They have identified four potential locations, and they want to use the Factor Rating method to determine which location is the best. The company has identified the following factors as important in the location decision, and assigned weights to each factor based on their relative importance:

1. Labor availability and cost (Weight: 40%)
2. Transportation infrastructure (Weight: 30%)
3. Proximity to suppliers and customers (Weight: 20%)
4. Quality of life factors (Weight: 10%)

Next, the company scores each potential location on each factor, using a rating scale from 1 to 10:

Table 2.4: Ratings of different factors and location

Location	Labor availability and cost	Transportation infrastructure	Proximity to suppliers and customers	Quality of life factors
Location A	7	6	8	9
Location B	9	5	7	8
Location C	6	8	6	7
Location D	8	7	9	6



To calculate the overall score for each location, the company multiplies each score by its respective weight and adds them up:

Table 2.5: Ratings of different factors and location

Location	Overall Score
Location A	$(7 \times 0.4) + (6 \times 0.3) + (8 \times 0.2) + (9 \times 0.1) = 6.9$
Location B	$(9 \times 0.4) + (5 \times 0.3) + (7 \times 0.2) + (8 \times 0.1) = 7.6$
Location C	$(6 \times 0.4) + (8 \times 0.3) + (6 \times 0.2) + (7 \times 0.1) = 6.6$
Location D	$(8 \times 0.4) + (7 \times 0.3) + (9 \times 0.2) + (6 \times 0.1) = 7.9$

Based on these scores, the company would choose Location D as the best location for the new manufacturing facility, as it has the highest overall score of 7.9.

e. **Centre of Gravity method:** It is a quantitative approach that considers the geographical locations of existing facilities, customers, and suppliers, and calculates the location that minimizes the total transportation costs. The basic steps involved in the COG method are as follows:

1. Identify the locations of existing facilities, customers, and suppliers, and their respective demand and supply volumes.
2. Determine the X and Y coordinates of each location, based on their latitude and longitude.
3. Calculate the weight of each location by multiplying its demand or supply volume by its distance from the origin (0,0) on a coordinate plane.
4. Sum the weights of all locations to get the total weight.
5. Calculate the X and Y coordinates of the COG by dividing the sum of the X and Y coordinates of all locations by the total weight.
6. Evaluate the feasibility of the COG location, based on factors such as the availability of land, labor, and utilities, as well as regulatory requirements and quality of life factors.

The COG method is useful for companies that have a dispersed customer or supplier base, as it takes into account the transportation costs of serving these locations. However, it does not consider factors such as labor availability or tax incentives, which may be important in making location decisions. Additionally, the COG location may not be feasible due to local conditions, such as the



availability of suitable land or infrastructure. Therefore, it is important to use the COG method in conjunction with other techniques and qualitative factors to make an informed decision about facility location.

Here's an example of how the Centre of Gravity (COG) method can be used to determine the best location for a distribution center. Let's say that a company operates a distribution center in City A and is considering opening a new distribution center to serve customers in Cities B, C, and D. The company wants to minimize transportation costs and needs to determine the best location for the new facility. The table below shows the demand volumes for each city, as well as their respective distances from City A:

Table 2.6: Demand volumes and distance from city A

City	Demand Volume	Distance from City A
B	1,000	300
C	2,000	150
D	1,500	200

Using the COG method, we can calculate the X and Y coordinates of each city, based on their latitude and longitude. For simplicity, let's assume that all cities lie on a straight line, with City A at the origin (0,0). The X and Y coordinates for each city are:

Table 1.7: Coordinates for each city

City	X Coordinate	Y Coordinate
B	300	0
C	150	0
D	200	0

Next, we calculate the weight of each city by multiplying its demand volume by its distance from the origin:

Table 1.8: Weight of each city

City	Weight
B	300,000
C	300,000
D	300,000



The total weight is 900,000. To calculate the COG, we sum the X and Y coordinates of all cities and divide by the total weight:

$$X \text{ Coordinate of COG} = (300 + 150 + 200) / 900,000 = 0.000833$$

$$Y \text{ Coordinate of COG} = (0 + 0 + 0) / 900,000 = 0$$

Therefore, the COG of the demand for the company's products is located at approximately (0.000833, 0) on the coordinate plane.

The company can then evaluate the feasibility of potential locations near the COG, based on factors such as land availability, labor supply, and local regulations. A location near the COG may be more favorable, as it can minimize transportation costs to all three cities. However, other factors such as the availability of suitable land or the cost of labor may also influence the final decision.

- f. **Transportation method:** The Transportation method is another quantitative approach used in determining the best location for a new facility. It is based on the concept of finding the minimum cost of transporting goods from the facility to the customers. The basic steps involved in the Transportation method are as follows:
1. Identify the potential locations for the facility and the customers' locations. This information can be used to create a transportation matrix that shows the distances between each facility and customer.
 2. Determine the production capacity of the facility and the demand for the product at each customer location.
 3. Calculate the transportation costs from the facility to each customer location based on the distance and mode of transportation (e.g., truck, rail, or air).
 4. Use linear programming techniques to find the minimum total transportation cost that meets the demand for the product at each customer location, taking into account the production capacity of the facility.
 5. Choose the location that results in the minimum total transportation cost.

The Transportation method is particularly useful when transportation costs are a significant factor in the location decision, such as when the product is bulky or has a short shelf life. It is also helpful when there are multiple customer locations with varying demand levels, as it can provide insight into how the facility should be sized to meet the demand. However, the Transportation method assumes that transportation costs are the only significant factor in the



location decision, which may not always be the case. Therefore, it is important to consider other factors, such as labor availability, taxes and regulations, and proximity to suppliers, when making a final location decision.

Suppose a company is considering two potential locations for a new warehouse to distribute its product to three customer locations. The transportation costs (in rupees per unit) from each location to each customer are as follows:

Table 1.9: Transportation costs (in rupees per unit)

	Customer 1	Customer 2	Customer 3
Location 1	5	8	10
Location 2	7	6	9

The company estimates the demand for the product at each customer location to be:

Table 1.10: Demand at each location

Customer	Demand (units)
1	150
2	100
3	200

The company is considering two potential warehouse locations, each with a different production capacity:

- Location 1 has a production capacity of 300 units
- Location 2 has a production capacity of 400 units

Using the Transportation method, the company can find the minimum total transportation cost by formulating a linear programming problem that minimizes the sum of the transportation costs from each location to each customer, subject to the constraints that the total production at each location must not exceed its capacity and the total demand at each customer location must be met.

Let:

X_{ij} = number of units shipped from location i to customer j

c_{ij} = transportation cost per unit from location i to customer j

d_i = demand for the product at customer j



a_i = production capacity at location i

The objective function to be minimized is:

$$\text{Minimize } Z = \sum_i \sum_j c_{ij} X_{ij}$$

Subject to the constraints:

1. Production capacity constraint for each location: $\sum_j X_{ij} \leq a_i$, for $i = 1, 2$
2. Demand constraint for each customer: $\sum_i X_{ij} = d_j$, for $j = 1, 2, 3$
3. Non-negativity constraint: $X_{ij} \geq 0$, for $i = 1, 2$ and $j = 1, 2, 3$

Substituting the values from the example, we get:

$$\text{Minimize } Z = 5X_{11} + 8X_{12} + 10X_{13} + 7X_{21} + 6X_{22} + 9X_{23}$$

Subject to the constraints:

1. Production capacity constraint for each location:

$$X_{11} + X_{12} + X_{13} \leq 300$$

$$X_{21} + X_{22} + X_{23} \leq 400$$

2. Demand constraint for each customer:

$$X_{11} + X_{21} = 150$$

$$X_{12} + X_{22} = 100$$

$$X_{13} + X_{23} = 200$$

3. Non-negativity constraint:

$$X_{ij} \geq 0$$

Solving this linear programming problem using the simplex algorithm, we get:

$$X_{11} = 0, X_{12} = 100, X_{13} = 50, X_{21} = 150, X_{22} = 0, X_{23} = 50$$

$$Z = \$2,900$$

Hence, the minimum total transportation cost is \$2,900 if the warehouse is located at Location 1. The same linear programming problem can be solved with the production capacity at Location 2 to determine the minimum total transportation cost for that location as well. Therefore, the company should choose location that results in the minimum total transportation cost.



IN-TEXT QUESTIONS

9. Facility location is decided on the basis of _____ and _____ factors.
10. Arbitrarily deciding facility location can increase total costs and can be risky for the business. True / False
11. At the break-even point, the total costs and revenues are:
 - a) Zero (0)
 - b) Total cost is greater than revenue
 - c) Equal
 - d) Total cost is less than revenue
12. Refer to the example in Table 1.3 and calculate the revised total operating cost for each facility location after considering the following changes and find out whether FL3 is still the best option out of the three available facility locations.
 - a. Cost for acquiring land has increased by 20%.
 - b. Construction charges have also increased by 30%.
 - c. Labor wages have decreased by 2%.
 - d. Electricity and water charges remain unchanged in case of FL1 and FL3, but increased by 5% at FL2.
 - e. The carrying cost has increased by the 5%.

2.4 SUPPLY CHAIN NETWORK

The supply chain network is the interlinkage between all the persons and stages involved in the movement of goods and completion of the various processes from procurement of raw material to delivery of final goods to the customer. The supply chain network is managed by the key nodal officers located at the various stages of production, procurement, and distribution. The role of the nodal officer is to ensure the smooth passage of information, raw material, final goods, and related services from one stage to another without any delays. A basic supply chain network is shown in Figure 1.2. It can be explained with help of an example. For example, there can be a number of suppliers, S1, S2, and S3. There can be a number of manufacturing units, MU1, MU2, and MU3. Now, any supplier, let us assume S1, can supply the raw material to any or all three manufacturing units. Similarly, a particular manufacturing unit, let us say MU2, can further send the finished goods to either retailer R1 or R2 or R3 or all of them together. Ultimately, all the retailers will try to target a segment of



potential customers by making the final goods available when the customer visits their store. The network diagram represents a complex structure of chains interlinked together to ensure connectivity with other members of the supply chain.

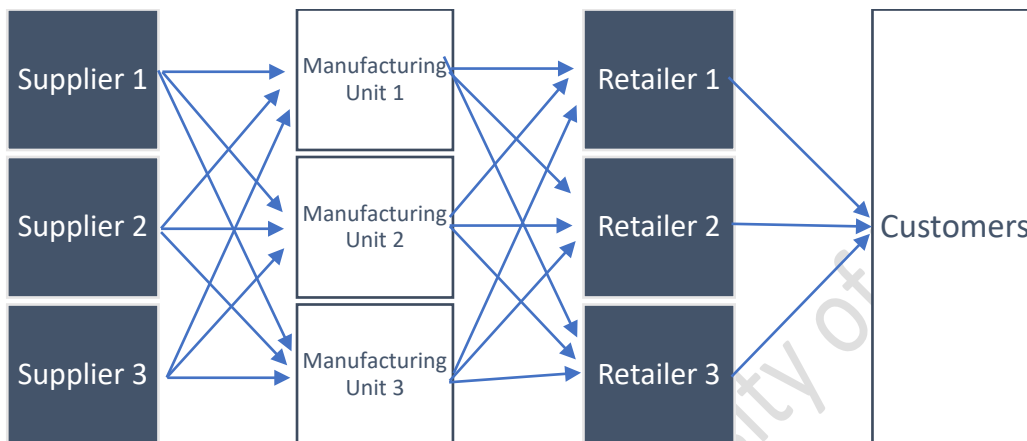


Fig 2.2: Supply chain network (source:author's compilation)

Effective monitoring and organized flow give rise to the concept of management of the supply chain or Supply Chain Management (SCM). SCM is an evolving concept and started gaining importance in recent years. The idea evolved from the traditional exchange and movement of materials and finding ways to effectively distribute by ensuring the lowest possible cost, resources, and time. SCM ensures the effective and efficient planning, implementation, and control of the overall operations linked to the supply chain. The concept of SCM is a more holistic approach to monitoring the development of the product from the beginning, i.e., from acquiring raw materials. Some of the main objectives of the supply chain are:

- Producing and delivering the right product at the right time and at the right place (Agrawal, Mohanty, Agarwal, Dixit, & Agrawal, 2022).
- Ensuring the cost involved in transportation is the least.
- Ensuring the time involved in all processes is the least and minimizing the waiting time.
- Management of space and warehouses effectively, by deploying methods such as LIFO (Last In, First Out), FIFO (First In, First Out), or the weighted average method.
- Supporting other departments whenever required to avoid any delays in the production line.



There are various functions to ensure an effective SCM. These are presented in Figure 1.3. The reason why SCM became a popular way of managing resources is because it helps in assessing the risks involved and predicting any uncertainty and delays. The ultimate goal of any SCM strategy is to optimize resource usage and minimize the total costs. Therefore, SCM is an attempt to control and manage the warehouse and inventory, effective planning and scheduling, forecasting the demand and ensuring the supply of raw material and final goods, handling the logistics and transportation-related issues, and finally, continuously evaluating all of the connected partners' performance, reliability, accuracy and precision based on certain benchmarking standards.

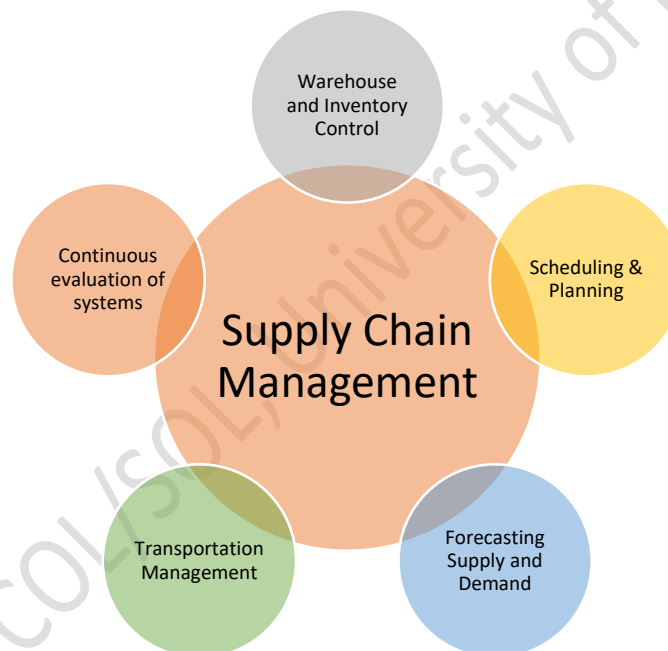


Fig 2.3: Functions for effective Supply Chain Management (source:author's compilation)

2.4.1 Latest trends in supply chain management

Researchers are exploring and discovering new areas in SCM. They are exploring the role of the Internet of Things (IoT) to have better connectivity with the machineries and other equipment, which will help to calculate the production time and any delays. The help of robots and driverless forklifts are also used by some manufacturers. Businesses are also concerned about the environment; hence, they are also exploring reverse logistics and Green Supply Chain Management (GSCM) and its impact on business performance (Hiremath, Sahu, & Tiwari, 2012). While reverse logistics promotes the submission of used goods back to the



company for refurbishing or proper disposal, GSCM considers all the activities involved in the customer order cycle, including product design, procurement, manufacturing, logistics, distribution, and managing product at the end of its life cycle. The relevance of GSCM is not only limited to minimizing the negative impacts of industrial activities on the environment, but it also ensures that the cost, quality, and performance are not compromised. It is important that managers identify and implement environmental sustainability practices that extend throughout the supply chain (Shah & Siddiqui, 2019). It has been found in studies that successful practices at the supply chain level also pave the way for an organization's success. Specifically, in a developing country, the goal of any manufacturer is to strike a balance between economic performance and environmental performance (Zhang, Gajpal, Appadoo, & Wei, 2020). GSCM ensures this balance between economic performance and environmental performance, which improves operational performance and ultimately enhances overall organizational performance.

2.4.2 Facilities location linkage with supply chain network design decisions

So far in this chapter, we have learned the importance of facility location and the concept of supply chain management. The decision of facility location is critical as it affects the management of the supply chain in the long run and impacts the effectiveness of the supply chain. The SCM planning decisions can be:

- a. Strategic
- b. Tactical, and
- c. Operational

The strategic SCM decisions involve long-term planning related to the facility location, number of facilities, supply chain network associated with each facility, and production capacity at each facility. Therefore, facility location impacts the supply chain in long term. The tactical SCM decisions involve different means to optimize the selected networks for the short term. The operational SCM decisions involve the identification of potential risks and developing a plan of action to mitigate each of the identified risks.

An effective supply chain network design (SCND) should be robust enough so that it can be useful for a long period of time. It should be flexible enough to accommodate the dynamic nature of various external factors that change and impact the supply chain. Some of the factors that influence the SCND decisions are:

- a. **Changes in requirements of the customers:** Due to the ever-evolving consumer behaviour, and their changing tastes, and preferences, it has been a strong deriving



force for businesses to adopt the dynamic nature of their customers and respond promptly to their changing needs. If they do not respond, then the customer will go and buy the competitor's product. Therefore, a swift response is required from the company to recalibrate its existing SCND for better response to customer needs.

- b. Changes in the markets:** Sometimes the global markets face a certain crisis, due to which some facility location becomes loss-making unit. Also, the global competition forces geographical shifts in the market, resulting in modifications in the existing SCND.
- c. Changes in the leadership (mergers & acquisitions):** When a company faces merger, acquired or overtaken by a larger company, the top management also changes. In case of a merger, where two companies decide to operate together on mutually decided terms, they also decide upon sharing their existing resources and also propose certain changes in the existing SCND. But in the case of acquisition, the larger company is the sole decision maker to decide on whether they want to continue their SCND or continue using the existing SCND.
- d. Cost control:** As a precautionary and reactive approach to competition and pressure from the market, the business should take steps to ensure long-term sustainability. In order to do so, they have to ensure that their operating costs are as low as possible. Therefore, they try to find out ways to reduce costs on warehouse storage and transportation costs. Such measures ultimately affect the SCND decisions.
- e. Revamp of the overall strategies of the business:** Sometimes businesses go through leadership changes and based on the inputs from the board, they take strategic decisions such as downsizing their current operations and restructuring of their existing operations for positive growth of business in the long run. Many businesses opt for a third-party vendor for logistics services because either they do not have expertise in logistics or do not have a big transportation network, or they would like to focus on only the production part and give away the responsibility of deliveries to the third-party vendor.

A probability-based method can be used to determine and calculate the chances of uncertainty and how well the SCND will perform. The process of SCND starts by identifying potential locations for opening the facility. The location will affect the decision deciding the size and possible capacity of the selected facility. It will further lead to the decisions related to logistics, transportation modes, and vehicle routing decisions. Overall, the facility location will impact every aspect of the supply chain network design. It will also impact the effective



collection and recovery of goods in case the business decides to implement the concept of reverse logistics. They will have to identify the collection centres, repair centres and recycling centres.

CASE STUDY

The impact of covid-19 on Facility Location: A Case Study of school uniform manufacturer

In 2020, covid-19 pandemic affected manufacturing operations all around the world. It affected the education sector and led to temporary closure of schools, colleges and other educational institutions due to lockdown. Mr. Suresh, a school uniform manufacturer faced the heat of the crisis. Since, schools were closed, therefore, there was hardly any demand for the school uniforms. Due to this, the manufacturer was unable to pay the factory rent, electricity and water charges, labor wages and other expenses.

One day Mr. Manoj, a friend of Mr. Suresh came to the factory and saw Mr. Suresh sitting alone holding his head due to the halted operations and no demand for school uniforms. Mr. Manoj gave an idea to start manufacturing face masks. Mr. Suresh liked the idea, as face masks were in demand, but he did not have the proper facility location and machineries to manufacture the face mask. Now, Mr. Suresh has the following options:

- a. Continue with manufacturing school uniform and hope for the covid-19 pandemic to end.
- b. Stop manufacturing school uniform and explore the possibility to start new venture of manufacturing face masks by investing at a new facility location.
- c. Continue with option a and b.
- d. Stop all operations at his factory.

Discuss and suggest the most suitable option after considering all the costs involved in the existing business, new business, and combining both businesses. Why do you think the selected option is the best? Provide your viewpoint with supportive arguments.



2.6 SUMMARY

The facility location plays a crucial role in operations management and other decisions related to facilities, resources, storage, etc., depend on this decision. An ideal facility location should be helpful in reducing the overall operational costs. It also sets a foundation for effective and efficient supply chain management (SCM) and supply chain network design (SCND)(Arani, Liu, & Abdolmaleki, 2020). A new facility location can be explored in for launching a new segment, expanding the manufacturing operations, cater the demand, reducing costs, and as a response to external and uncontrollable factors. Globalization of manufacturing operations helps in capturing the international markets, taking advantage of lower labor and raw material costs, access to new markets, tax rebates, and taking benefits of the trade agreements. Location decision is crucial for any business and therefore it depends on operational factors, labor factors, logistic factors, and socio-cultural, political, and climatic conditions. There are various qualitative and quantitative measures for location planning. Facility location also influences the supply chain network. The latest trends in SCM include the use of artificial intelligence, the internet of things (IoT), robotics, etc. Consumer awareness towards the environment has also led to the emergence of the concept of green SCM (GSCM). An effective SCND should be flexible as well as robust to accommodate any changes in the long run.

2.7 GLOSSARY

Facility Location: An adequate space to run the business operations without compromising on time, and money, and use the available resources to their full potential.

Artificial Intelligence: A simulation-based intelligence in computer systems that processes input information and results in output like human beings.

Internet of Things: Controlling and making non-electronic objects to communicate by sending signals and data through sensors and connecting them with the internet and computer systems.

Supply Chain Management: It is a holistic approach for effective planning, scheduling, forecasting, and controlling of resources in order to ensure the effective management of demand and supply of raw materials and final goods.



2.8 ANSWERS TO IN-TEXT QUESTIONS

1. Quantitative and Qualitative
2. True
3. Equal (the difference between them is zero).
4. Yes, FL3 is still the best option with the least total operating cost of 19,64,200.

2.9 SELF-ASSESSMENT QUESTIONS

1. Explain the concept of facility location. Discuss the various factors affecting the facility location by citing suitable examples.
2. Discuss some effective methods of evaluating the various facility location options. Explain with examples.
3. Why do businesses open their manufacturing unit in some other country? What are the core reasons behind it? Explain with the help of a real example.
4. Does merger and acquisition affect facility location and supply chain-related decisions? What are the reasons for such decisions?
5. Explain the concept of break-even analysis and how it acts as a tool for facility location decision
6. As a business owner, would you keep yourself updated with the latest trends in the supply chain or prefer to ignore them as long as your business is running perfectly fine? List down some latest trends in supply chain management.
7. How does facility location decision affect the supply chain network design (SCND)?

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2.11 SUGGESTED READINGS

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LESSON 3

DESIGN OF PRODUCTION PROCESS

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STRUCTURE

- 3.1 Learning Objectives
- 3.2 Introduction
- 3.3 Design of production process
- 3.4 Facility Layout
- 3.5 Process Design and Analysis
- 3.6 Self-Assessment Questions
- 3.7 References
- 3.8 Suggested Readings

3.1 LEARNING OBJECTIVES

A key concept in production process is the customer order decoupling point which determines where inventory is positioned to allow processes or entities in the supply chain to operate independently.

Production processes are used to make everything that we buy ranging from the apartment building in which we live to ink pens with which we write. The high level view of what is required to produce something can be divided into three simple steps:

- The first step is sourcing the parts we need,
- Followed by actually making the item ,
- Then sending the item to the customer.



3.2 INTRODUCTION

In process design, the product is divided into several stages, which is also useful for the actual manufacturing process.

For instance, a product may have appealing packaging to provide the appropriate aesthetics as well as features and functionality that add value for customers. The smooth and continuous relationship between the required output and all intermediate processes is guaranteed by process design.

For instance, the production of air conditioners requires process design that maximises supply during the summer's hot months, when demand for the product is at its highest. In order to meet seasonal demand, people, processes, and machines must cooperate to provide continuous production throughout the year.

Seven action steps to sustainable manufacturing

Map your impact and set priorities: Bring together an internal “sustainability team” to set objectives, review your environmental impact and decide on priorities.

Select useful performance indicators: Identify indicators that are important for your business and what data should be collected to help drive continuous improvement.

Measure the inputs used in production: Identify how materials and components used into your production processes influence environmental performance.

Assess operations of your facility: Consider the impact and efficiency of the operations in your facility (e.g. energy intensity, greenhouse gas generation, emissions to air and water).

Evaluate your products: Identify factors such as energy consumption in use, recyclability and use of hazardous substances that help determine how sustainable your end product is.

Understand measured results: Read and interpret your indicators and understand trends in your performance.

- 1. Take action to improve performance:** Choose opportunities to improve your performance and create action plans to implement them.

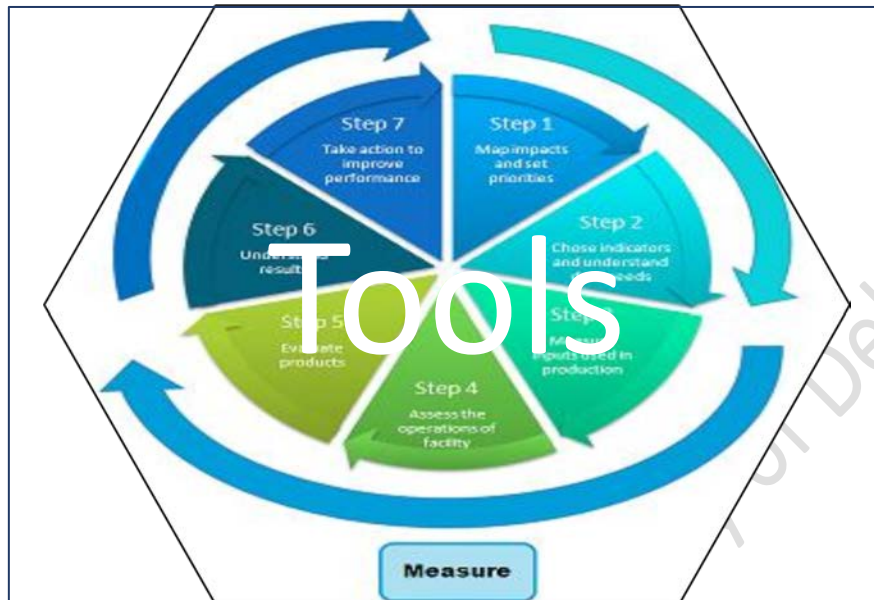


Fig 3.1: 7 Action steps to sustainable manufacturing (Source: <https://www.oecd.org>)

3.3 DESIGN OF PRODUCTION PROCESS

Any business's offerings of goods are what makes it what it is. The success of the company and the design of those goods are clearly related. Companies with well-designed goods are more likely to achieve their goals compared to those whose goods are poorly designed. As a result, companies have a big interest in producing quality products. Product design strategically affects how well an organisation can accomplish its objectives. It has a significant impact on production expenses, product quality, and customer satisfaction. The link with the client is clear. Customers' primary concerns are the company's goods, which serve as the ultimate yardstick for evaluating the business.

For this, businesspeople must keep them well-informed about the development of the product design and procedure. Think about this problem. The fundamentals of product design and process, the product development process, process flow design and process selections, and automation are all covered in this course.

3.3.1 Process Planning:

Process development for process design can be summarized through following steps:



1. **Process Requirement:** Information gathering is the first step in providing structure with the end objective. This entails creating a process requirement document that highlights the various stages, risks, and production stakeholders. This will involve assessing the technology that is currently available, the amount of raw materials required, the layout of the factory or plant, and the demand projection.
2. **Team Building:** After the process requirements are completed, a team is selected for each objective based on experience and skill level. The team's role is to become familiar with the entire procedure.
3. **Planning and Execution:** After receiving approval, the process planning team will develop the modules, policies, and procedures needed for production.
4. **Audit:** A regular audit is carried out to ensure that process thus implemented is in line and delivering value to customers.
5. **End of Life:** Over a course of time there may be enhancement of the product or product may get discontinued.

3.3.2 Production Process

Production or conversion processes can be broadly categorised into two groups based on the nature of the product and service: continuous production (assembly line, oil refinery) and intermittent production (job work, service).

Based on the standardisation of a product or service, the production process for both the manufacturing industry and the service industry can be divided into broad categories. It can range from a single project assignment, such as a building or bridge (manufacturing), to interior design (service), mass production projects, such as a car (manufacturing), and even a fast-food restaurant (Services).

3.3.3 Process Design: An effective process design must take into account how well the process fits with the overall organisational goal. Process design should not have a narrow focus and needs to take into account the entire organisation. Additionally, the process should provide value to the customer while involving management continuously at different stages. Effective process strategy, which addresses a single line item needed to manufacture the product, is needed to achieve a good process design. Procuring raw materials, customer participation technology, investments, etc. are all covered by effective process strategy. Over time, process design has changed, and fresh ideas have emerged, such as Flexible



Manufacturing Systems, which facilitate effective and efficient production design and analysis.

3.3.4. Integrated Product and Process Development - Meaning, Advantages and Key Factors:

Every organization's goal is to provide customers with satisfaction by developing goods and services that meet their needs and desires while also adding value to their lives. This necessitates product design that takes into account customer feedback and a production method that not only cuts costs but also gives a product a competitive edge. However, the majority of businesses tend to use traditional production methods and procedures.

However, in the global age of new technology and competition, organisations must reinvent how they serve customer needs, with an ever-increasing emphasis on specialisation and customization. The organisation must immediately incorporate technology and innovation into the framework of integrated product and process development in light of this situation.

A new standard for producing competitive, high-quality products is created by integrated product and process development, which combines the processes for designing both products and processes.

The process of product design is given a completely new dimension by the integration of new technologies and methodologies. Starting with the definition of the product requirements based on customer feedback while taking the design layout and other limitations into account. As soon as the last details are decided upon, they are fed into CAD models for extensive testing and modelling to produce the best possible result.

Integration of product design and process design follows naturally from the integration of production method, technology, and technology. So, an integrated product and process development process is one that uses contemporary technology and process management techniques to develop a product from conception to completion while minimising costs and maximising efficiency.

Advantages of Integrated Product and Process Development (IPPD)

Organization stands to benefit greatly from the implementation of IPPD. Some of the advantages are as follows:

- Using modern technologies and implement logical steps in production design, the actual production cost is likely to come down, thereby improving the profit of the company.



- Through optimum usage of resources and using efficient process, organizations are able to minimize cost of production thus improving profitability of the organization.
- Since extensive uses of CAD model are employed, chances of product or design failure are greatly reduced thus reducing risk for organization.
- As the focus is solely in delivering value to customer, quality is paramount importance and achieved through technology and methods.

Key Factors for IPPD

There are certain factors, which can vastly improve IPPD. These factors are as follows:

- IPPD success is greatly dependent on agreement on the end objective which is the successful address to customer requirements. All the stakeholders and management should be aligned to the single objective.
- Since this is a scientific approach, its success dependent on building up of plan, implementation of plan and constant review of the implemented plan.
- With implementation of modern methods and technology comes usage of modern tools and systems. These tools, and systems need to be integrated within the organization framework.
- Skilled manpower is another essential; therefore, organization need to make investment in human capital.

Customer is the focal point of IPPD. Therefore, constant feedback from them is essential for IPPD to be a success.

Therefore, IPPD is approach design to address all the concern of modern organization in the globalized world.

3.4 FACILITY LAYOUT

It is crucial to pay close attention to the facility layout if a business wants to have a productive and effective manufacturing unit.

The layout of a facility is the optimal arrangement of various manufacturing components to accomplish specified output outcomes. Facility layout addresses available space, final product, safety of users and facility and simplicity of operations.



A well-designed facility makes sure that production materials, tools, and labour flow smoothly, steadily, and economically. The physical distribution of space for economic activity in the plant is examined by facility layout. Consequently, the primary goal of facility layout planning is to create an efficient workflow that will increase the productivity of both personnel and equipment.

3.4.1 Objectives, Design and Factors Affecting the Layout

The contents should be divided into smaller chunks and structured under heading and sub-headings. The purpose is to present a logical and graded arrangement of subject matter. The language should be simple and easy to understand. It should not be bookish and full of jargon. The language used should be appropriate to the level of the learner.

Facilities Layout Goal

Model facility plan should be able to offer the best possible interaction between raw materials, tools, labour, and the finished product at the lowest possible cost in a secure and comfortable setting. The following goals are covered by an efficient and effective facility layout:

- To provide a safe and comfortable working environment and to provide the best area for organising equipment and facilitating the movement of items.
- To encourage organisation in production with a focus on a particular goal.
- To limit the movement of equipment, raw materials, and employees.
- To encourage both worker and plant safety.
- To make it easier to extend or modify the layout to make room for a new product line or technological advancement.
- To boost the company's production capability.

A business can achieve the aforementioned objective by guaranteeing the following:

- enhanced training raising awareness of safety regulations and health risks.
- The most effective use of personnel and resources.
- Promoting empowerment and minimising indirect work such as administrative tasks.
- Factors affecting Facility Layout

Many elements can affect how a facility is laid out and how it is implemented. These variables differ between industries but affect how a facility is laid out. These elements are as



follows: The layout of the facility should be designed with the organization's overarching aims in mind.

Process and technology need to have the most room possible.

An appropriate safety measure to prevent accidents.

The organization's long-term goals and general management principles.

Facility Design and Layout

The purpose of the facility layout, the factors impacting the facility layout, and the limits of the facility layout must all be taken into account in the design principles. The following are these guidelines:

Flexibility: The design of the facility should allow for extension or alteration.

Space Utilization: Effective space use speeds up the flow of people and materials while enhancing security.

Capital: While deciding between several facility layout concepts, the least amount of capital should be invested.

Design Layout Methods

Three design layout methods exist, and they are as follows:

1. **Two- or three-dimensional templates:** This method involves creating a scaled-down version of a drawing that has been given the go-ahead.
2. **Sequence Analysis:** This method uses computer technology to plan the layout of the facility by first sequencing all activities, then arranging them in a straight line or a circle.
3. **Line balancing:** This type of assembly-line approach is applied.

Layouts for Facilities There are six different layouts for facilities, and some of them are as follows:

- Fixed Position Layout,
- Product Layout,
- Process Layout
- Cellular Technology Layout



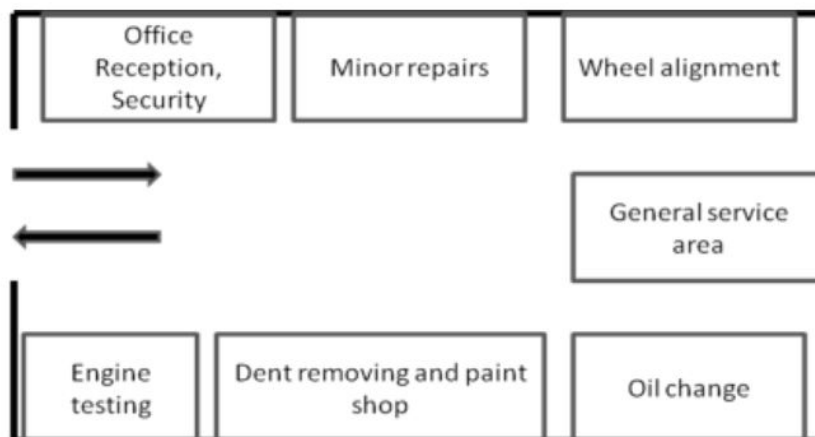
- Hybrid Layout

1. Process Layout

Depending on the sequence or order of operations required for the product, the arrangement of equipment and machines in an industrial unit may occasionally be done on a single line. Additionally, there is no deviation in the order in which different materials, such as raw materials and semi-finished goods, are moved between workstations.

Under process layout, machines are grouped and arranged in a single sequence. Therefore, raw materials are input into the first machine, and finished goods can freely move from one machine to another. The output from one machine is used as an input of the next machine.

For example, Several departments or functions may be present in the service and repair centre for two- or four-wheelers. These activities or divisions are organised according to the technological requirements or available space, taking into account factors like the total number of employees, installed equipment, the typical number of cars the centre receives, and any other requirements.



- Any vehicle must take the following actions when entering the centre.
- Arriving for work.
- Notifying the appropriate staff of the nature of the customer's issue.
- The front desk personnel tells the client to drive the car to the appropriate departments.
- The car receives the appropriate maintenance.
- Customers are further guided to make payment at the front office.



- After making the payment, the customer leaves the service centre.

Merits of Process Layout

Different merits or benefits of process layout are as under:

Minimal Spending on Machinery and Equipment

There aren't any sets of operation sequences in the process layout that the machines and equipment must go through. Its arrangement enables the development of products of various varieties that adhere to the established criteria, and it also eliminates the need for additional equipment during the process.

Less expensive overhead costs

Because to the low initial capital input, investment risk is kept to a minimum. Moreover, this arrangement does not include any duplicate machines. Also, because to the commonality of the processes, multiple machines can be operated and controlled by a single person. Hence, overhead costs per unit will be lower.

Maximum Usage of Machinery

As a machine is not related to any specific product in a layout through the process, it can be used to a maximum degree.

Increased Flexibility

Many comparable sorts of operations in the process layout can be carried out by a single machine. So, in the event of a machine failure, another machine in the same department or even a machine that is comparable but located in a different department can do the same role. Thus, this architecture offers more flexibility in processing industrial procedures.

Improved Supervision

The design of the process enables supervisors to use their specialised abilities more successfully or better. In this process, a foreman is allotted machine operations of respective departments in limited form, and in a reasonable amount of time, he is able to obtain proficiency in the whole supervisory activities of that particular department such as planning, controlling, directing which come under his work preview.

Using Employees' Potential and Abilities to the Fullest



Due to the division of the work into separate portions and the assignment of a specific portion of the job to each department, it is feasible to exploit the abilities and potential of employees to the fullest extent in the process layout. As a result, labour becomes more specialised.

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Drawbacks or Demerits of Process Layout

The following are a few of the process layout's drawbacks or demerits:

Increasing Expenses of Material Handling

Due to the daily regular duties of several departments and the greater distances across which jobs must be moved, the cost of material handling is higher in the process plan.

More Room on the Floor

For the aim of placing different departments and installing machines, process layout takes up a significantly larger space on the floor. It is impossible to utilise the entire available floor area because of the vast size of the floor space.

Additional Processing Time

Because each task will move across several departments according to the process structure, the time it takes to finish a job will be longer in the production process. Once the work has been gathered from the prior department, machine loading takes a long time.

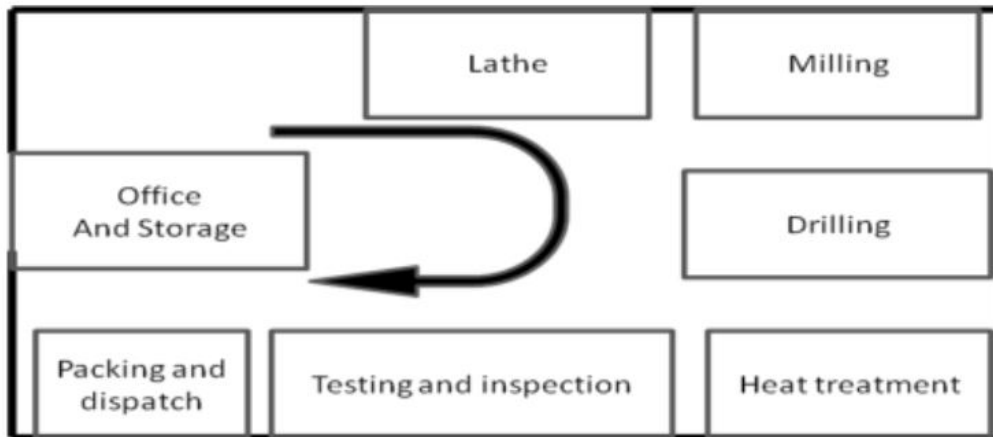
Often Required Inspection

The production department that handles one product also handles another according to the process plan. As a result, it is frequently necessary to inspect the work before moving it to the next stage of execution in another department. As a result, inspection work becomes more challenging and ineffective.

2. Product Layout

The location of machines and other auxiliary services in accordance with the processing order of the product is what is meant by product layout or line layout. Its primary emphasis is on the order of production or assembly steps necessary for the manufacturing or assembly of a product or any of its components. Typically, product layout is advantageous for companies that have mass or continuous production such as oil refining, automotive assembling, cement manufacture.

Facilities can be aligned for the efficient flow of materials and lower cost/unit in product designs if there is a high production volume of one or more products. To accomplish the



specified tasks quickly and effectively, machines made specifically for a given task (specialised machines) are used.

The advantages of Product Layout

A Flowing Production The product layout incorporates the entire production process. So, there is no chance that any of the production's many stages will be blocked. Consequently, its design guarantees a seamless production process.

Material Handling Expense is Lower

Since the machines are arranged in Product Layout in accordance with the order of operations, there is no backward or forward movement. The time and money spent on material handling are reduced as a result. Additionally, it avoids the transportation costs associated with moving materials between machines.

Decreased work-in-progress

Because manufacturing is continuous and hassle-free with Product Layout, there is also less work-in-progress. The necessity of both investment and storage space is also smaller for work-in-process.

Space use at its best

The order of the equipment allows for efficient utilisation of the available area. Also, if the area is crowded, machines can still be set up properly since they can be stacked in a U form.

Effective Resource Management

Product layout enables the efficient use of resources since it encourages reduced worker movement, decreased work-in-process, decreased waste, continuous manufacturing process, etc.



Successful Supervision

The production process is simple to monitor and manage due to its integration. Inspection points are incorporated into the manufacturing process.

Possession of Production

Due to the continuous production process, the product layout makes production control easier. The management may find it simple to plan operations and may take action to complete the work in accordance with the plans.

Timesaving

The design of the product reduces the amount of time needed to carry materials because materials can be moved by a variety of automated devices, such as conveyor belts. This assists saving adequate time.

Disadvantages of Product Layout

Stiff System

The adaptability of the product layout is a problem. When a series of procedures are being carried out, modifications cannot be made in the middle of the production process.

Challenges with Expansion

It's challenging to increase production beyond what production lines can handle.

Expensive Layout

When machines are arranged in accordance with the sequence of operations, product layout is regarded as a costly layout because it may result in the duplication of machines of the same types needed for several production lines.

Monotony

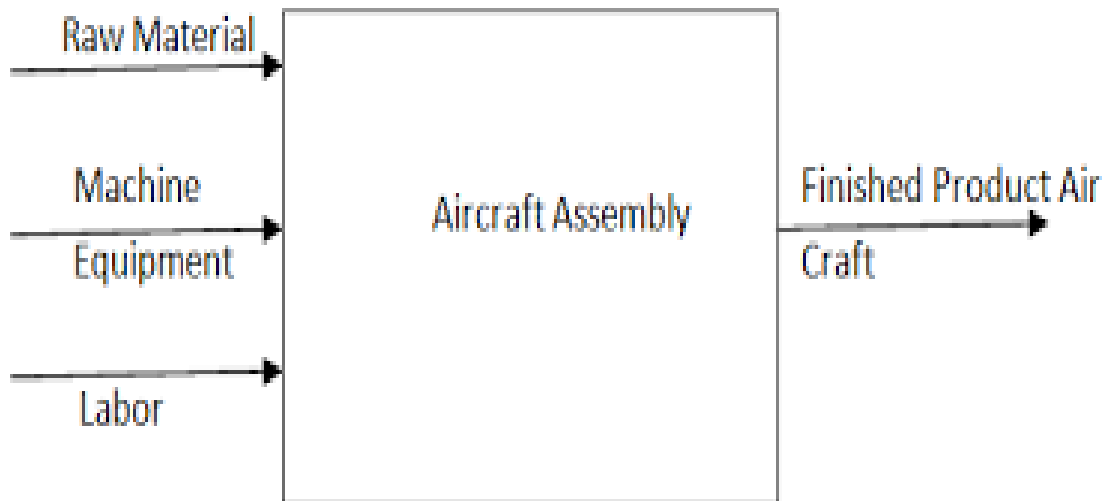
Because workers' tasks are repetitious, product layout breeds boredom. The worker has very little chance to demonstrate their abilities.

The Additional Expense of Overstaffed Teams

Although the personnel are skilled at using certain machines, they lack knowledge of how to operate others. Therefore, if a worker who is engaged in performing a specific task is away for a few days, it will negatively affect the entire workforce. In such circumstances, it could be necessary to hire additional personnel and train them to operate various machines.



3. Fixed Position Layout



This kind of arrangement enables a product to be maintained at a certain location while the materials, labour, machines, and other resources are transported to the product's location. In other words, because of the product's larger size or heavier body, the location of the primary component or component remains stable. Also, transferring resources will be less expensive in terms of shifting or transportation costs than moving products, which will incur higher expenditures.

So, it is more practical to move the necessary personnel, tools, materials, and equipment to the area where the product is constructed as opposed to moving the finished good.

For example, Different items like aircraft, large ships, and construction-related projects are typically produced using a fixed-position layout. This design is also frequently used for various on-site services, such as landscaping, services for housecleaning and pest control, etc. The fixed-position design is employed by numerous organisations that produce boilers and turbines.

A Fixed Position Layout's Benefits

- Enhances worker abilities and makes it easier to expand employment opportunities.
- Little capital expenditure.
- More flexibility.



Disadvantages of Fixed Position Layout

Equipment Expense

With a fixed position layout, the product stays in one spot but various pieces of machinery, tools, and equipment must move to reach it. As a result, there are significant transportation expenses, equipment maintenance costs, and equipment repair costs.

Workdays of Employees

A plant, which has implemented a factory position layout, needs to organise the work schedule for workers in a meticulous manner so that each one of them is assigned the required time to work on the particular stage of the production process. The speed of other phases of the process may be slowed down in the event that a worker is unavailable or is not in a position to work. The product's development time may lengthen as a result, and the plant may incur losses as a result of higher overhead expenses.

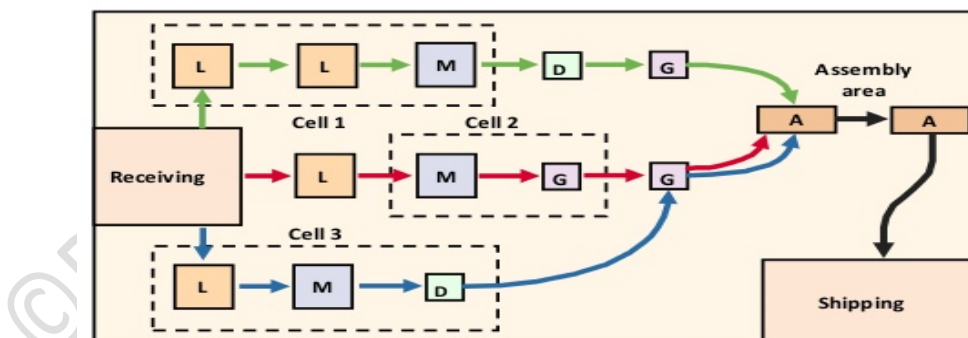
Need-based Material Requirements

One drawback of using a fixed-position layout is that materials and equipment must be transferred when they are needed. whereby supplies and equipment can be stored in the desired location until they are needed for the subsequent stage of the manufacturing process.

Little Workspace

Because different manufacturing steps demand varying numbers of personnel, there may be a limit on available space.

4. Cellular Layout



(b) Line flows in a job shop with three GT cells

Cellular layout is thought of as a mechanism through which it is possible to identify and group comparable or related pieces engaged in the manufacturing process in order to utilise the built-in economy of flow production techniques.



To put it another way, a cellular manufacturing layout is a form of layout where various machines can be grouped according to the process needs for a similar set of products or families of similar parts that require the same kind of processing. Cells are defined as such groups of organisms.

Cells in this kind of structure are created by bundling many activities. This procedure includes the identification of parts having similar characteristics in terms of their design i.e., size, function, and shape. Also, features of a related process, such as the kind of processing that is necessary, the apparatus needed to carry out the process, and the order in which processing occurs

In a cellular structure, employees receive cross-training to improve their abilities to run various pieces of equipment in a certain cell and be in charge of that cell's output. In a few instances, the construction of a cell is predicated on the use of certain machinery to create the components of a family, in which case moving the machinery into a physical cell is not necessary. Nominal or virtual cells are the names for these cells. An organisation can avoid the hassle of changing its current layout by doing this.

One manufacturing facility, for instance, makes 10,000 pieces every day. It may group these parts into the group of 50/60 families of parts. Each family has manufacturing traits and design elements that are similar.

Hence, each member of a certain family will undergo comparable processes. This encourages improving manufacturing process efficiency.

Advantages of Cellular Layout

Lower Cost

This structure has several advantages, including quicker processing times, shorter setup times, and fewer work-in-process inventory. Cost-saving benefits come from this.

Increases Flexibility

Small batch production is possible using group layout or cellular layout, increasing flexibility to some level.

Boosts Motivation

Because there is less chance of boredom in this layout, the cross-training that various personnel receive to operate all the machinery in their cell helps to increase their motivation.



5. Hybrid design

The majority of manufacturing units employ combined layout types. For instance, the manufacturing process can include both the layout of the process and the product. Hybrid layouts are the name given to these kinds of blended layouts.

3.4.2 Facility Location - Factors Influencing the Location

The goal of facility location is to find the ideal location for a manufacturing facility so that an organisation will have easy access to its target market, as well as to workers, customers, and transportation. The crucial elements for commercial success and competitive advantage are as follows:

An organization's main goal is to excite and please customers with its goods and services. As a result, it becomes crucial for a business to develop its strategy around its manufacturing unit. A manufacturing facility is where all the components, including labour, equipment, and raw materials, come together to create products for consumers. The location is one of the most important elements in determining the success of the manufacturing unit.

Choosing where to locate a facility is a crucial strategic choice for the firm. The placement of a facility is influenced by a number of variables, including cost, competition, and any resulting repercussions. Facility location is a methodical process utilizing various systems.

Location Choice Elements

Cost, available infrastructure, labour expertise, governmental rules, and the environment are crucial considerations for a corporation that operates in a global setting. A good site gives customers, skilled workers, transportation, etc. enough access. The success of a firm in the contemporary, fiercely competitive global market depends on its location.

Industrialization

Based on a variety of criteria, concerns, and restrictions, a certain geographic area is used as the focal point for different facility sites. These variables can be separated into primary and secondary variables. Material, labour, and the presence of similar manufacturing facilities are three main factors that cause a place to industrialise for the purpose of producing goods. Credit finance, communication infrastructure, and insurance are offered as auxiliary factors.

Location Selection Mistakes



The location of the facility is crucial to the organization's performance and business continuity. So, it's critical to choose a place carefully and to avoid making mistakes. The two basic categories of selection errors are behavioural and non-behavioural.

Behavioural errors are decisions made by corporate executives where personal factors are prioritised over the performance of the location, for instance, moving a personal business from one place to another.

Non-behavioural mistakes include failing to do enough investigations and analyse the results, as well as neglecting important industry traits and aspects.

Placement Strategy

Customer satisfaction is the ultimate goal of any business, thus getting access to clients should be as inexpensive as feasible. It is accomplished by creating a location strategy. The organisation can determine its product offering, market, demand projections in various markets, optimum customer access location, and optimal manufacturing and service location with the aid of location strategy.

Location-Relating Variables for Facilities

The company will have adequate access to clients, workers, transportation, etc. if it can choose the ideal site for the production facility. The crucial elements for commercial success and competitive advantage are as follows:**Customer Proximity:** Facility locations are selected closer to the customer as to reduce transportation cost and decrease time in reaching the customer.

Business Sector

Business area is favourable for facility establishment because of the nearby presence of other manufacturing units that are similar.

Labour with Talent is Available

Another factor that affects facility location is the availability of labour with the appropriate education, experience, and competence.

Free Trade Agreement/Zone

By offering incentives in the form of custom taxes and levies, free-trade zones encourage the construction of manufacturing facilities. On the other side, a free trade agreement between nations encourages the establishment of businesses in a particular nation.

Suppliers



Another important aspect in choosing the site of a manufacturing facility is the reliable and consistent supply of raw materials.

Environmental Policy

Pollution management is crucial in the modern, globalised world, therefore understanding the environmental regulations that apply to the facility's location is also essential.

3.5 PROCESS DESIGN AND ANALYSIS

The goal of the organisation is to deliver services and goods that delight customers and add value for them. Based on customer feedback and industry demands, products and services are developed. The product is divided into components during the process design stage, which can be useful during the real manufacturing process.

For example, a product may have appealing packaging to provide the appropriate aesthetics as well as features and functionality that add value for consumers. The smooth and continuous relationship between the necessary output and all intermediate processes is guaranteed by process design.

For example, the production of air conditioners requires process design that maximizes supply during the summer's hot months, when demand for the product is at its greatest. In order to meet seasonal demand, people, processes, and machines must work together to provide continuous output throughout the year.

3.5.1 PROCESS ANALYSIS

Flow Chart/Process Flow Diagram A Flow Chart (also known as a Process Flow Diagram or Process Map) is a diagram of the steps in a process and their sequence. Two types of flow charts are utilized in quality improvement. A high-level flowchart, outlining 6-10 major steps, gives a high-level view of a process. These flowcharts display the major blocks of activity, or the major system components, in a process. These charts are especially useful in the early phases of a project and help to set priorities for improvement work. A detailed flowchart is a close-up view of the process, typically showing dozens of steps. These flowcharts make it easy to identify complexity, excessive steps, etc. in a process and should be used when you want to standardize or make changes in the process.

There are many types of flow charts/process maps including swim lane, value stream, cross functional and workflow.

When to Use a Flow Chart

- When you need to define or analyze an existing process.
- When you need to standardize or redesign a process.



- When you need to find areas for improvement in a process such as unnecessary steps, gaps, barriers, etc.

How Flow Charts Are Constructed

1. Identify the goal for creating the flowchart and the level of detail required-high or detailed.
2. Assemble the people who know the process best and outline the process steps.
3. Define the first and last steps in the process.
4. Begin documenting the process steps in sequence. Some steps may be parallel-they happen at the same time. Describe the process as it really exists, not the ideal. Most flow charts are made up of three main types of symbol:

- Elongated circles, which signify the start or end of a process.



- Rectangles or squares which show instructions or actions.



- Diamonds which show decisions that must be made



5. Work through the entire process, showing actions and decisions appropriately in the order they occur. Link these together using arrows to show the flow of the process. (Tip: Self-adhesive notes are a flexible way to document steps, using one note for each step. This allows you to easily change the order or add new steps.)
6. At decision symbols, choose the most natural branch and continue to the end.
7. Use notes for unfamiliar steps and continue to the end.
8. When you reach the last step, go back to fill in any branches.
9. Follow up on unfamiliar steps and update chart.
10. Validate your flow chart. Work from step to step asking yourself and others if you have correctly represented the sequence of actions and decisions involved in the process.



11. Identify areas for improvement and redesign the process

3.5.2 UNDERSTANDING PROCESSES

It is useful to categorize processes to describe how a process is designed. By being able to quickly categorize a process, we can show the similarities and differences between processes. The first way to categorize a process is to determine whether it is a single-stage or a multiple-stage process. If the slot machine were viewed as a simple black box, it would be categorized as a single-stage process. In this case, all of the activities involved in the operation of the slot machine would be collapsed and analysed using a single cycle time to represent the speed of the slot machine. A multiple-stage process has multiple groups of activities that are linked through flows. The term stage is used to indicate that multiple activities have been pulled together for analysis purposes.

3.5.3 JOB DESIGN DECISIONS

Thus far in the chapter, we have assumed that we know how long it takes to perform a task. Determining this time is a significant task in itself. In this section, concepts that relate to designing meaningful jobs are discussed together with the problem of estimating how long it should take to do the jobs. Job design may be defined as the function of specifying the work activities of an individual or group in an organizational setting. Its objective is to develop job structures that meet the requirements of the organization and its technology and that satisfy the jobholders' personal and individual requirements. The diversity of the workforce's cultural and educational background, coupled with frequent organization restructuring, calls for a high level of people management skills. The operations and supply chain manager uses job design techniques to structure the work so it will meet both the physical and psychological needs of the worker. Work measurement methods are used to determine the most efficient means of performing a given task, as well as to set reasonable standards for performing it.

3.6 SUMMARY

The main points and themes covered in the lesson must be reviewed and highlighted at the end of the lesson in the form of a summary. Please note that 'this is not a conclusion: rather it will help the learners in remembering the main points of the lesson and therefore it is written at the end of the lesson. It should be one paragraph and should not be too long. Further, if the



author feels the need, key points can be given as a numbered or bulleted list or a diagram chart.

3.7 SELF-ASSESSMENT QUESTIONS

1. Productivity rises whenever:
 - (a) Increasing input without changing output.
 - (b) decreased intake with constant output.
 - (c) output falls while input stays the same.
 - (d) The ratio of input to output increases.
 - (e) Inputs and outputs grow at the same rate.
2. Services often:
 - (a) are tangible.
 - (b) are standardized.
 - (c) are knowledge based.
 - (d) are low in customer interaction.
 - (e) have consistent product definition.
3. How can CAD help in product specification?
4. Describe the steps that might be in writing and producing a play. Compare these steps to the product development steps.
5. Why is inter-functional cooperation important for product development?

3.8 REFERENCES

12th Edition to be referred

Jay, H., Barry, R., Chuck, M., & Amit, S. (2019). Operations Management (Sustainability and supply Chain Management) Pearson Publications.

3.9 SUGGESTED READINGS

(Fifteen Edition)

Richard, B. C., Ravi, S., & Robert, F. J. (2018). Operations and Supply Chain Management. McGraw Hill Education (India) Private Limited.



LESSON 4

DESIGN OF PRODUCT AND SERVICES

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STRUCTURE

- 4.1 Learning Objective
- 4.2 Introduction
- 4.3 Product Design
- 4.4 Design Service Product
- 4.5 Production Tools
- 4.6 Summary
- 4.7 Glossary
- 4.8 Answers to In-text Questions
- 4.9 Self-Assessment Questions
- 4.10 References
- 4.11 Suggested Readings

4.1 LEARNING OBJECTIVES

- Interpret the issues associated with product design and the typical processes used by companies.
- Explain the various criteria influence the design of the product.
- Compare how service products can have different design criteria compared to manufactured products.
- Assessing the economic impact of new products on companies.
- Describes how product development is measured at the company.



4.2 INTRODUCTION

IDEO (pronounced "ideo") is one of the world's most acclaimed design and innovation consultancies. As co-founder David M. Kelley and his colleagues, work is a game, brainstorming is a science, and the most important rule is to break the rules (www.ideo.com). The company's focus is solely on creating new products, services and other interactive experiences that customers desire for.

IDEO's core principle is empathy for the end user of its products. They believe the key to finding out what people really want is to do two things:

- User Behaviour Tracking: Try to understand people by tracking them.
- You put yourself in the shoes of the end user: IDEO does this to understand what the user experience is really like; feel what their users feel.

The scope of work done by the company ranges from projects related to Smart Mobility with Ford Motor Company to the development of digital healthcare apps that give people the ability to track and understand their mood, sleep, and breathlessness. Rather than thinking of design as a linear process requiring a set of steps, IDEO sees the process as overlapping thought spaces. These spaces are referred to as follows:

- Inspiration-the problem or opportunity that inspires the need for a new design;
- Ideation-where model prototypes, visual pictures, or quantitative analysis is done to test ideas;
- Implementation-where ideas become new products and services.

The key concepts of the IDEO design thinking methodology are human desirability, business viability, and technical feasibility, and innovation necessitates the integration of these principles. Apple Computer's first mouse, a striking and stunning design that has stood the test of time, was one of IDEO's initial design efforts.

4.3 PRODUCTION DESIGN

Today, companies often utilize critical functions (like product design) instead of supporting them internally. Companies that have the speciality of developing and manufacturing products for other companies are very successfully established. These companies that manufacture are called contract manufacturers and are established in industries such as apparel, plastics, pharmaceuticals, electronics and contract manufacturing.



Many business experts will agree that product design identifies a market opportunity, defines users' needs and problems, develops a solution for that problem, and validates the solution through the user goals

If we simply define a contract manufacturer, it is an organization that produces and/or purchases devices or products required for the manufacturing or devices as a service to another company, but not for its own sake. For example, take the experience with engines of Honda. This ability of core competency has enabled Honda to develop products of high-quality range, from grass cutters and snow blowers to trucks and automobiles. Consider another case from the automotive industry, Volvo's core competence should be safety. Core competencies have majorly three features/characteristics.

1. It provides potential access to various markets.
2. Perceived customer benefit is increased.
3. It gets difficult for competitors to copy.

CASE STUDY

When designing food products:

Principal factors for marketing are acceptance by customers, competitive positioning, legal regulations, ethical needs, environmental laws and requirements by retailers;

Principal technical factors are raw materials accessibility, processing convenience, cost, achievability and dependability of product quality, durability, equipment's requirements, human logics and skills.

Principal financial factors are production and costs of distribution, and required investments.

All are included in various parts of the design and can all be considered in the management suitability report at the last stage of the product design and process development.

The design process

The philosophy of design thinking holds that one must adopt a designer's attitude and approach the issue from the perspective of the user in order to come up with novel solutions.

Design activities are grouped into the following steps: "Getting a feel" results to screening, superficial research, manufacturing and marketing optimization and scaling, and at last



product and process specification, marketing tactics, and financial analysis. This gives you hold over the design process as consumer, product and process activities are coordinated in small projects with their desirable goals. Some activities and experimental strategies at various stages of product design and process development are: (marketing).

4.3.1 Product Development Process

A product development process provides a methodology and structure that can assist all team members when creating and developing a product, starting from initial user research to implementation and final launch.

First, define a general product manufacturing process that gives a detailed description of the basic steps required for designing a product. This process represents the basic set of steps a company uses to conceive, design, and launch a product to market. Many of these tasks involve intellectual rather than just a physical activity. Some companies define and follow a accurate and briefly detailed development process, while others cannot even explain the process. Every organization uses a different process than every other organization. In fact, the same organization may involve different processes for different product groups.

The following are the six stages of the generic development process:

- **Phase 0: Planning:** The initial planning activities, which come before the approval of the project and the commencement of the actual product development process, are commonly known as "Phase Zero." This phase starts with the corporate strategy and encompasses the evaluation of technology development and market objectives. The outcome of the planning phase is a project mission statement that identifies the intended audience for the product, business objectives, significant assumptions, and limitations.'
- **Phase 1: Concept development:** In this stage, the requirements of the target market are identified, and various product ideas are created, evaluated, and shortlisted for further development and testing. A concept refers to a detailed explanation of a product's features, structure, and function, typically accompanied by a set of specifications, analysis of rival products, and a business case for the project.'
- **Phase 2: System-level design:** During the system level design phase, the product architecture is established, and the product is divided into subsystems and components. Additionally, the assembly process plan for the production system (which is discussed later in the chapter) is typically determined at this stage. The outcome of this phase often comprises the physical arrangement of the product, operational specifications for each product subsystem, and a preliminary process flowchart for the final assembly process.



- **Phase 3: Detail design:** During this phase, all unique parts of the product are fully defined in terms of their geometry, materials, and tolerances, and all standard parts procured from suppliers are identified. A process plan is formulated, and tooling is designed for each part manufactured within the production system. The deliverables of this phase include drawings or computer files that describe the geometry and production tools for each part, specifications of the procured parts, and a process plan for producing and assembling the product.
- **Phase 4: Testing and refinement:** In the Testing and Refinement phase, numerous prototype versions of the product are constructed and assessed. Initial prototypes are generally created using parts with the same geometry and material properties as the final product, but they may not be produced using the intended manufacturing processes. The prototypes are tested to determine whether they function as intended and meet the needs of the customer.
- **Phase 5: Production ramp-up:** In this phase, the product is manufactured in the intended production facility. The start-up team trains and oversees the workforce, and resolves any remaining issues in the manufacturing process. The products produced during the ramp-up phase are provided to selected customers and closely examined to detect any remaining flaws. The move from production start-up to continuous production is generally gradual. At some stage in this process, the product is released and made available for widespread distribution.

Platform Products

Platform products are constructed using pre-existing technology subsystems and technology platforms.

Process Intensive Products

Process-intensive products, such as semiconductors, food, chemicals, and paper, require product design and manufacturing process design to be closely linked since the manufacturing process impacts the product characteristics.

Custom Products

These products are slight modifications of standard configurations, usually made to order based on a customer's preferences. Examples include motors, switches, batteries, and containers. The development process for these products primarily involves determining values for design variables such as physical dimensions and materials.

High Risk Products

High Risk Products refer to items that have a notably high level of uncertainty in either their technical aspects or market performance, which may involve substantial risks in either or both of these areas. The standard process of developing a product has been altered to focus on



managing high-risk situations, with an emphasis on identifying and mitigating the most significant risks during the early stages of product development.

Quick Build Products

Prototyping and testing have become speedy procedures for the development of certain products, such as software and electronics, enabling numerous cycles of design, building, and testing.

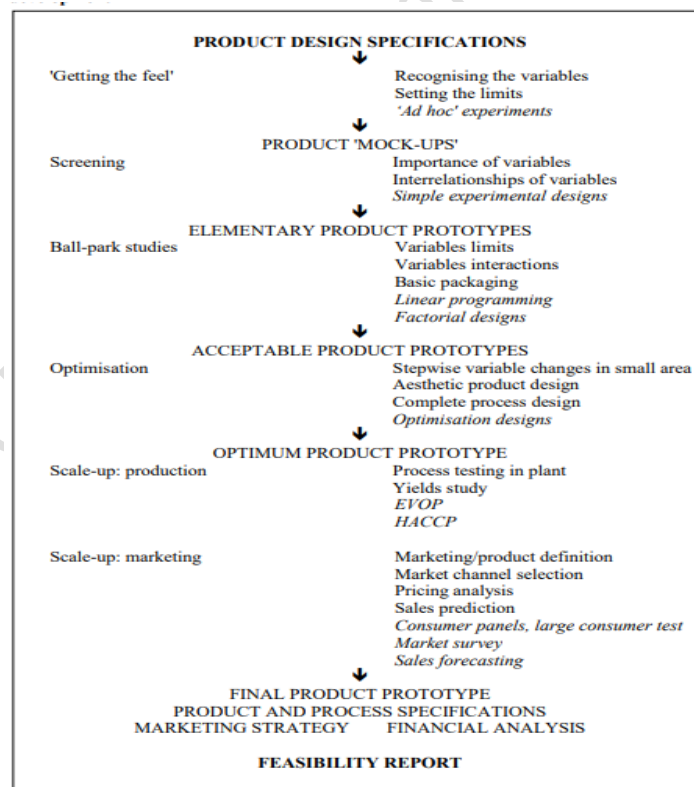
Complex Systems

The development of intricate systems, like airplanes and cars, involves several interconnected subsystems and components. While creating such complex systems, modifying the overall product development process can address various system-level concerns.

Product Testing

As shown in Figure 4.2, product testing is an integral part of product design and process development.

Figure 4.2 Testing activities & techniques in product design and process development





To create a prototype of the final product, it is crucial to conduct testing at each stage of the design process to ensure compliance with technical specifications, consumer expectations, and cost constraints, as illustrated in Figure 5.2. Example 5.1 provides a list of test types employed in the development of Thai Fermented Sausage.

Product formulation

Numerous food products are produced by blending raw materials in specific proportions and compositions. During product design, research is conducted to evaluate the impact of various compositions on the quality of the end product. System formulation comprises five steps:

- Identifying the necessary product characteristics
- Gathering information on the quality, composition, and cost of raw materials
- Establishing the boundaries for raw materials and processing variables
- Employing quantitative techniques like linear programming, experimental designs, and mix designs
- Conducting product profile and technical tests to establish the correlation between product characteristics and compositional changes.

(*There are numerous computer software programs that can assist with the application of these statistical methods.)

Raw materials are typically categorized into two groups: primary manufacturing raw materials and "top" or aesthetic raw materials. This doesn't imply that the primary raw materials don't contribute to the aesthetic quality of the product – in fact, modern food design recognizes this as a crucial factor. However, at times it may be necessary to add colors and flavours to enhance the visual impact. When designing a product, key characteristics of raw materials are taken into consideration with respect to the desired product properties, as demonstrated in Example 4.2.

Example 4.2 The raw materials used in the production of Thai Fermented Sausage (Nham) are categorized into six groups:

- Meat system: consisting of fresh lean pork and pork that has been kept at Thai ambient temperature for three hours after slaughter.
- Hardeners: including sodium chloride, sodium nitrate, and sodium tripolyphosphate.
- Spices: white pepper and fresh garlic.
- Carbon sources for fermentation: jasmine rice (boiled) and glucose.
- Source cultures: *Lactobacillus plantarium*, *Lactobacillus brevis*, *Pediococcus cerevisiae*, and *Micrococcus varians*.



- Sausages: cylindrical tubes with a diameter of 22.5 mm and a length of 30 cm, made of laminated 15micron uncoated nylon and 50 micron linear low density polyethylene.

Limits on raw materials

Meat system was set at 80% ground meat 20% sliced pork skin. The low and high levels for the other ingredients and starter cultures were:

Raw materials	% meatsystem	Starter Cultures	cfu/g meatsystem
sodium chloride	1,4	<i>Lactobacillus plantarium</i>	0, 10 ⁶
sodium nitrate	0.01, 0.03	<i>Lacobacillus brevis</i>	0, 10 ⁶
sodium tripolyphosphate	0, 0.5	<i>Pediococcus cerevisiae</i>	0, 10 ⁶
minced garlic	3, 7	<i>Micrococcus varians</i>	0, 10 ⁶
white pepper	0, 0.05		
cooked rice	5, 8		

- **Screening experiments:** Plackett and Burnam's experimental design was utilized to analyze the raw materials for Thai Fermented Sausage (Nham). Through this method, four source cultures and rice were identified as significant raw materials that influence the properties of Nham. Further experiments were conducted on these materials under different levels and processing conditions. Glucose was also studied as a secondary carbon source. The other ingredients used were sodium chloride at 3%, sodium nitrate at 0.02%, sodium tripolyphosphate at 0.3%, garlic at 7.0%, and white pepper at 0.05%. This information was obtained from the Ph.D. thesis of Wiriyaacharee, P., titled "Systematic development of a controlled fermentation process for Thai semi-dry sausage Nham" which was completed at Massey University in New Zealand.
- **Product and Process Specifications and Marketing Strategy:** To plan a manufacturing process, several factors need to be considered, such as the required raw materials, process flow, quality standards, control points, and testing methods. This information is used to create product and process specifications, estimate costs, and seek legal or official approval if necessary. Furthermore, customer acceptance and sales forecast can be predicted based on market research, and a marketing strategy can be developed accordingly.
- **Product and Process Specifications:** The ultimate specifications consist of the raw material specifications, product composition, process flow diagram, processing



conditions in each unit, initial process HACCP analysis, intermediate and final product testing, and the final product characteristics. These specifications are determined based on the initial production stage only, and may undergo changes during the distribution process.

- **Costs and Prices:** The estimation of costs and prices is done by considering trial production times and consumer testing. However, since the production quantities are still based on small-scale testing and prices are determined based on consumer feedback rather than actual purchases, the estimated costs and prices are presented as ranges. Typically, three projections are made for costs and prices: pessimistic, most likely, and optimistic.

4.3.2 Ecodesign

Ecodesign is the incorporation of environmental considerations in the design and development of products or services. It is an extension of other important factors that are considered in the design process such as quality, costs, manufacturability, functionality, durability, ergonomics, and aesthetics. Consequently, ecologically designed products are innovative, have better environmental performance, and meet at least the market standard in terms of quality. This makes the use of ecodesign increasingly significant for companies and offers clear advantages to those who utilize it.

Ecodesign takes a comprehensive approach to the relationship between products and services and the environment on three levels.

- i) Firstly, it takes into account the entire life cycle of the product or service, considering its environmental impact not only during manufacture, use, and disposal, but throughout its entire life cycle, including resource recovery and transportation, production processes, distribution, use, maintenance, recycling, and waste management.
- ii) Secondly, it treats the product as a system, considering all the elements necessary for the development of its functionality, such as consumer goods, packaging, and energy networks.
- iii) Finally, it takes a multi-criteria approach, analyzing all the different environmental impacts that a product system can have during its life cycle to avoid trade-offs between different impact categories, such as depletion of natural resources, greenhouse effect, and toxicity.



The application of ecodesign can bring benefits to companies, users, and society simultaneously because it meets the common interest of having more efficient products both economically and environmentally. The manufacturer can produce the product using fewer materials, less water, energy, and so on, resulting in reduced production costs. The user benefits by purchasing a more reliable and durable product that requires less energy or consumables to operate and can be easily repaired if necessary. Society benefits by increasing the availability of resources for other products or services in the future and avoiding possible ecological damage, which saves the corresponding maintenance or renovation costs.

4.4 DESIGNING SERVICE PRODUCTS

When developing or modifying a service, it is crucial to determine how the new service is distinct from the existing services of the company. To make an informed decision, there are three primary factors that should be taken into account:

- 1. Similarity to current service.** To ensure a positive customer experience, new services should align with the existing service experience. For instance, Disneyland provides cameras at various locations in the park for visitors to capture memorable moments, which they can view online later. This is a part of the overall service experience that aims to fulfill visitors' dreams and keep them excited throughout their visit, rather than detracting from it.
- 2. Similarity to the current process.** Operational support is essential for implementing any service idea, even the best ones. For instance, grocery stores deciding to offer home delivery services as an extension of their service experience required entirely new operational capabilities, such as selecting fresh food for customers and delivering frozen items.
- 3. Financial justification.** Developing and introducing new services can be a costly endeavor, thus requiring an economic justification. Although this is often viewed as a positive outcome, the launch of a new service should also aim to avoid losing existing loyal customers.

4.4.1. Impact on Designers

Involving designers in the development of a PSS (Product-Service System) involves extending their traditional role into new areas that equip them with the required knowledge and skills to handle the unique features of a PSS. This expansion of design activity represents a new dimension.



- **New Dimensions of Design Activities:** To create new services, it's important to consider both the technical possibilities (what can be done?) and the social and cultural factors (what is needed and how can behavior be influenced?). These aspects are related to the ability to suggest reorganization and enhance the organization's learning capacity. Although this is similar to design management, using PSS for innovation requires a unique understanding of the organization's capacity for learning and improvement.

The social aspect of technology domains focuses on how social actors are able to influence innovation processes and shape the overall context in which new technologies, products, and services are either accepted or rejected. This highlights the importance of actors' ability to interpret even small signals of innovation and foster exploration across different disciplines.

The previous section's questions suggest three methodological directions for investigation:

- i) Analyzing the system as a social construct,
- ii) Examining the PSS through various stages before and during the use phase, and
- iii) Representing the PSS technically in the design process.

These directions are related to other disciplines, such as social studies, marketing and management, and information science, and the following section will discuss some methodological proposals from these areas.

ANALYSIS OF PSS AS A SOCIAL STRUCTURE

The development of a product or service involves a complex interplay between different actors and technical components during the use phase. Therefore, the design process should prioritize the areas of overlap between various social and technological factors, such as: Technical Knowledge Embedded in Artifacts Used in the Services.

Launching a new product involves a complex series of stages, such as idea generation, concept development and testing, marketing strategy, business analysis, product development, test marketing, and commercialization. These stages are associated with considerable uncertainty and costs. Therefore, it is essential to thoroughly validate an idea in terms of its desirability, feasibility, and viability before committing resources to product development. This is particularly crucial for software products where the landscape of business and technology is rapidly evolving. In order to ensure that the decision-making process for validating ideas adds value to the organization, it should be based on a product design process.



4.5 PRODUCTION TOOLS

There are multiple processes defined in Product Design:

- **Agile UX**
- **Lean UX**

Tools/techniques for designing products revolve around people and their goals. We build our products to help our users achieve their goals. Is it important to understand who we are building for? Why should we use our products? '

- **Techniques: User Stories**
 - Who are your users?
 - What do they need?
 - Why is it necessary?
- **Personas:** Personas provide detailed information about user groups, such as the example of a medium-sized publishing platform with various story categories. By identifying user interests, subscription plans, and other details, product designers can have more meaningful conversations and gain a better understanding of user issues, ultimately leading to better product design.
- **Emotional Thinking:** Suppose we take the medium example again. If a user publishes an article and receives applause, it can create an emotional connection between the user and the platform, resulting in a feeling of happiness. Additionally, if the user has invested significant effort into creating the content, they may not want to lose it. Product design that takes into account these emotional factors can often be successful. One example of such emotional design is the Like button on Facebook/Twitter/LinkedIn, which creates a connection between the user and the platform.
- **Simplicity:** Many people believe that being focused means agreeing to everything that needs attention. However, this is not what focus is about. Instead, it is about rejecting numerous other excellent ideas and making a careful selection. I am proud of the things we chose not to do, as much as I am of the things we did. Innovation involves saying no to countless things.



Steve Jobs

- **Simplicity:** The key to setting a product apart from others is to identify one specific aspect that distinguishes it. This can be achieved by repeatedly asking the question until complete certainty is reached. The unique aspect should be easily understandable, succinct, and simple enough to be communicated to anyone.
- **Usability Testing:** Imagine you produce a movie with different genres such as comedy, thriller, and emotional scenes. As a director, you would expect the audience to react accordingly to the different parts of the movie. For example, laughing during comedy scenes or being emotional during dramatic scenes. However, if the audience doesn't react as expected, it indicates that there are errors that need to be fixed. This is where usability testing comes in, which aims to measure the effectiveness of a product in achieving its intended purpose. It is recommended to conduct usability testing during the design process to identify and address any issues. The next question is how quickly these techniques can be implemented and what the process should be.

Q: What process is required for product design? The goals of the product design team are to:

- To quickly develop a feature-enumerated product prototype, do you design your product to describe how it works?
- Get corporate funding
- Get to market faster

There are several processes defined for product design.

Design Sprint – Overview

Day 1: Define Problem and Agree on Long-Term Goals

Day 2: Learn Solutions - Long-Term Goals Emphasizing Critical Thinking.

Day 3: Create a storyboard. This is a step-by-step plan for a prototype.

Day 4: Prototype this storyboard. The goal is to focus on the customer-facing interface of your product or service and have a prototype ready in just one day.

Day 5: Survey your customers and learn by watching how they react to your prototype.

After all, you know exactly how far you have to go and what to do next. A quick note about design sprints. The process may make you feel like you can get things done quickly, but if you don't do these things it might not:



- Start the sprint. Before you do, it's important to know your goals. team to join. their understanding and motivation.
- If a problem expert can research the problem and be prepared for any business, technical or market questions, the problem can be defined on day one.
- A good facilitator is the key to a successful sprint that gets things done every day. Facilitators need to know specific action items and goals.
- Who ultimately agrees or disagrees? Though polls are a good idea for reaching consensus. The solutions that have been discussed so far should never be ignored.
- What happens after the sprint? What results are produced and how can things be done? I tried to answer many questions, but it's important to know the basics. Your process/techniques may vary, but if the basics are solid, your product design should be successful.
- Design, like any creative endeavor, is an iterative process, requiring a lot of thought to arrive at a simple but worthwhile solution.
- Design helps define how users interact with your product and how users communicate with your product.
- Yes, design is finally becoming a big part of product development and maintenance, and the whole software accessory will undoubtedly be an important addition to your projects. Each program satisfies different needs such as structure, visual design, illustration, interaction and animation, enabling the best and most efficient work performance. Since no single software meets all these requirements, it can be a little daunting to choose from the multitude of software on the market today.

The tools we will soon introduce are dedicated to different aspects of the digital product design process.

- **Information Architecture**
- **Visual Design**
- **Branding**
- **Illustrations**
- **Animation**
- **Prototypes**

We can help you with these difficult decisions based on our current and past experience.



4.6 SUMMARY

Product development projects require a crucial component that involves designing the product and developing its process. This involves conducting research on the product, process, market, and consumers. These various disciplines are interconnected and play a highly creative role in the project. The scope of knowledge involved in product design is broad, but some aspects may lack depth. At the conclusion of the design process, a factual feasibility study must be created from this wealth of information. Hence, product design requires a methodical plan and control while still permitting room for innovative approaches.

In the past, the food industry relied on a trial-and-error approach for product development. However, with the advent of computers and the availability of more comprehensive knowledge, it has evolved into a technologically-driven process that prioritizes the input of consumers. Consumer feedback is now a crucial component of product design, and they are actively involved in testing prototype products.

Throughout the design process, three key factors must be taken into account: consumer acceptance, technical feasibility, and cost. These factors are crucial to testing the product's viability and should be considered at every stage of the design.

The culmination of product design involves initial efforts to establish product specifications and a marketing strategy that will serve as the foundation for commercialization. Financial considerations such as cost, pricing, and sales potential are anticipated, along with the necessary investment for future development.

Product development is a major challenge that directly impacts the long-range success of a firm.

- Effectively managing the process requires an integrated effort involving all the functional areas of the firm.
- Many companies today outsource product design to companies that specialize in different industries. The use of contract manufacturers has changed the way many companies now operate.
- An issue is often deciding what a firm's core competency should be to yield a long-term competitive advantage to the company.
- Product development is a multistep process that is unique to each organization. Typical steps in the process are planning, concepts development, system-level design, design detail, testing and refinement, and production ramp-up.



- While I tried to answer many of the questions it is important to know the basics. Process/techniques may differ but if the fundamentals are strong then a product design has to be successful.

A design like any other creative work is an iterative process and requires a lot of thinking in coming to a simple yet ...valuable solution.

- Design helps in defining the interaction of the user with product and users communicate with the product.

4.7 GLOSSARY

Lean: It is a work methodology based mainly on the Toyota model and that works side by side with Agile. The methodology envisages a way of working that always seeks to maintain focus and avoid unnecessary expenses, both time and money. The product in the Lean methodology follow this same premise, avoid having unnecessary or excess functionality.

DOR (Definition of Ready): It is the phase of the project where the whole team is aligned and understands what will be the deliverable at the end of a Sprint. Everyone must understand the “done” criteria of the product.

DOD (Definition of Done): It is the stage where all the Sprint stories have been completed. Done, that’s when the features of a story were all developed and tested, ready to be “delivered”.

4.8 ANSWERS TO IN-TEXT QUESTIONS

1. Describe the product development process. How does this process works?
2. Describe product types to the appropriate product development.
3. Identify the key factors affecting the design of products or service of given organization and possible benefit to be gained from good design.
4. Explain the operational layout of the business/ department under consideration. Discuss the salient features of the layout?

4.10 REFERENCES

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UNIT-III

LESSON 5
INVENTORY MANAGEMENT

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STRUCTURE

- 5.1 Learning Objectives
- 5.2 Introduction
- 5.3 Basic Concepts and Terminology
- 5.4 Inventory Modelling
- 5.5 Deterministic Inventory Models
- 5.6 Probabilistic Inventory Models
- 5.7 Selective Inventory Models
- 5.8 Multiple Choice Question
- 5.9 Summary
- 5.10 Glossary
- 5.11 Answers to In-Text Questions
- 5.12 Self-Assessment Questions
- 5.13 References

5.1 LEARNING OBJECTIVES

To familiarize students with the concept of inventory management, and its applications in different areas. To introduce the mathematical framework to develop and solve different types of inventory models.

Students completing this course will be able to gain an understanding of key concepts of inventory management and its role in various organizations. They would be able to apply selective inventory control techniques and understand its significance. Further students would learn to formulate, solve and determine optimal order quantity for various deterministic and probabilistic Inventory models.



5.2 INTRODUCTION

Inventory or Stock consists of all the goods and materials that are stored by an organization. It is a store of items that is kept for future use.

An inventory is a list of the items held in stock.

Further, according to Fred Hansmann Inventory is defined as *an idle resource of any kind provided that such resource has economic value*. If money makes the world go round, inventory makes logistics go round. The control and maintenance of inventory is a problem faced by all organizations in any sector of the economy. The problems of inventory are not only confined to profit making institutions. Inventories are common to agriculture, manufactures, wholesalers, retailers, hospitals, universities and national, state and local governments. Indeed, inventories are also relevant to the family unit in relation to food, clothing, medicines, etc. Since the inventory is essential in any modern industrial undertaking it plays a very significant role in the business operations of all enterprises.

Inventories are of vital interest not only to management but also to the stockholders who are concerned about any drastic changes that might occur from time to time. Inventories have a two-way effect on financial health of a firm. On the one hand inventories are an asset and represent stored value which when sold will generate revenue and hopefully will generate profit; while on the other hand inventories are usually a major investment being financed by equity or debt. Therefore, inventory levels directly affect the return on investment. Return is reduced by the cost of the capital (debt interest), while investment is increased by inventories. Here, the question arises that if the inventories are non-productive assets which earn no return and are subject to loss, pilferage, obsolescence and taxes, then why have inventories at all.

The control and maintenance of inventories of physical goods is a problem common to all enterprises in any sector of a given economy. Two fundamental questions that must be answered in controlling the inventory of any physical goods are when to order and how much to order.

Inventory management is the function responsible for all decisions about stock in an organization. It makes decisions for policies, activities and procedures to make sure the optimal amount of each item is held in stock.

Types of Inventories

An organization may hold different types of stock which may be classified as



- raw materials, which have arrived from suppliers and are kept until needed for operations;
- work in progress, stock which is currently being worked on;
- finished goods, which are waiting to be shipped to customers.

This is a fairly arbitrary classification, as one organization's finished goods are another organization's raw materials. Some organizations specially retailers and wholesalers have stocks of finished goods only, while others like manufacturers have all three types.

Another classification of stock describes its overall purpose:

- Cycle stock is the normal stock used during operations;
- Safety stock is a reserve of materials that is held for emergencies.

Purposes for keeping Inventories

The major purposes that Inventories serve, are of three kinds: transaction, precautionary, and speculative motives.

- The transaction motive results from the fact that it is not generally possible even in the case of certainty to synchronize perfectly the inflow and outflow of the commodity in question. Inventories are therefore held in order to compensate for the lack of synchronization and maintain operational smoothness.
- The precautionary motive results from the usual inability to predict demand exactly. Most of inventory problems are under risk; therefore inventories are built to act as a cushion between supply and demand.
- The speculative motive results when prices are rising or when there are expected changes in costs. Under these circumstances, profits may be made by holding inventories at the lower price until the higher price obtains. In usual inventory analysis the speculative motive is given the lesser importance. Apart from these motives another reason for maintaining inventories, a reason particularly important to retail establishments, is that sales and profits can be increased if one has an inventory of goods to display to customers.

5.3 BASIC CONCEPTS AND TERMINOLOGY

The basic concepts and terminology associated with an inventory system are follows:

- **Demand:** Inventories are usually held for ultimate purpose of satisfying the future demand, which may be forecasted on the basis of the recent past available data. The demand may be classified as *deterministic* or *probabilistic*.



In case of deterministic demand, the future demand for an item may be foreseen with an element of certainty. The demand considered in this restricted sense is only an approximation of reality. In actual practice, however, the demand may often be random which takes on values in accordance with a specific probability distribution. The parameters and the forms of distribution may also vary from time to time.

Further, the demand may also be categorized as *primary* or *secondary*. The primary demand results from individual or collective needs of human beings, where as secondary demand arises as a result from the organized activities directed towards transformation of raw materials into finished product.

However, in real practice, the demand of a product may depend upon various parameters viz. inventory-level, the frequency of advertisement, fluctuation in prices, price elasticity, etc.

- **Economic Order Quantity (EOQ):** It is the optimal size of an order when the total variable cost of an inventory system is minimal.
- **Order Cycle:** The time period between placements of two successive orders is referred to as an order cycle. The orders may be placed on the basis of the following two types of inventory review systems: *continuous* and *periodic*.

In Continuous Review system, a predetermined re-order level is set for each item and inventory level is continuously checked. When the stock level falls to the re-order level, a replenishment order is issued. The replenishment quantity is invariably the EOQ. This is also known as the two bin system. This divides the inventory into two parts and places it physically in two bins. Items are drawn from only one bin and when it is empty, a new order is placed. Demand is then satisfied from the second bin until the order is received. Upon receipt of the order, specified items are placed in the second bin and the remaining items are placed in the first bin. Every time this process is repeated.

In Periodic Review system the inventory levels are reviewed at equal time intervals and orders are placed at such intervals. The quantity ordered each time depends on the available inventory level at the time of review and not necessarily the EOQ.

- **Lead Time:** The time gap between the placement of the order and actual realization of the order is known as lead time. Lead time has two components viz. administrative lead-time from initiation of procurement action until the placing of an order, and the delivery lead time from placing of an order until the delivery of the ordered material.



- **Planning Horizon:** The time period over which the inventory level will be controlled is called the planning horizon. It may be *finite* or *infinite* depending upon the nature of the inventory system of the commodity.
- **Safety stock or Buffer stock:** In inventory control, it is very difficult to avoid the stock out situation due to many factors. To avoid the stock out position, one should maintain some extra stock, which is generally known as Buffer Stock, or Safety Stock. The level of this stock depends on the demand pattern and the lead-time. This should be judiciously calculated because, if we stock more the inventory carrying cost increases and there is chance of pilferage or theft. If we maintain less stock, we may have to face stock out position. The buffer stock or safety stock is generally the consumption at the maximum rate during the time interval equal to the difference between the maximum lead time and the normal (average) lead time or say the maximum, demand during lead time minus the average demand during lead time.

Different costs involved in Inventory System

Basically, inventories constitute an alternative to production in the future. To have available one unit of product tomorrow, one may either produce it or purchase it today and store it until tomorrow. The choice between the two procedures depends upon their relative profitability. The cost of an item is a parameter, which depends upon the item itself as well as the source. In fact, the cost incurred in operating an inventory system plays a major role in determining what the operating doctrine should be. The criterion for selecting the operating doctrine is that of profit maximization. For constructing the optimal operating doctrine, the costs included are the unit cost, ordering/setup cost, inventory carrying cost and shortage cost.

- **Unit cost** is the price charged by the suppliers for one unit of the item, or the cost to the organization of acquiring one unit. In general, it is fairly easy to find values for the unit cost by looking at the quotations or recent invoices from suppliers. Although, at times it becomes difficult to find an accurate unit cost, when different suppliers offer alternative products with varying conditions. On the other hand, when the company is producing the goods, it is fairly difficult to set a reliable production cost or to calculate a valid transfer price.
- The **ordering/setup cost** originates from the expenses of issuing a purchase order to an outside supplier or from internal production set up costs. This cost is usually assumed to vary directly with the number of orders or setups placed and not at all with the size of the order. The order cost includes such items as making requisitions, analyzing vendors,



writing purchase order, receiving materials, at times transportation cost, inspecting materials, following up orders and doing the paper work necessary to complete the transaction. Whereas the setup cost comprises the cost of changing over the production process to produce the ordered item. It usually includes preparing the shop orders, scheduling the work, pre-production setup, etc.

- The **inventory carrying cost** frequently referred as the holding cost or storage cost originates from many sources. This is the cost of holding one unit of an item in stock for one unit of time. It includes such item as capital costs, insurance, handling, storage, depreciation, shrinkage, obsolescence and deterioration. Capital cost reflects lost earning power or opportunity cost. If the funds were invested elsewhere, a return on investment would have resulted. Capital cost is a charge that accounts for this un-received return. Insurance coverage requirements are dependent on the amount to be replaced if the warehouse is destroyed. Insurance premiums vary with the size of the inventory investment. Obsolescence is the risk that an item will lose value because of shifts in style or customer's preference. Shrinkage is the decrease in inventory quantities over time from loss or theft.
- If an organization runs out of stock for an item and there is demand from a customer, then there is a shortage that has an associated cost which is known as **shortage cost** or stock out cost. The avoidance of this cost is the one of the basic reason why stocks are being held. The stock out cost results from *External* and *Internal* shortages. An external shortage occurs when a customer of the organization does not have his order filled; an internal shortage occurs when a group or department within the organization does not have its order filled. External shortages result in backorder costs, the loss of potential profit and loss of good-will, in terms of permanent loss of customers and loss of future sales. Internal shortages can result in lost production (ideal man and machine) and a delay in completion date. The stock out cost depends on the reaction of the customer to the out-of-stock condition. If the demand occurs for an item out-of-stock, the economic loss depends on whether the shortage is backordered, satisfied by substitution of another item or cancelled. In the first situation, the sale is not lost but only delayed a few days in shipment. Typically a company would institute an emergency expediting order to get the item as a backorder. The backorder case results in expediting costs, handling costs and frequently special shipping and packing costs. In the other situation, the sale is lost. In that case the stock out cost ranges from the profit loss on the sale to some un-specifiable loss of goodwill. The stock out cost can be extremely high if the missing item forces a production line to shut down.



5.4 INVENTORY MODELLING

Basically, inventory problems have been encountered by most of the organizations, but it was not until the twentieth century that analytical techniques were developed to study them. In twentieth century attentions were focused on the development of mathematical approaches designed to help the decision-making authorities in setting optimum inventory levels. Since then increasingly sophisticated analytical tools have been brought to bear on the problem of inventory management.

The earliest derivation of what is often called the *simple lot-size formula* was obtained by *Ford Harris* in 1915. The same formula also developed independently by *R.H. Wilson*. Since then it is often referred to as *Wilson formula*.

Now, we here discuss the methodology for modelling inventory situations which is based on four steps:

- i) Examine the inventory situation carefully listing characteristics and assumptions concerning the situation
- ii) Develop the total relevant cost equation in narrative form.
- iii) Transform the total annual cost equation from narrative into the shorthand logic of mathematics.
- iv) Optimize the cost equation by finding the optimum **for how much to order** (order quantity) **when to re-order** (re-order point) and the total relevant cost.

The inventory situations can be classified as either **deterministic (variable are known with certainty)** or **stochastic (variable are probabilistic)**.

5.5 DETERMINISTIC INVENTORY MODELS

In this section, we will discuss the basic inventory models when all the parameters are known with certainty.

5.5.1. Model 1: Basic Economic Order Quantity model (EOQ)

This section describes one of the standard analyses of inventory control. It shows how we can balance the various costs involved in the system to answer the question, 'How much to order?' The approach is to build a model of an imaginary inventory system and calculate the fixed order quantity that minimizes total costs. This optimal order size is called the economic order quantity (EOQ). The EOQ calculation is the most important analysis of inventory



control, and arguably one of the most important results derived in any area of operations management.

5.5.1.1. Assumptions and Notations

The EOQ model is applicable under the following assumptions and notations:

- the demand is known exactly, is continuous and is constant over time;
- all costs are known exactly and do not vary;
- replenishment rate is infinite;
- replenishment is instantaneous, so that entire ordered lot arrives in stock at the same time and can be used immediately;
- no shortages are allowed i.e shortage cost is very high
- lead time is negligible – so a delivery is made as soon as the order is placed;
- The model is for only one item.

Notations:

λ : demand rate per unit time

Q : order quantity

T : inventory cycle length

A : Cost of ordering (or procurement cost or replenishment cost). For manufacturing goods. it is known as set up cost.

q(t) : instantaneous inventory level at any time t

C : unit purchase cost of item

I : inventory carrying charge per unit per unit time and

IC : Cost of holding (also known as inventory carrying cost) is IC per unit per unit time.

5.5.1.2. MODEL FORMULATION:

The EOQ derivation uses a standard approach that is suitable for basic inventory control models. It has three steps, as follows:

1. Find the total cost of one inventory cycle.
2. Divide this total cost by the cycle length to get a cost per unit time.
3. Minimize this cost per unit time by differentiating the cost function with respect to the order quantity which is the decision variable.



Now we can describe the situation of inventory for one inventory cycle using figure 1.1, at time $t=0$, we place an order for a quantity, Q , which arrives instantly and is used at a constant demand rate, λ . And at the end of cycle at $t=T$, no stock remains and it is time to place another order. The cycle has a length T . We know that during the cycle the amount entering stock is Q , while the amount is leaving constantly at the rate of λ during the whole cycle (T) which is equal to $\lambda \times T$. These must be equal as the stock level at both the start and finish of the cycle is zero. amount entering stock in cycle = amount leaving stock in cycle

$$\text{so } Q = \lambda \times T$$

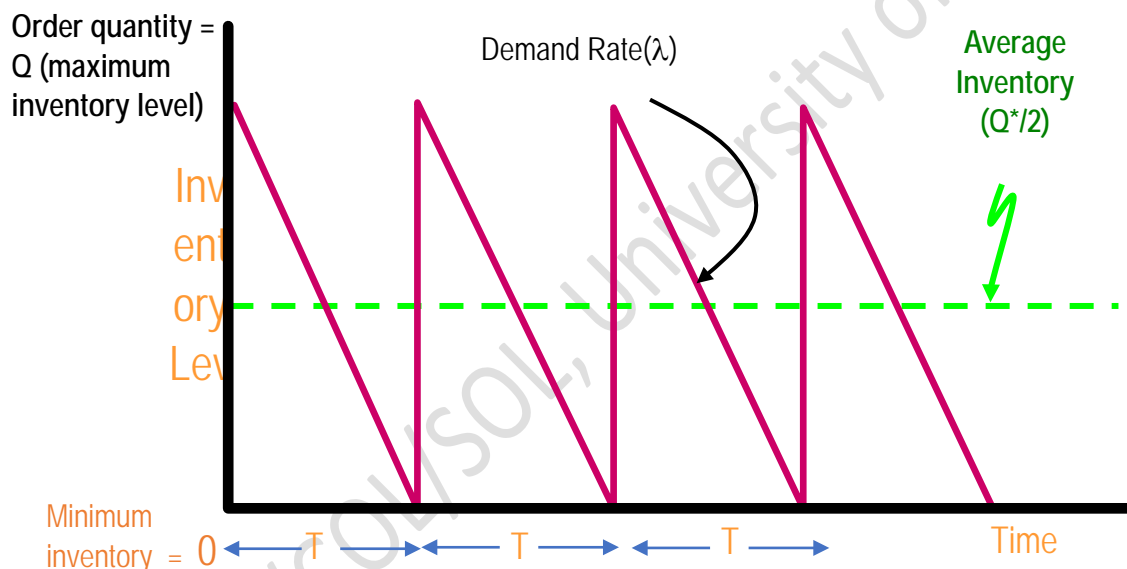


Fig 5.1: EOQ model behaviour

The first step of the analysis finds the total costs for a cycle, and we find this by adding the three separate components; purchase cost for Q units, ordering or set up, and inventory carrying cost (remembering there are no shortage costs).

Hence:

Total cost per cycle = purchase cost for Q units + ordering cost + inventory carrying cost

The various components of the Total cost are calculated as follows:

1. Purchase cost per cycle = CQ



2. Ordering cost per cycle = A

3. The inventory holding cost per cycle is calculated as

$$= \text{holding cost (IC)} \times \text{average stock level (Q/2)} \times \text{time held (T)} = \text{IC} \times \text{Q/2} \times \text{T}$$

Adding these three components, the total cost per cycle becomes as:

$$\text{Total cost per cycle} = \text{C Q} + \text{A} + (\text{IC Q T})/2$$

Now to determine the total cost per unit time (TC(Q)), we divide the above total cost per cycle by the cycle length, T, hence we get

$$\text{Total cost per unit time, TC(Q)} = \text{CQ/T} + \text{A/T} + \text{IC Q/2}$$

But we know that $Q = \lambda T$ or $\lambda = Q/T$

and substituting this in above cost function, we get:

$$\text{TC(Q)} = \text{C}\lambda + \text{A}\lambda / \text{Q} + \text{ICQ/2}$$

In the above cost function, demand and all costs are fixed, so the only variable on the right-hand side of this equation is Q. So we can see how the total cost per unit time varies with order quantity. The most convenient way of doing this is to plot each of the cost components separately against Q and then add them together (as shown in Figure 5.2).

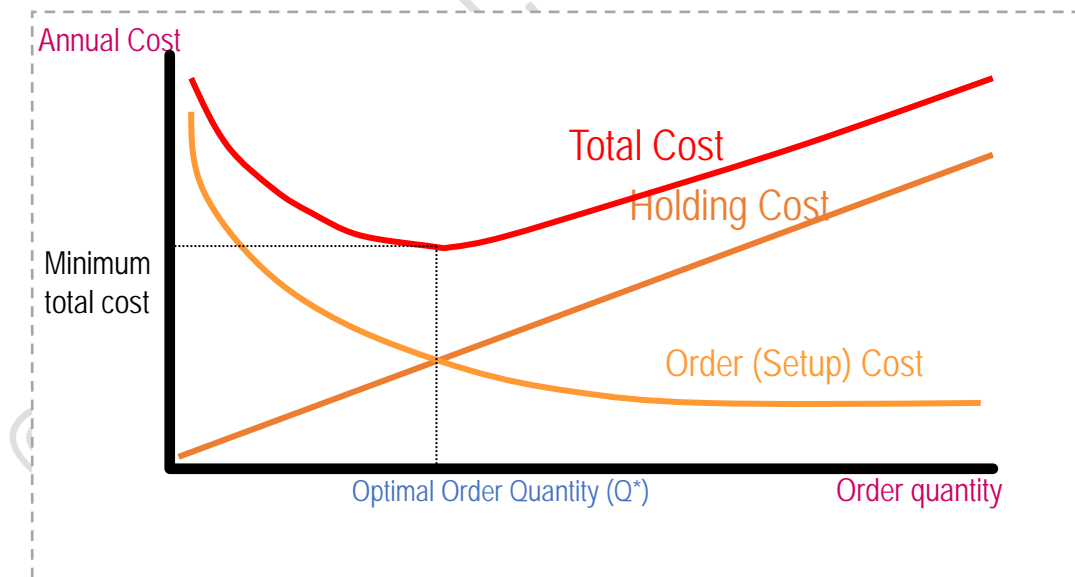


Fig 5.2: Relationship between total cost and order quantity



The unit cost component ($C \lambda$) is independent of order quantity and is ‘fixed’. The other two components vary with order quantity and form the ‘variable’ cost per unit time. In particular, the holding cost component rises linearly with Q while the reorder cost component falls as Q increases. Adding the three components together gives a total cost curve which is an asymmetric ‘U’ shape with a distinct minimum. This minimum corresponds to the optimal order size. With orders smaller than this, costs rise because of the higher reorder cost component; with orders larger than this, costs rise because of the higher holding cost component.

Now, we have to determine the best order quantity which gives the minimum cost per unit time. For this we differentiate the equation for $TC(Q)$ with respect to Q and set the result equal to zero:

$$\frac{dTC}{dQ} = -A \frac{\lambda}{Q^2} + \frac{IC}{2} = 0$$

and after rearranging, we get the optimal order quantity or economic order quantity (let us denote it by Q^*):

$$EOQ = Q^* = \sqrt{\frac{2A\lambda}{IC}}$$

This is the most important result and answers the question, ‘How much should we order?’ Now we can find the corresponding optimal length of the inventory cycle. We know that $Q = \lambda T$, and if we substitute Q^* for Q , we find the optimal cycle length (T^*) as

$$T^* = \frac{Q^*}{\lambda} = \sqrt{\frac{2A}{\lambda IC}}$$

The total number of orders per year ($=N$) is the reciprocal of the cycle period i.e.

$$N = \frac{\lambda}{Q^*}$$

We can also find the optimal cost per unit time, $TC^*(Q)$, by substituting the value for Q^* in total cost function $TC(Q)$. Further, the unit cost component is fixed, so we can concentrate on the last two terms which form the variable cost (VC). then

$$VC(Q) = A \lambda / Q + ICQ / 2$$



Substituting Q^* in this, we get optimal variable cost as

$$VC^*(Q) = \sqrt{2A\lambda IC}$$

And the optimal total cost is given as,

$$TC^*(Q) = C\lambda + \sqrt{2A\lambda IC}$$

Economic Order Quantity by Trial and Error Method: Now we would find the EOQ formula by trial and error method to understand the average inventory concept. The steps involved are:

1. Select the number of possible lot sizes to purchase.
2. Determine total cost for each lot size chosen.
3. Calculate and select the order quantity that minimizes total cost.

While working the problems, we will consider Average inventory concept. This is because, the inventory carrying cost which is the cost of holding the inventory in the stock, cannot be calculated day to day as and when the inventory level goes on decreasing due to consumption or increases due to replenishment. Consider a simple example and see how this will work out.

5.5.1.3 Worked examples

Problem 1. A customer orders from a manufacturing company shipment of parts at a uniform rate of 2400 parts per year. The company makes the parts on a machine that can produce any number of parts at a time. The cost of setting up the machine for a production run is Rs. 42/-. The cost of carrying inventory is Rs. 0.56 per part per year. No shortages are allowed to occur. The manufacturing company's problem is to find how many parts should be produced for each production run.

Solution:

Listing the values we know in consistent units:

Demand rate = $\lambda = 2,400$ parts a year

Set up cost = $A = \text{Rs. } 42/-$ an order

Holding cost = $IC = 0.56$ a unit a year

I. Solution using direct formula:

Substituting these figures into the economic order quantity equation gives:



- a. Optimal order quantity, EOQ (Q^*) = $\sqrt{\frac{2A\lambda}{IC}} = \sqrt{\frac{2 \cdot 42 \cdot 2400}{0.56}} = 600$ parts
- b. Optimal Cycle length (T^*) = $\frac{Q^*}{\lambda} = \sqrt{\frac{2A}{\lambda IC}} = 600/2400$ year = 0.25 year (3 months)
- c. Number of orders per year (N^*) = $\frac{\lambda}{Q^*} = 2400/600 = 4$ orders per year
- d. Optimal variable cost = $C^*(Q) = \sqrt{2A\lambda IC} = IC \cdot Q^* = 0.56 \cdot 600 = 336/-$ per year

Hence, the manufacturing company should produce 600 parts for each production run after every 3 months.

II. Solution using Trial and error method:

Variation of various costs for different order quantity is shown in Table 1.1.

Order Quantity(q)	Avg Inventory	Carrying Cost/year	Avg no of orders/year	Replenishment cost/year	Total costs/year
100	50	28	24	1008	1036
200	100	56	12	504	560
300	150	84	8	336	420
400	200	112	6	252	364
500	250	140	4.8	202	342
600	300	168	4	168	336
700	350	196	3.4	144	340
800	400	224	3	126	350
900	450	252	2.6	112	364
1000	500	280	2.4	108	388

Table 1.1: Total Cost per year for various Order quantity

Observe the last column. The total cost goes on reducing and reaches the minimum of Rs. 336/- and then it increases. Also as lot size goes on decreasing, the carrying cost decreases



and the ordering cost goes on increasing. Hence we can say the optimal order quantity is 600 units and optimum number of orders is 4 per year. See at the optimal order quantity of 600 units, **both ordering cost and inventory costs are same.** Hence we can say that the **optimal order quantity occurs when ordering cost is equal to the inventory carrying cost.** This we can prove mathematically and illustrate by a graph. It is not always easy to work for economic order quantity by trial and error method as it is difficult to get exact quantity and hence we may not get that ordering cost and inventory carrying costs equal. Hence it is better to go for mathematical approach which we have already discussed.

Problem 2.

The demand for an item is 8000 units per annum and the unit cost is Re.1/-. Inventory carrying charges of 20% of average inventory cost and ordering cost is Rs. 12.50 per order. Calculate optimal order quantity, optimal order time, optimal inventory cost and number of orders.

Solution: Here demand rate, $\lambda = 8000$ units/year, unit cost, $C = \text{Re.1/-}$,

Inventory carrying charge per year, $I = 20\%$ of average inventory or 0.20,

And hence, Inventory carrying cost per year per unit = $I * C = 0.2 * 1 = \text{Rs. } 0.2/\text{unit/year}$

Ordering cost, $A = \text{Rs. } 12.50$ per order.

- a. Optimal order quantity, $EOQ (Q^*) = \sqrt{\frac{2A\lambda}{IC}} = 1000$ units
- b. Optimal Cycle length $(T^*) = \frac{Q^*}{\lambda} = \sqrt{\frac{2A}{\lambda IC}} = 1000/8000 \text{ year} = 1/8 \text{ of a year. (45.6 days)}$
- c. Number of orders per year $(N^*) = \frac{\lambda}{Q^*} = 8000/1000 = 8$ orders per year
- d. Optimal variable cost = $C*(Q) = \sqrt{2A\lambda IC} = IC*Q^* = 0.2*1000 = 200/-$ per year
- e. Total cost per year = optimal variable cost + purchase cost $(C\lambda)$

= Rs. 200 + Rs. 8000 = Rs. 8200/-

5.5.1.4.Reorder Level

All of the above has talked about HOW MUCH to order, Reorder level tell WHEN to order.



Reorder level is the amount of inventory left at which one should place the next order. Basically, it is the lead time demand, therefore, the basic reorder level (R) equation is

$$R = dL$$

where d = demand rate and L = lead time

Problem 1. For a fixed order quantity system find the EOQ and Reorder level(ROL) for an item with the following data: Annual demand (λ) = 10000 units, Unit cost(C) = Rs. 1.00, Inventory Carrying cost(IC) = Rs. 0.24 per unit, Ordering cost(A) = Rs. 12/- per order, Lead time (L) = 15 days.

Solution:

a. Optimal order quantity, EOQ (Q^*) = $\sqrt{\frac{2A\lambda}{IC}} = 1000$ units

b. Reorder level = demand rate * lead time = $10000 * 15 / 365 = 411$ units

Hence, one should place order of 1000 units whenever stock level arrives at 411 units.

5.5.2. Economic Order Quantity with finite rate of replenishment or production

In previous discussed section 5.5.1, we have assumed that the replenishment rate is infinite and the items are procured in one lot. But in real practice, particularly in manufacturing model, items are produced on a machine at a finite rate per unit of time; hence we cannot take the replenishment rate as infinite. Here we assume that the replenishment rate is finite say at the rate of Ψ units per unit of time and greater than the demand rate. ($\Psi > \lambda$)

Under all the assumption of Model 1 except infinite replenishment rate (Ψ), the economic order policy in this case can be determined using the same approach as of Model 1. The optimal parameters are given as:

$$\text{Optimal order quantity, EOQ (} Q^* \text{)} = \sqrt{\frac{2A\lambda \Psi}{IC (\Psi - \lambda)}}$$

$$\text{Optimal Cycle length (} T^* \text{)} = \frac{Q^*}{\lambda} = \sqrt{\frac{2A \Psi}{\lambda IC (\Psi - \lambda)}}$$

$$\text{Number of orders per year (} N^* \text{)} = \frac{\lambda}{Q^*}$$

$$\text{Optimal variable cost per unit time} = C^*(Q) = \sqrt{2A IC \lambda \frac{\Psi}{\Psi - \lambda}}$$



5.5.3. Economic Order Quantity with fully backlogged shortages

If an organization runs out of stock for an item and there is demand from a customer, then there is a shortage that has an associated cost which is known as **shortage cost** or stock out cost. The avoidance of this cost is the one of the basic reason why stocks are being held.

In such case if the customer is agree to wait, the organization can fulfil his order soon after the next lot of inventory is received and if the customer is not ready to wait, the organization would lost the order. The first situation is known as back-logged or back order situation and the second one is known as shortages or lost sales situation.

Here we are considering first situation when the shortages are allowed and fully backlogged, and the shortage cost is ΠC per unit per unit time.

Under all the assumption of Model1 except no shortages allowed, the economic order policy in this case can also be determined using the same approach as of Model 1. The optimal parameters are given as:

$$\text{Optimal order quantity, EOQ (Q*)} = \sqrt{\frac{2A\lambda}{IC} \frac{(IC+\Pi C)}{\Pi C}}$$

$$\text{Optimal amount of shortages, (S*)} = \sqrt{\frac{2A\lambda IC}{(IC+\Pi C) \Pi C}}$$

$$\text{Optimal Cycle length (T*)} = \frac{Q^*}{\lambda} = \sqrt{\frac{2A}{\lambda IC} \frac{(IC+\Pi C)}{\Pi C}}$$

$$\text{Number of orders per year (N*)} = \frac{\lambda}{Q^*}$$

$$\text{Optimal variable cost per unit time} = C^*(Q) = \sqrt{2A IC \lambda \frac{\Pi C}{(IC+\Pi C)}}$$

5.5.4. Economic Order Quantity for finite rate of replenishment and fully backlogged shortages

In previous discussed models in section 5.5.2 and 5.5.3, we assume that the replenishment rate is finite and shortages are allowed and fully backlogged respectively.

Now by combining these two models, we can determine optimal ordering policy for finite rate of replenishment and fully backlogged shortages. The optimal parameters are given as:

$$\text{Optimal order quantity, EOQ (Q*)} = \sqrt{\frac{2A\lambda}{IC} \frac{(IC+\Pi C)}{\Pi C} \frac{\Psi}{(\Psi-\lambda)}}$$



$$\text{Optimal amount of shortages, } (S^*) = \sqrt{\frac{2A\lambda IC (\Psi - \lambda)}{(IC + \Pi C) \Pi C \Psi}}$$

$$\text{Optimal Cycle length } (T^*) = \frac{Q^*}{\lambda}$$

$$\text{Number of orders per year } (N^*) = \frac{\lambda}{Q^*}$$

5.6. PROBABILISTIC INVENTORY MODELS

Some finished goods inventories have very short selling seasons. Items such as holiday decorations, Christmas trees, long-stemmed red roses, newspapers, and magazines are good examples. These products typically have a high value for a relatively short period; then the value diminishes dramatically to either zero or some minimum salvage value. For example, week-old newspapers are inexpensive compared to newspapers offering fresh news. The question is how many of these products you should order to maximize your expected profit.

In probabilistic inventory models, demand is considered as a random variable with known probability distribution. Now demand can be instantaneous or uniform over time. Further, demand can also be discrete or continuous.

5.6.1. Single Period Model:

But here we would study only instantaneous demand rate inventory model for single period only.

The formula to find the optimal EOQ (Q^*) for discrete and instantaneous demand is

$$\sum_{x=0}^{Q^*-1} p(x) \leq \frac{\pi c}{IC + \Pi c} \leq \sum_{x=0}^{Q^*} p(x)$$

where $p(x)$ is probability mass function of demand x ,

IC is inventory carrying cost

Πc is shortage cost

5.6.2. Worked Examples

Problem 1: Theodore's gift shop places orders for Christmas items during a trade show in July. One item to be ordered is a dated sterling silver tree ornament. The ornament will sell for \$80. The best estimate for demand is:



Demand	5	6	7	8
Probability	0.2	0.25	0.3	0.25

The ornaments cost \$55 when ordered in July. Ornaments unsold by Christmas are marked down to half price and always sell during January. How many ornaments should be ordered?

Solution:

Here, Inventory carrying cost (Ic) = Unit Purchase price- Unit Salvage value
 = \$55 per ornament- \$40 per ornament
 = \$15 per ornament

And Shortage cost (πc) = Unit Selling price-Unit Purchase price
 = \$80 per ornament - \$55 per ornament
 = \$25 per ornament

since ratio is = πc / (πc+Ic) = 25/(25+15)=5/8=0.625

The formula to find the optimal Q is as

$$\sum_{x=0}^{Q^*-1} p(x) \leq \frac{\pi c}{Ic + \pi c} \leq \sum_{x=0}^{Q^*} p(x)$$

And

Demand (x)	5	6	7	8
Probability (p(x))	0.2	0.25	0.3	0.25
Cumm. Prob. $\sum_{x=0}^{Q^*} p(x)$	0.2	0.45	0.75	1.00

$$\sum_{x=5}^{Q^*-1=6} p(x) \leq 0.625 \leq \sum_{x=5}^{Q^*=7} p(x)$$

i. e. 0.45 ≤ 0.625 ≤ 0.75

hence, optimal order quantity is, Q *= 7

Problem 2: A news vendor boy purchases paper for Rs.3 each and sells them for Rs.7 each. He can't return the unsold newspapers. Daily demand has the following distribution:

X	30	31	32	33	34	35	36
P(x)	0.10	0.20	0.30	0.20	0.10	0.05	0.05



If each day's demand is independent of the previous day, how many newspapers he should order.

Solution: Here, $I_c = \text{Rs. } 3$ and $\pi c = \text{profit loss} = 7-3 = \text{Rs. } 4$

And ratio, $\pi c / (I_c + \pi c) = 4 / (3+4) = 4/7 = 0.571$

Now find the cumulative probabilities as

X	30	31	32	33	34	35	36
P(x)	0.10	0.20	0.30	0.20	0.10	0.05	0.05
$\sum P(x)$	0.10	0.30	0.60	0.80	0.90	0.95	1.00

Now using the formula,

$$\sum_{x=0}^{Q^*-1} p(x) \leq \frac{\pi c}{I_c + \pi c} \leq \sum_{x=0}^{Q^*} p(x)$$

we have

$$\sum_{x=30}^{31} p(x) \leq 0.571 \leq \sum_{x=30}^{32} p(x)$$

hence,

$$0.3 \leq 0.571 \leq 0.60 \quad \text{is satisfied for } Q^*=32$$

Newsvendor boy should order 32 newspapers to minimize this cost.

5.7 SELECTIVE INVENTORY CONTROL

Selective Inventory Control emphasises on **variations in methods of control** from item to item based on selective basis. It is an effective starting point for designing **cost-effective inventory control** in an organization. We cannot apply uniform control since it is **expensive** and gives a **diffused effect**.

There are many techniques to classify inventory items depending upon various criteria i.e demand rate, price, availability of raw material, usage, criticality etc. Some major techniques are shown in Figure 5.7.1 and also summarized in Table 5.7.1.

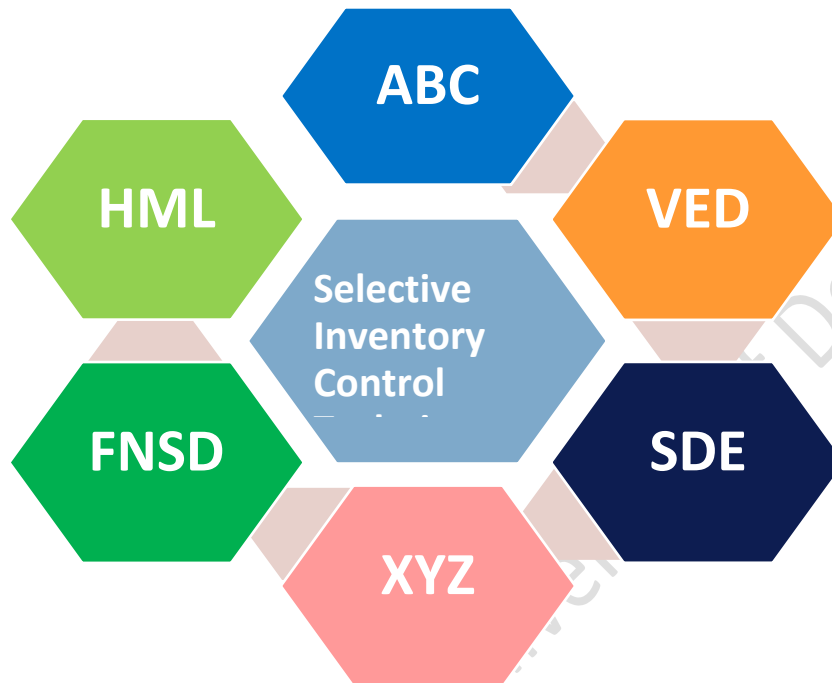


Fig. 5.7.1: Major Selective Inventory Control Techniques

Table. 5.7.1: Selective Inventory Control Techniques

CLASSIFICATION	FULL FORM	CRITERION
ABC	Always Better Control	Usage Value (ie. Consumption per Period x Unit price)
HML	High Medium Low	Unit Price
FNSD	Fast Normal Slow & Dead	Usage Rate
SDE	Scarce Difficult Easy	Procurement Difficulty
VED	Vital Essential Desirable	Criticality of the Item or Loss of Production
XYZ		Variability of demand

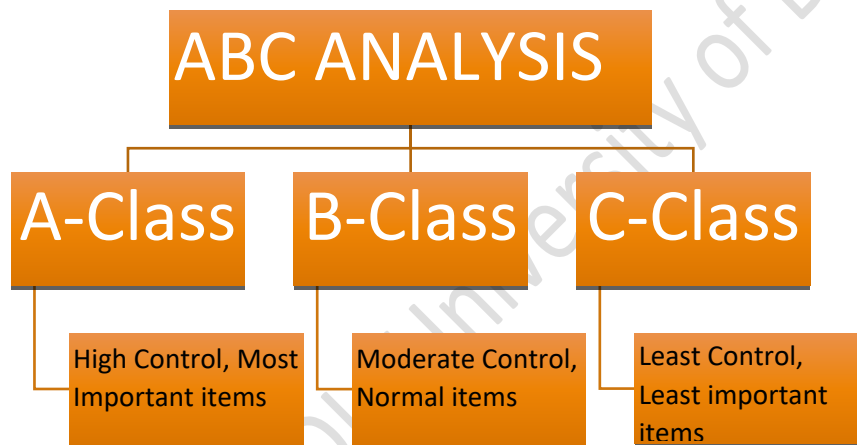
Now we will explain these technique in detail.



5.7.1.ABC ANALYSIS

ABC analysis is a system for inventory control used throughout **materials and distribution management**. It provides a **mechanism for identifying different categories** of stock that will require different management and controls.

The ABC analysis suggests that inventories of an organization are **not of equal value**. Thus, the inventory is grouped into **three categories (A, B, and C)** in order of their estimated importance.



CATEGORIZATION

Item A

In the ABC model of inventory control, items categorized under A are goods that register the highest value in terms of annual consumption. It is interesting to note that the top 70 to 80 percent of the yearly consumption value of the company comes from only about 10 to 20 percent of the total inventory items. Hence, it is crucial to prioritize these items.

- a) These are subjected to strict inventory control and are given highly secured areas in terms of storage.
- b) These goods have a better forecast for sales.
- c) These are also the items that require frequent reorders on a daily or a weekly basis.
- d) They are kept as a priority item and efforts are made to avoid unavailability or stock-out of these items.



Item B

These are items that have a medium consumption value. These amount to about 30 percent of the total inventory in a company which accounts for about 15 to 20 percent of annual consumption value.

- a) These items are not as important as items under section A or as trivial as items categorized under C.
- b) The important thing to note is that since these items lie in between A and C, they are monitored for potential inclusion towards category A or in a contrary situation towards category C.

Item C

The items placed in this category have the lowest consumption value and account for less than 5 percent of the annual consumption value that comes from about 50 percent of the total inventory items.

- a) These items are manufactured less often and follow the policy of having only one of its item on hand or in some cases they are reordered when a purchase is actually made.
- b) Since these are low demand goods with a comparatively higher risk of cost in terms of excessive inventory, it is an ideal situation for these items to stock-out after each purchase.

Category A	Category B	Category C
This is the smallest category and consists of the most important stock items. These are the products that contribute heavily to our overall profit without eating up too much of our resources.	It will generally be slightly larger in terms of volumes of SKUs and will usually be made up of products of less value. 'B' items are important, but of course less important than 'A' items and more important than 'C' items. Therefore, 'B' items are inter group items .	This will typically be the largest category where products will contribute the least to your business's bottom line. 'C' items are marginally important .



Steps to perform ABC Analysis

1. Obtain list of items along with their unit cost and the annual consumption.
2. Determine Annual Usage Value = Unit Cost X No. of Units
3. Arrange them in descending order of Usage Value.
4. Express the value for each item as a % of the Aggregate Usage Value and Cumulate it.
5. Obtain the % value of each item.
6. Using the Cum. % value of items & Cum.% usage Value, plot the curve which is known as Pareto Curve. The graph is divided approximately into three segments, where the curve sharply changes its shape. This indicates the three segments A, B and C.

5.7.2. Worked Example

A small firm X inventories only ten items, but decide to setup an ABC inventory system. The company records provide the information shown below.

Part no.	1	2	3	4	5	6	7	8	9	10
Demand per year	1100	600	100	1300	100	10	100	1500	200	500
Unit Cost	20	400	40	10	600	250	20	20	20	10

Solution:

First, calculate annual usage value (demand * unit cost) and then place them in descending order in Table 7.2.2:

Part No.	AUV in Descending order	Cumulative AUV	Cumulative % AUV	Cumulative % of Items	Class
2	240000	240000	62.75	10	A
5	60000	300000	78.43	20	A
8	30000	330000	86.27	30	B
1	22000	352000	92.03	40	B



4	13000	365000	95.42	50	B
10	5000	370000	96.73	60	C
3	4000	374000	97.77	70	C
9	4000	378000	98.82	80	C
6	2500	380500	99.48	90	C
7	2000	382500	100	100	C

Table 5.7.2: Steps of ABC Analysis

Now, draw a graph by taking cumulative % items on x-axis and cumulative % usage value on y-axis. Divide the graph into three segments, where the curve sharply changes its shape. The three segments are A, B and C class items as shown in Fig 5.7.2.

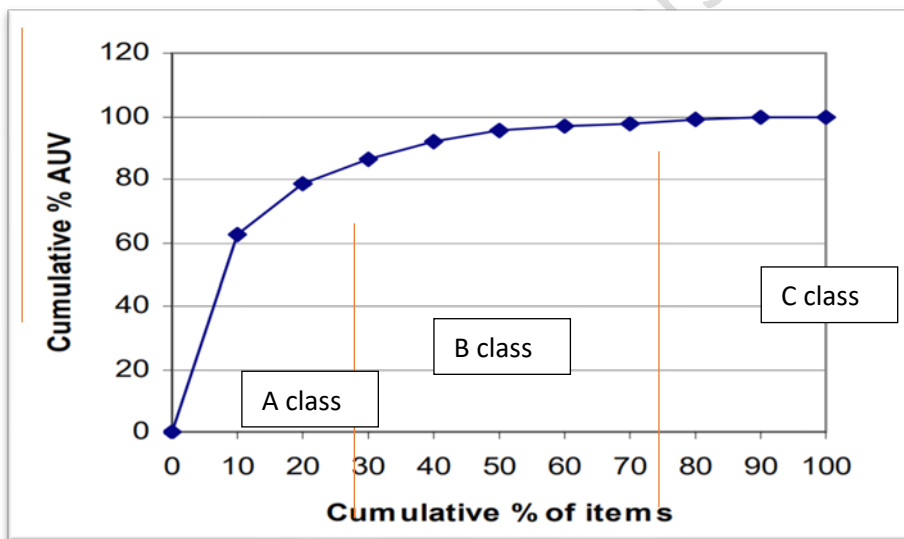


Figure 5.7.2

Result of ABC analysis is summarised as

Cumulative % AUV	Cumulative % of Items	Class (items)
78.43	20	A (item 2,5)
16.99	40	B(item 1,4,8,10)
4.58	40	C(item 3,6,7,9)



5.7.2. HML Analysis

HML analysis is very similar to the ABC Analysis, the difference being instead of usage value, the price criterion is used. In their classification, the items used by the company are arranged in descending orders of their unit price. After this, the management of the company uses its discretion and judgment to decide the cut off lines for deciding the three categories.

- **H CLASS:** These are the costly item and are generally 10-15% of total items.
- **M CLASS:** These items are low cost item as compared to H class items, this are generally 20-25% of total items.
- **L CLASS:** These items are low class item and generally 60-70% of total items.

5.7.3. FNSD Analysis

FNSD analysis is done with a view to **control obsolescence of consumable spare parts** and takes into account the consumption pattern of the items. In this exercise, **quantity** and **consumption rates** of all items are analysed and accordingly classified. Such classifications help in arranging (storing) the items in the stores. There are 4 categories:

- **Fast Moving items:** Items that are consumed quickly. These items are properly ordered to avoid 'stock-out' of such items.
- **Normal Moving items:** Items which are exhausted over a period of a year or so. These items are reviewed at regular intervals and orders for restoring shall be made as per a planned schedule.
- **Slow Moving items:** Items which are not consumed frequently but are expected to be exhausted over a period of two years or more. Stock of slow moving items of stores are reviewed very carefully to avoid over stocking of such items.
- **Dead items:** Items and the consumption of such items is nil. Dead stock items are taken as obsolete items which have become outmoded and have no further use.

5.7.4. SDE Analysis

The criterion for this analysis is the availability of the materials in the market. In industrial situations where certain materials are scarce (specially in a developing country like India) this analysis is very useful and gives proper guideline for deciding the inventory policies.

- **S:** Refers to **scarce items**, items which are in short supply. Usually these are raw materials, spare parts and imported items.



- D: Stands for **difficult items**, items which are not readily available in local markets and have to be procured from faraway places, or items for which there are a limited number of suppliers; or items for which quality suppliers are difficult to get.
- E: Refer to items which are **easily available** in the local markets.

5.7.5.VED Analysis

It attempts to classify the items used into three broad categories, namely Vital, Essential, and Desirable. The analysis classifies items on the basis of their criticality for the industry or company. VED Analysis is very useful to categorize items of spare parts and components. A vital equipment is one, which feeds a battery of equipment downstream.

- **Vital:** Vital category items are those items without which the production activities or any other activity of the company, would come to a halt, or at least be drastically affected.
- **ESSENTIAL:** Essential items are those items whose stock – out cost is very high for the company.
- **DESIRABLE:** Desirable items are those items whose stock-out or shortage causes only a minor disruption for a short duration in the production schedule. The cost incurred is very nominal.

5.7.6. XYZ Analysis

The XYZ analysis is a way to classify inventory items according to **variability of their demand**. For XYZ analysis to work, it's vital to understand and apply an appropriate time span for assessing demand volatility. The variability is measured by the **coefficient of variation (C.V.)**

- **X CLASS: Very little variation**, characterised by steady turnover over time, future demand can be reliably forecast, ($CV \leq 0.3$)
- **Y CLASS: Some variation**, Variability in demand can be predicted to an extent, It's more difficult to forecast demand accurately, ($0.3 < CV \leq 0.56$)
- **Z CLASS: The most variation**, Demand for Z items can fluctuate strongly or occur sporadically, There are no trends or predictable causal factors, making reliable demand forecasting impossible, ($CV > 0.56$)



5.8. Multiple Choice Questions

- Which of the following is not an assumption underlying the fundamental problem of EOQ?
 - Demand is known and uniform
 - Lead time is not zero
 - Holding cost per unit time is constant
 - Stock-out (shortages) are not permitted.
- Re-order level of an item is always
 - Less than its minimum stock
 - More than its minimum stock
 - More than its maximum stock
 - Less than its maximum stock.
- The production department of a company requires 3600 kg of raw material for manufacturing a particular item per year. It has been estimated that the cost of placing an order is Rs 36 and the cost of carrying inventory is 20% of the investment in the inventories. The price is Rs. 10 per kg. Then the EOQ will be,
 - 360 kg per order
 - 350 kg per order
 - 300 kg per order
 - None of the above
- For the inventory model with planned shortages, the optimal order quantity results in
 - Annual holding cost = annual ordering cost.
 - Annual holding cost = annual backordering cost.
 - Annual ordering cost = annual holding cost + annual backordering cost.
 - Annual ordering cost = annual holding cost — annual backordering cost.



5. Which of the following is not implied when average inventory is $Q/2$, where Q is the order quantity?
 - (A) An entire order quantity arrives at one time.
 - (B) The previous order quantity is entirely depleted when the next order arrives.
 - (C) An order quantity is depleted at a uniform rate over time.
 - (D) Backorders are permitted.
6. For the EOQ model, which of the following relationships is incorrect?
 - (A) As the order quantity increases, the number of orders placed annually decreases.
 - (B) As the order quantity increases, annual holding cost increases.
 - (C) As the order quantity increases, annual ordering cost increases.
 - (D) As the order quantity increases, average inventory increases.
7. Which of the following is not considered to be a part of inventory holding costs?
 - (A) opportunity cost of blocked capital
 - (B) maintenance cost of warehouse used for this inventory
 - (C) obsolescence
 - (D) cost of postage and telephone for placing order
8. Annual demand for an item is 12100 units. Ordering cost is Rs. 2000 per order and the holding cost is Rs. 10 per unit per annum. What is the economic order quantity?
 - (A) 2200
 - (B) 2100
 - (C) 2000
 - (D) 2300
9. Inventory carried for the purpose of providing flexibility to each decision-making unit to manage its operations independently is known as
 - (A) Seasonal inventory
 - (B) Safety inventory
 - (C) Decoupling inventory
 - (D) Pipeline inventory



10. ABC analysis is an inventory control technique in which:
- (A) Inventory levels are maintained
 - (B) Inventory is classified into A, B and C category with A being the highest quantity, lowest value.
 - (C) Inventory is classified into A, B and C Category with A being the lowest quantity, highest value
 - (D) Either b or c.
11. Inventory carried for the purpose of providing flexibility to each decision-making unit to manage its operations independently is known as
- (A) Seasonal inventory
 - (B) Safety inventory
 - (C) Decoupling inventory
 - (D) Pipeline inventory
12. _____ is used primarily for control of spare parts.
- (A) ABC Analysis
 - (B) JIT Inventory System
 - (C) VED Analysis
 - (D) Perpetual Inventory System
13. The ordering cost per order and average unit carrying cost are constant, and demand suddenly falls by 75 % then EOQ will:
- (A) Decreases by 50 %,
 - (B) Does not change
 - (C) Increases by 50 %,
 - (D) Decreases by 40%
14. If shortage cost is infinity, then
- (A) Shortages are not allowed;
 - (B) Inventory carrying is not allowed,
 - (C) Ordering cost is zero,
 - (D) Purchase cost = Inventory Carrying cost.



15. The lead-time is the time
- (A) To place orders for materials,
 - (B) Time of receiving materials,
 - (C) Time between receipt of material and using materials
 - (D) Time between placing the order and receiving the materials

5.9 SUMMARY

This chapter presents the basics of inventory management, solve and formulate the basic deterministic EOQ model. Probabilistic inventory model (Single period model) for one item is also discussed along with numerical examples. Further, various selective inventory control techniques for classification of inventory into various categories is also presented. Numerical example for ABC analysis is also shown.

5.10 GLOSSARY

ABC Analysis – a method of classifying inventory items depending on demand and unit cost

Backorder – a situation where the demand of a customer cannot be met from stock, but the customer waits for the good to come into stock

Customer – anyone that creates demand for goods

Demand – amount of goods wanted by customers

Economic Order Quantity – order size minimizing simple inventory system costs

Holding Cost – the cost of keeping the unit of an item in stock for specific time

Inventory – idle stock having economic value

Item – a single article held in stock

Lead Time – the difference between time of order and time of delivery

Lost Sales – when customer withdraws their demand because it cannot be met

Order – a message from an organization to a supplier asking for delivery of items

Pareto Analysis – ABC analysis

Pipeline Stock – items that are being moved from one place to another



Price – amount charged by seller for an item

Reorder level – inventory level at which next order should be placed

Replenishment – addition of items to stock as replacement for used up units

Replenishment Rate – the rate at which materials are added to stock

Safety Stock – extra stock kept to cover for unexpected circumstances

Scientific Inventory Control – finding optimal ordering policies and stock levels using mathematical models

Shortage – occurs when customer demand cannot be met from stock

SKU – stock keeping unit

Warehouse – a location where goods are held

Work in Process – the units being worked on currently

5.11 ANSWERS TO IN-TEXT QUESTIONS

Answers of MCQ in section 5.8 :

1. B
2. B
3. A
4. C
5. D
6. C
7. D
8. A
9. C
10. C
11. C
12. C
13. C
14. A
15. D



5.12 SELF-ASSESSMENT QUESTIONS

1. The aim of inventory management can be summarized as “achieving a specified level of customer service at minimum cost”. To what extent do you think that this is true. What costs are incurred by holding stock? How would you set about finding these? Why are shortage costs so difficult to find?
2. What assumptions are made in calculating an economic order quantity (EOQ)? What is the EOQ? If we place orders that are larger than the EOQ, why does the total cost rise? What does the variable cost per unit time vary with? If we use the economic order quantity, which is bigger, the reorder cost component or the holding cost component?
3. What is the optimal level of inventory? Explain the kind of problems faced when very high or very low inventory is maintained for items? Why is the ABC classification of items done? Is there a scope of applying the ABC classification of inventory in the modern retail stores?
4. What is a ‘single period model? Give some examples where single period models might be used. At the beginning of December Southern Conifers Limited employs a contractor to cut enough trees to meet the expected demand for Christmas trees. They sell these to a local wholesaler in batches of 100. Over the past few years the demand has been as follows.

Batches	1	2	3	4	5	6	7	8	9
Probability	0.1	0.1	0.2	0.2	0.1	0.1	0.1	0.1	0

If it costs £16 to cut and trim a tree that sells for £25, how many trees should the company cut down?

5. Demand for an item is constant at 1,000 units a year. Unit cost is £50, reorder cost is £100, holding cost is 25 per cent of value a year and no shortages are allowed. Describe an optimal inventory policy for the item. What order size will give a variable cost within 10 per cent of optimal? What is the cost if suppliers only make deliveries of 200 units?
6. Vishal Computer Sales is a leading dealer of computer servers and networking devices. Servers are expensive machines and, therefore, the company follows a backordering policy. The carrying cost is Rs. 50000 per server per year and the ordering cost is Rs.1200per order. The cost of shortage per server is estimated at Rs



20,000 per year. The annual demand of servers is 300 units. Find (a) the optimal order quantity, (b) the maximum shortage level, (c) the maximum inventory level and (d) If the lead time is 7 days then find the reorder level.

7. Classify the following items according to ABC classification.

Item No.	Annual Usage (Units)	Unit cost(in Rs.)
1	100,000	5
2	2,600	35
3	420	79
4	13,600	68
5	210	800
6	670	2,300
7	76	450
8	400	6
9	6,100	92
10	250,000	3

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LESSON 6

AGGREGATE PRODUCTION PLANNING, MASTER PRODUCTION SCHEDULE AND MATERIAL REQUIREMENTS PLANNING

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STRUCTURE

- 6.1 Learning Objectives
- 6.2 Introduction
- 6.3 Aggregate Production Planning (APP)
- 6.4 Master Production Schedule (MPS)
- 6.5 Material Requirements Planning (MRP)
- 6.6 Summary
- 6.7 Glossary
- 6.8 Answers to In-Text Questions
- 6.9 Self-Assessment Questions
- 6.10 References
- 6.11 Suggested Readings

6.1 LEARNING OBJECTIVES

After reading the unit, students will be able to

- Describe the concept of Aggregate production planning (APP), Master production schedule (MSP) and Material requirements planning (MRP) Achieve financial goals by reducing overall variable cost.
- Do maximum utilization of the available production facility.
- Define the process of Material requirements planning.
- Create an optimized and efficient production schedule that will ensure for on-time delivery.
- Understand the Benefits of master production scheduling.



6.2 INTRODUCTION

A crucial aspect of corporate planning is aggregate planning. The company's key product lines' production output levels are shown in the aggregate production plan. The department's strategies for sales and marketing must be integrated with the overall plan. The aggregate production plan must take into account both current and future inventory levels of the products and their component parts because it comprises products that are presently being produced. Since the overall plan will also incorporate any new items that are currently being developed. The marketing strategies and campaigns for both existing and new items need to be balanced against the company's entire capacity resources.

The aggregate plan's production volumes for the key product lines must be translated into the master production schedule, a very detailed schedule of individual goods. (MPS). It is a list of the goods to be produced, along with information on when and how much of each should be produced.

The integrated information technology (IT) systems that sought to increase business productivity by utilising computers and software technologies were first introduced as material requirements planning. The first mainframe computer-based MRP inventory management systems emerged in the 1940s and 1950s, extrapolating data from a bill of materials for a particular final product into a production and purchase plan. Information feedback loops were added to MRP systems so that production managers may modify and update the system inputs as necessary.

Manufacturing resources planning (MRP II), the successor to MRP, also included areas of marketing, finance, accounting, engineering, and human resources in the planning process. operation resources planning (ERP), which was created in the 1990s and builds on MRP, utilises computer technology to connect multiple functional areas throughout a whole commercial operation.

6.3 AGGREGATE PRODUCTION PLANNING (APP)

The acronym APP stands for aggregate production planning, which is helpful for operation management. It relates to setting up production, inventory, and staffing levels to meet shifting demand over a planning horizon of anything between six months and a year. Plans for aggregate production are essential for operations management and are required to take advantage of labour opportunities. It lowers expenses while facilitating the balancing of supply and demand.



In other words, aggregate production planning is the process of figuring out the total number of products that will be manufactured or produced in a plant or other manufacturing facility over a medium-term planning period, like a month or a quarter. The overall output of the plan includes the total quantities of each product or group of products that will be produced during the plan period, including the specific timing of the various manufacturing activities needed to reach the projected production levels. Additionally, the aggregate production won't provide information on specifics like the dates when materials ordered in response to each customer order would be available for delivery.

The purpose of the aggregate production plan is to set overall production goals and serve as a planning tool for the availability of other inputs and auxiliary activities needed to reach the goals. The more detailed production schedules, like daily and weekly production calendars and customer delivery timetables, are built on top of the aggregate plans. Fig.1 depicts the aggregate production planning process flow.

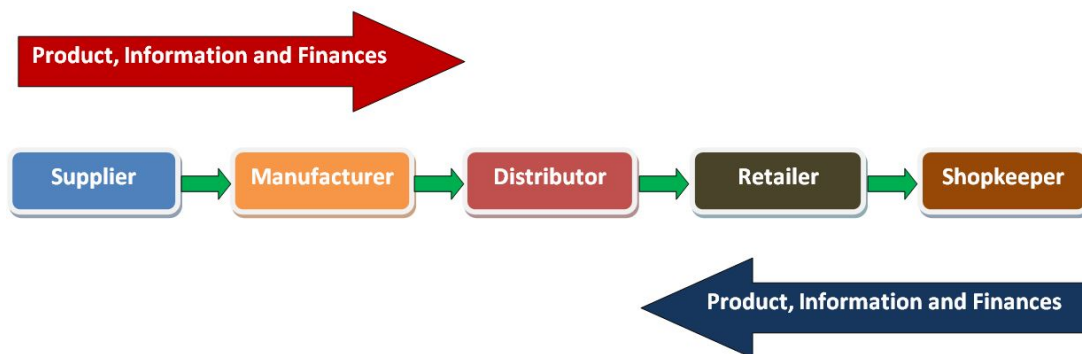


Fig.1 Aggregate Production Planning Process

6.3.1 Importance of Aggregate Planning

In order for the organisation to achieve its long-term goals, aggregate planning is crucial. A few areas where aggregate planning is useful are as follows:

- Achieving financial objectives by bringing down overall variable costs and boosting profitability.
- The best possible use of the production facility.
- Provide client satisfaction through minimising customer wait times and matching demand.
- Cut back on inventory stocking expenditures.



6.3.2 Techniques of Aggregate Planning

Aggregate planning is a work that is carried out using a variety of ways. There are typically two categories: informal trial-and-error methods and mathematical methods. In actuality, less formal methods are more frequently employed. Although there has been a lot of study on mathematical procedures, they are still not as widely applied. Nevertheless, they are frequently used as a basis for evaluating the efficacy of various techniques for aggregation planning.

There are several steps in general procedure for aggregate planning:

Step-1: Determine demand for each period.

Step-2: Determine capacities (regular time, overtime, subcontracting) for each period.

Step-3: Identify company or departmental policies that are pertinent.

Step-4: Determine unit costs for regular time, overtime, and sub-contracting, holding inventories, back.

Step-5: Orders, layoffs, and other relevant costs.

Step-6: Develop alternative plans and compute the cost for each activity.

6.3.3 Costs relevant to aggregate production planning

- **Basic production costs:** material costs, direct labour costs, and overhead costs. It is customary to divide these costs into variable and fixed costs.
- **Costs associated with changes in the production rate:** Costs involved in hiring, training, and laying off personnel, as well as overtime compensations.
- **Inventory related costs:** Aggregate production planning models may be supportive as decision support systems and to appraise proposals in union negotiations.

6.3.4 Algorithm to develop the Aggregate Production Plan

When utilising a spreadsheet solver to construct an optimal aggregate production plan, there are some rules to follow. The step-by-step algorithm for planning aggregate production is shown in Fig.2. Gathering the relevant data is the first step in creating an aggregate production planning mode. Create the APP model in spreadsheet format next. The next stage is to evaluate the results. To accomplish this, it is possible to offer the created spreadsheet aggregate production planning model and its solutions to relevant corporate departments, such as production, personnel, planning, sales and marketing, and warehousing, and assess



whether the solutions are satisfactory. The optimal plan produced by the aggregate production planning model may be compared to the existing aggregate production plan in terms of cost. If the solution is unsatisfactory, it could be necessary to change the restrictions or the values of some input parameters. We will modify the spreadsheet APP model until the solutions are satisfactory. Implementing the plan for aggregate production is the final step. After the spreadsheet APP model has been successfully created and solved, the discovered solutions may be put into practise. Some model elements, including as demands, productivity rates, associated costs, workforce size, and inventory levels, may change during the execution of the aggregate production plan. The APP model is solved to determine the revised aggregate production plan, and these parameters should be updated on a regular basis.

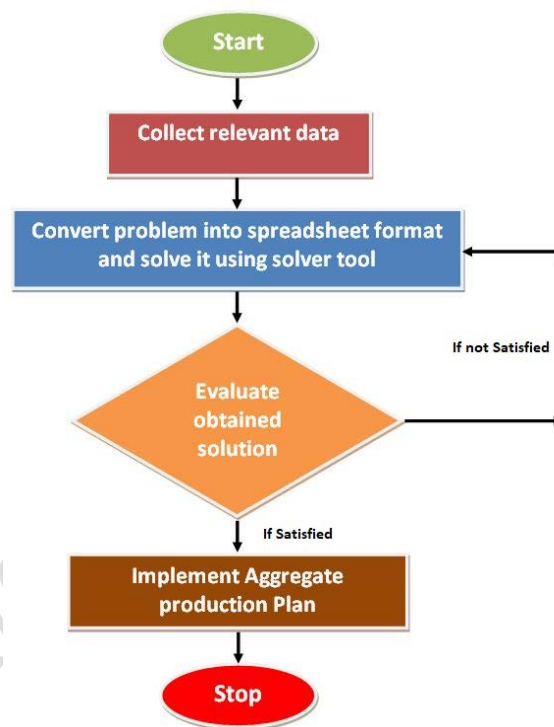


Fig.2 Aggregate Production Planning Algorithm

In conclusion, aggregate production planning, which focuses on meeting demand as it pertains to production, labour force, inventory, and other models, is an effective approach to operations management. Facility planning and scheduling decisions can be integrated with aggregate production planning. It helps to reduce manufacturing costs, the impact of fluctuating demand, inventory expenses, and personnel costs. Planning for aggregate production also makes use of and profits from plants and equipment. A production plan that



specifies the number of workers required during each period, the volume and kind of output, and the units that must be produced, stored, and placed on backorder each month or each quarter is an efficient aggregate production plan. A useful method for creating and evaluating options is aggregate production planning. Examples include adjusting the workforce, using subcontractors, building anticipatory inventory, and even creating equivalent goods and pricing plans.

6.3.5 Aggregate planning as an Operational Tool

As the organisation strives to strike a balance between long-term strategic planning and short-term production success, aggregate planning is a crucial operational activity. Aggregate planning includes all production processes, not only individual production runs or the creation of individual goods, within a facility (or for large businesses, across numerous locations). Since client orders, supply chain dynamics, and other factors can significantly affect the demand for a given product, aggregate production planning enables producers to maximise resource utilisation despite these variances. Aggregate planning aids in striking a balance between the organisation's operational, financial, and overarching strategic goals. It acts as a platform for managing demand and capacity planning. An organisation can strive to balance both by managing orders, pricing, promotions, and creating new demand in a situation where demand exceeds capacity.

6.3.6 Aggregate Planning Strategies

Level Strategy: The level strategy aims to keep the workforce and output rates stable. In order to increase or decrease output in anticipation of lower or higher client demand, an organisation must have a reliable prediction of demand. The level plan has the benefit of a consistent workforce, but the disadvantages include large inventory and growing backlogs.

Chase Strategy: The chase strategy seeks to dynamically balance output and demand. Lower inventory and backlogs are a benefit of the chasing approach. Lower productivity, lower quality, and a demoralised workforce are the drawbacks.

Hybrid Strategy: The hybrid strategy looks to balance between level strategy and chase strategy.

Example: There are four models A, B, C and D of a product. The respective daily production rates and requirements for the next month are given in the table below. Calculate the aggregate requirements for the next month, using product C as standard product. Is there sufficient capacity to produce these units, if the plant will operate for 23 days next month?



Product	Production rate per day	Production requirement
A	2500	8500 Units
B	1500	12000 Units
C	1000	7000 Units
D	2000	12000 Units

Solution:

Product	Production rate per day	Production requirement	Requirement in standard units
A	2500	8500 Units	$(8500/2500)*1000=3400$
B	1500	12000 Units	$(12000/1500)*1000=8000$
C	1000	7000 Units	$(7000/1000)*1000=7000$
D	2000	12000 Units	$(12000/2000)*1000=6000$
Aggregate Requirement			24400

Standard production = 1000

Plant operational days = 23

Total production in 23 days = $1000*23 = 23000$

Aggregate requirement = 24400

Therefore, it is clear that the plant does not have the sufficient capacity.

Example: Aggregate demand and the starting inventory for a plant with a four-quarter planning horizon are shown in the table. You do not want any safety stock / inventory at the end of the planning horizon, since the product will be phased out. Provide a basic production plan and the inventory level at the end of each quarter, using the level strategy.

Month	Q0	Q1	Q2	Q3	Q4
Aggregate demand		3400	2200	3900	4500
Inventory	800				



Solution:

Total aggregate demand = 3400 + 2200 + 3900 + 4500 = 14000 units

Initial inventory = 800

Production required = 14000-800 = 13200 units

Production required in each quarter = 13200/4 = 3300 units

Inventory level = Inventory available + Basic production – Aggregate demand

The basic production plan and the inventory level at the end of each quarter, using the level strategy is shown below:

Month	Q0	Q1	Q2	Q3	Q4
Aggregate demand		3400	2200	3900	4500
Basic Plan		3300	3300	3300	3300
Inventory	800	700	1800	1200	0

6.4 MASTER PRODUCTION SCHEDULE (MPS)

The goods a company will create, when they will be produced, and in what quantities are specified in a master production schedule (MPS). An MPS connects production capacity and demand in the market. The goal of master production scheduling is to develop a practical strategy that reduces overstock and increases on-time delivery. A visual representation of the master production schedule is shown in Fig.3.

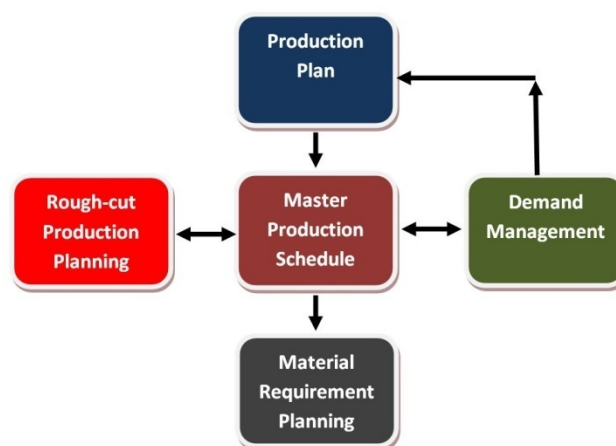


Fig.3 Master Production Schedule



A component of contemporary advanced planning and scheduling (APS) software is master production scheduling software. The process of master production scheduling is dynamic, and MPS software is built to quickly take into account changes in demand or capacity. In order to make sure that the MPS is based on the most recent data, it extracts actual order and capacity data. Forecasts, known and anticipated orders, significant capacity restraints, inventory levels, stock buffer requirements, and requests from departments like research and development are all taken into account in MPS calculations. The master production schedule is generated by MPS software automatically, although manual adjustments are sometimes possible to meet particular requirements or goals. The ability to override planned production volume with scheduled volume is another feature of master production scheduling software. After then, the master production schedule is updated to reflect the present situation. Your marketing and production teams employ rough cut capacity planning as a long-term strategy to balance the available capacity and capacity required so that you can adjust your production schedule or available capacity.

The master production schedule is used by APS software to allow interactive schedule visualization, where data can be shown as capacity consumption graphs and stock profile graphs. To coordinate effective production, APS software's master production schedule works in conjunction with the bill of materials (BOM) and material requirements planning. After the MPS software has established the timing and volume of completed goods to be produced, this data is merged with the BOM to establish the kind and quantity of materials required to complete production in accordance with the MPS. In order to maximise actual production output, manufacturing capacity planning is aided by data from the master production schedule, which also gives information on the capacity requirements needed to fulfil existing orders.

6.4.1 Benefits of master production scheduling

- Manufacturers may make sure that the master production schedule appropriately reflects current demand and capacity and that it rapidly adapts to any changes by using master production scheduling software.
- MPS software speeds up the MPS development process as part of an effective APS system, relieving planners of the time and effort required for manual MPS development.
- MPS also aids in enhancing communication between the manufacturing and sales teams, decreasing equipment downtime, preventing shortages and overstocks, and decreasing manufacturing costs.



6.4.2 Functions of MPS

Software for master production scheduling primarily addresses planning, inventory, and other production control needs. The main objective of the master production schedule is to reduce the amount of time spent managing all parts of the production flow by giving you access to all the information required to complete all orders and requests from customers. Prior to deploying a master production scheduling system, it is crucial to evaluate the system's primary productivity-enhancing features.

Translating Plans - The amount of activities that balance market demand with material, labor, and equipment capacities is determined by this section of the master production scheduling. This is so that the plan can be converted into the number of products that must be produced in a certain amount of time using the master schedule.

Evaluating Alternative Schedules - The master schedule generates trial-and-error schedules that provide alternative production paths to take. This ensures that any production-related emergencies are handled right away.

Produce Capacity Requirements - By identifying capacity needs, this programme facilitates capacity planning. Master production scheduling provides direct access to capacity requirements, which correlate with capacity planning. Planning and scheduling must include this since capacity restrictions will have an impact on the production's output.

Facilitating Information Processing - The master schedule determines whenever deliveries are needed to be made. This coordinates with various management information systems such as marketing, finance, and others.

Utilization of Capacity - Master production scheduling software establishes load and utilization requirements for machines and equipment. This allows for the absolute best capacity utilization and a much more efficient flow of production.

A Master Production Schedule is beneficial for all sizes of manufacturing enterprises. The MPS provides for the effective and optimal allocation of resources and takes demand variability into account, all of which help prevent material and item shortages. The increase in productivity inside the manufacturing organisation is MPS's main benefit. This is so that MPS can keep an eye on production and quickly adapt to changes in scheduling and production to prevent any wasted production.

Example: The Wicked Witch Whisk Company manufactures a line of broomsticks. The most popular is the 36-inch model, and the sales department has prepared a forecast for 6 weeks.



The opening inventory is 30. As master scheduler, you must prepare an MPS. The brooms are manufactured in lots of 100.

Week		1	2	3	4	5	6
Forecast Sales		10	50	25	50	10	15
Projected Available balance	30						

Solution: Opening inventory = 30 unit

Lot size = 100 units

Projected available balance = Projected available balance + MPS – Forecast sales

Week 1 forecast sales = 10 and availability = 30

Week 1 projected available balance = 30 – 10 = 20

Week 2 projected available balance = 20 + 100 – 50 = 70

Week 3 projected available balance = 70 + 0 – 25 = 45

Week 4 projected available balance = 45 + 100 – 50 = 95

Week 5 projected available balance = 95 + 0 – 10 = 85

Week 6 projected available balance = 85 + 0 – 15 = 70

Week		1	2	3	4	5	6
Forecast Sales		10	50	25	50	10	15
Projected Available balance	30	20	70	45	95	85	70
MPS			100		100		

Hence, it is concluded that MPS receipts is made in week 2 and week 4

6.5 MATERIAL REQUIREMENTS PLANNING (MRP)

A system called material requirements planning (MRP) determines the materials and parts required to make a certain product. It consists of three main steps: listing the materials and components already present, deciding which more are required, and then planning for their manufacture or acquisition. MRP works backward from a production plan for finished goods to help businesses and manufacturers determine what is needed, how much is needed, and when it is needed. Using MRP, a plan is transformed into a list of the components, raw materials, and subassemblies required to manufacture a finished good on schedule.



Item Name or Nomenclature: The finished good title, sometimes called Level "0" on BOM.

Master Production Schedule (MPS): It delineates what products a manufacturer will produce, when and in what quantities

Shelf life of Stored Materials: the length of time that a commodity may be stored without becoming unfit for use, consumption, or sale.

Inventory Status File (ISF): Materials available that are in stock and materials on order from suppliers.

Bills of Materials (BOM): Details of materials and components required to make each product.

Planning Data: Restraints and directions like routing, labor and machine standards, quality and testing standards, and lot sizing techniques.

6.5.1 Objectives of Material Requirements Planning

Three main goals are what the software aims to accomplish.

- To guarantee that supplies of raw materials for manufacturing and goods for consumer delivery are easily available.
- To maintain the lowest levels of completed goods and raw resources in stock.
- To plan production, delivery windows, and purchasing tasks.

6.5.2 The MRP process

Step 1: Estimates demand and necessary materials - MRP divides demand into particular raw materials and components after evaluating client demand and using the bill of materials.

Step-2: Distributes Material Inventory - MRP distributes Material Inventory to the precise regions that are required.

Step 3: Schedules Production - A timeline is made when time and labour needs for manufacturing are determined.

Step-4: Monitors the process - The MRP automatically notifies management of any delays and even makes backup plans to meet build deadlines.

Example: Each unit of product A is made by using 1 unit of product B and 2 units of product C. At the beginning of time period 1, the following information is given:



Item ID	Quantity on Hand	Lead time
A	100	1
B	150	2
C	80	1

The gross requirement of unit A is 200 units for period 4 and 250 for period 5. Using the information given develop a MRP material plan:

If the lead time for item A increases by 1 week and the lead time for item C also increases by 1 week, what will be revised material plan look like? Are there any problems which need immediate action?

Solution: The MRP material plan is as follows:

	Period				
	1	2	3	4	5
Item A					
Gross requirement				200	250
On hand receipts	100				
Net requirement				100	250
Planned order releases			100	250	

	Period				
	1	2	3	4	5
Item B					
Gross requirement			100	250	
On hand receipts	150				
Net requirement				200	
Planned order releases		200			



	Period				
	1	2	3	4	5
Item C					
Gross requirement			200	500	
On hand receipts	80				
Net requirement			120	500	
Planned order releases		120	500		

The revised MRP materials plan is as follows:

	Period				
	1	2	3	4	5
Item A					
Gross requirement				200	250
On hand receipts	100				
Net requirement				100	250
Planned order releases		100	250		

	Period				
	1	2	3	4	5
Item B					
Gross requirement		100	250		
On hand receipts	150				
Net requirement			200		
Planned order releases	200				

	Period				
	1	2	3	4	5
Item C					
Gross requirement		200	500		
On hand receipts	80				
Net requirement		120	500		
Planned order releases	500				



Yes, there is a problem which need immediate action. Item C is behind schedule and will need to be expedited immediately to ensure that 120 units of C are available in week 2. Alternatively, the master schedule could be revised to accommodate the availability of item C. Combinations of these two alternatives could also be considered.

6.6 SUMMARY

The acronym APP stands for aggregate production planning, which is helpful for operation management. It relates to setting up production, inventory, and staffing levels to meet shifting demand over a planning horizon of anything between six months and a year.

The integrated information technology (IT) systems that sought to increase business productivity by utilising computers and software technologies were first introduced as material requirements planning.

The goods a company will create, when they will be produced, and in what quantities are specified in a master production schedule (MPS). An MPS connects production capacity and demand in the market. Master production scheduling aims to provide a practical strategy that reduces excess while enhancing on-time delivery.

6.7 GLOSSARY

Aggregate Production Planning - Aggregate production planning determines the production, inventory, and labour levels, in order to fulfill fluctuating demand over a planning horizon of between six months and a year.

Master Production Scheduling - Master Production Scheduling (MPS) is a manufacturing procedure that determines which items to create and how much of them are necessary to meet the demand in a specific amount of time.

Level Capacity Strategy - Using a combination of stocks, overtime, subcontracting, and back orders to maintain a constant rate of output while accommodating variations in demand.

Chase Demand Strategy - Matching capacity to demand i.e, operations would be planned to meet expected demand for that period.

MRP - Material requirements planning (MRP) is a system for calculating the materials and components needed to manufacture a product.

Inventory Status File (ISF): Materials available that are in stock and materials on order from suppliers.



Basic production costs: material costs, direct labour costs, and overhead costs. It is customary to divide these costs into variable and fixed costs.

Costs associated with changes in the production rate: Costs involved in hiring, training, and laying off personnel, as well as overtime compensations.

Inventory related costs: Aggregate production planning models may be supportive as decision support systems and to appraise proposals in union negotiations.

6.8 ANSWER TO IN-TEXT QUESTIONS

- | | |
|------------------------|-----------------------------|
| 1. (b) Demand Forecast | 3. (d) Aggregate production |
| 2. (a) Chase | 4. (d) All of these. |

6.9 SELF-ASSESSMENT QUESTIONS

1. What are the Aggregate Planning Strategies?
2. Describe the process of MRP.
3. Explain the cost relevant to Aggregate production planning.
4. Discuss the functionality of MPS.

6.10 REFERENCES

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LESSON 7

QUALITY MANAGEMENT

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STRUCTURE

- 7.1 Learning Objectives
- 7.2 Introduction
- 7.3 Meaning and Dimensions of Quality
- 7.4 Statistical Quality Control
- 7.5 Process Capability
- 7.6 Acceptance Sampling
- 7.7 Six Sigma
- 7.8 Glossary
- 7.9 Answers to In-text Questions
- 7.10 Self-Assessment Questions
- 7.11 References
- 7.12 Suggested Readings

7.1 LEARNING OBJECTIVES

The objective of this lesson is to impart the knowledge of concepts related to Quality Management, to resolve concerns related to Quality and learn practical tools for quality control.

After completing this course, you will be able to:

- Elucidate the basic concepts related to quality management such as what is quality, dimensions of quality and cost of quality
- Classify the causes of variations in process, explain statistical control techniques and plot and analyse control charts



- Explain concepts like sampling plan, operating characteristic curve, consumer's and producer's risk
- Describe the DMAIC and DMADV models in addition to the six sigma idea and its importance.

7.2 INTRODUCTION

“Quality is not an act. It is a habit.” ~Aristotle

Quality is one of the treasured order winning attributes of any product. In fact, it is one of the most frequently used term in any sphere of life. Every process, every product, every organization dire to have Quality as its habit. On the other hand, a fact is that “Quality” is perceived and defined in many different ways, however as such there is no commonly agreed definition of quality. Quality is referred as the ability of a product or service to meet the requirements of customers. Whereas, From the perspective of the client, value is connected to quality, which denotes how effectively a product accomplishes its stated goal. The compliance to requirements, on the other hand, is what an organisation views as quality.

As per ISO 9000 standards, quality is defined as “totality of characteristics and features of a product/service that bear on its ability to satisfy the stated/implied needs”. This definition is now used in all industry and business-related activities. And from the perspective of operations management this aspect is taken as a critical success factor.

In this lesson we will explore this critical strategy because without quality the survival of an entity is not possible; without quality it's difficult for an organization to enter in a market or to compete in market. So, the unit will take on to the journey from the definition of a quality system to quality control techniques to quality charts to six sigma quality standards which any company is thriving for, in today's world.

7.3 MEANING AND DIMENSIONS OF QUALITY

Quality is considered as one of the aspects of the product or service that might be an order winning or entry criterion, but the fact is that it is invariably present and is frequently promoted by suppliers in an attempt to gain competitive advantage. Quality is an issue of universal relevance which, righty needs to be addressed in all operations. In absence of quality there will be no yardstick for comparing the quality of goods/services, there will be dissatisfied customers due to increased maintenance and operating costs of products/services. So, its vital to have a Quality system.



7.3.1 Definition of a Quality System

A quality system works in tandem with the production process to guarantee that the latter yields items of the highest possible quality. A quality system's reach extends beyond the production process. The vendors that make the product's parts are covered by a quality system. It also covers other departments in the company to ensure that customers are properly informed, trained and serviced whenever problems are presented. Last but not least, it addresses the design division to guarantee that goods are created according to requirements and that they function as planned.

ACTIVITY

Imagine you are the owner of a company that manufactures Water Purifier. List out all the chaos that would happen if you do not have Quality Control Check in the company.

7.3.2 Dimensions of Quality

In order to evaluate the quality of product and services, we first have to examine the dimensions which are intrinsic to the quality (fig 1).

- **Design Quality** – A product or service is always designed in such a way that the requirements of the customers should be satisfied. So careful attention is needed in designing a product which set quality standards at par with the requirements of the customers. For this, provider should go for understanding the specifications of the different features that are required in the product. Materials, durability, aesthetics and cost are some features that should be considered when designing a product. The quality of the product is introduced by the impact of these parameters. Inspection of the manufacturing processes is of utmost importance in ensuring quality of performance.
- **Conformance Quality**– Product or service conformance is a measure of how closely the final product meets the parameters incorporated in its design. It refers to the degree to which design specifications are met. It ensures that the variability in the process does not compromise the functionalities that the designer intended.
- **Utilization conditions** –To maximize the customer's satisfaction, utilization conditions require that the customer be informed or trained so the product is used for



what it was intended for. Instructions, manuals, help-lines, and on-site training by the manufacturers' personnel improve the perception of quality.

- Troubleshooting** – There can be various reasons of a product being not able to function to the expected levels. It may be improper use, unexpected or additional demands, improper assembly or even manufacturing defects. There is a need to rectify these and make products or services perform up to the expected standard. To ensure client satisfaction, the company has to put in place a structure that allows these possibilities to be foreseen and handled. This is an important dimension of quality which is very popular these days.

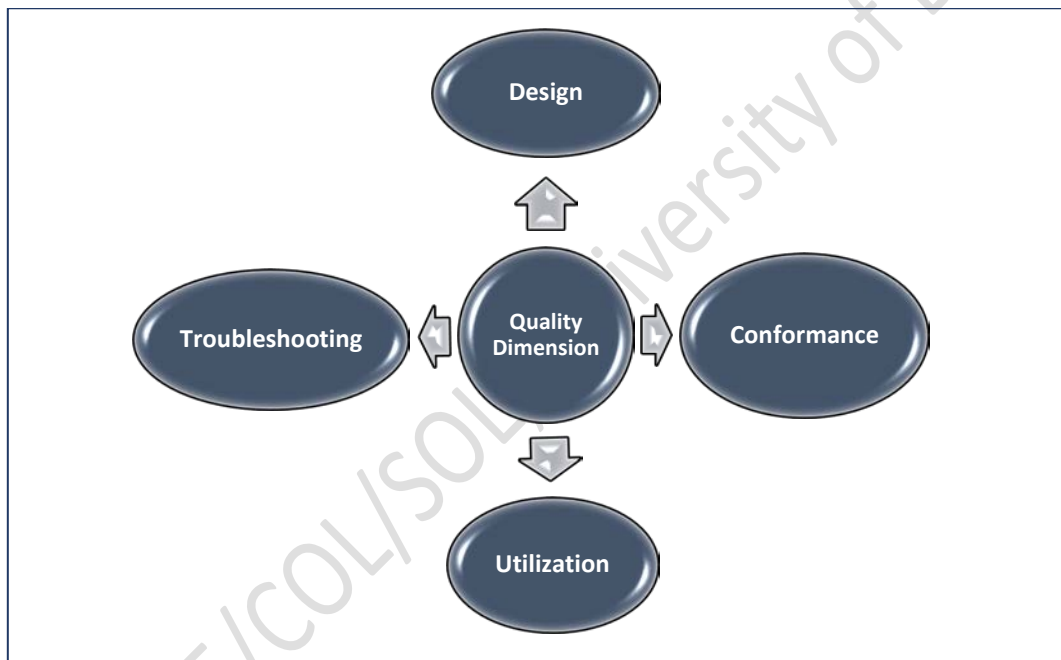


Fig 1: Dimensions of Quality

7.3.3 Cost of Quality

Broadly considering, cost of quality is a trade-off between cost of conforming and cost of failure. If there are too many defects in the products then provider has to bear the cost of failure in terms of goodwill loss and operational repair cost. On the other hand, before releasing the product or service, producer has to conform to the quality standards of the product which require cost.

The components of cost of quality are shown in fig2.



The Cost of Conformance has two components namely cost of prevention and cost of inspection.

Cost of Prevention include:

- staff and customers training
- locating high-quality components and preserving relationships with suppliers
- appropriate set-up of plant, sourcing of quality plant; maintenance of plant
- redundancy in the product and the process
- design and redesign of product and process

Cost of Prevention include:

- testing
- the stock costs of holding goods for inspection or test
- conducting product, process and service audits

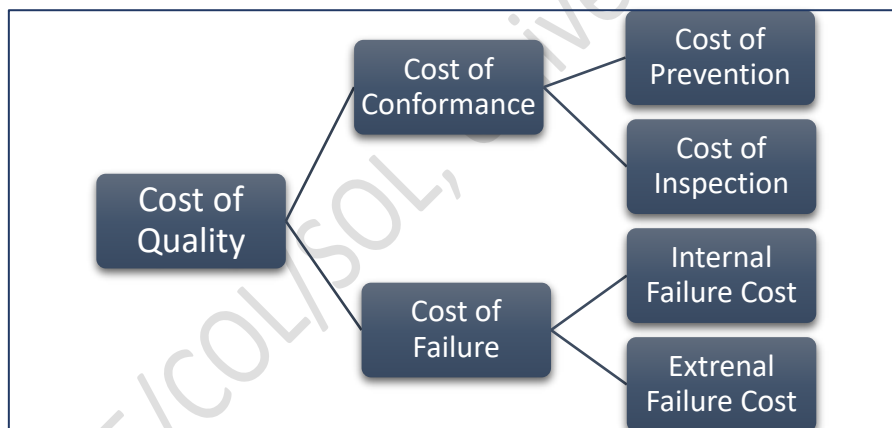


Fig 2: Cost of Quality

IN-TEXT QUESTIONS

13. _____ is intrinsic in the product or service that is provided to the client.
14. Design Quality is the degree to which design specifications are met. True / False
15. Cost of Quality is trade-off between _____ and _____.



7.4 STATISTICAL QUALITY CONTROL

Quality Control may be defined as ‘a system that is used to maintain a desired level of quality in a product or service’. Quality control can also be defined as ‘that industrial management technique by means of which product of uniform acceptable quality is manufactured’. It is the entire collection of activities that ensures that the operation will produce the optimum quality products at minimum cost. And Statistical Quality Control (SQC) is a methodology that uses statistical methods to gather and analyse data in the determination and control of quality. It is based on sampling, probability, and statistical inference, i.e., judging an entire lot by the characteristics of a sample.

1.4.1 Basis of Statistical Quality Control:

The basis of statistical quality control is the degree of ‘variability’ in the size or the magnitude of a given characteristic of the product. Variation in the quality of manufactured product in the repetitive process in industry is inherent and inevitable. These variations are broadly classified as being due to two causes, viz., (i) chance causes, and (ii) assignable causes.

Chance Causes: Some ‘stable pattern of variation’ or “a constant cause system” is inherent in any particular scheme of production and inspection. This pattern results from many minor causes that behave in a random manner. The variation due to these causes is beyond the control of human hand and cannot be prevented or eliminated under any circumstances. One has got to allow for variation within this stable pattern, usually termed as allowable variation. The range of such variation is known as ‘natural tolerance of the process.’

Assignable Causes: The second type of variation attributed to any production process is due to non-random or the so-called assignable causes and is termed as preventable variation. The assignable causes may creep in at any stage of the process, right from the arrival of the raw materials to the final delivery of goods. Some of the important factors of assignable causes of variation are sub-standard or defective raw materials, new techniques or operations, negligence of the operators, wrong or improper handling of machines, faulty equipment, unskilled or inexperienced technical staff and so on. These causes can be identified and eliminated and are to be discovered in a production process before it goes wrong, i.e., before the production becomes defective.

Table 1.1 elaborates on these two types of variations.



Table 1.1: Comparison of Chance causes of variation and Assignable causes of variation

<i>Chance causes of variation</i>	<i>Assignable causes of variation</i>
Consist of many individual causes	Consist of just a few individual causes
Any one chance cause results in only a small amount of variation.	Any one assignable cause can result in a large amount of variation
Chance variation cannot economically be eliminated from a process.	The presence of assignable variation can be detected, and action to eliminate the causes is usually economically justified.
Some typical chance causes of variation are: <ul style="list-style-type: none"> - Slight vibration of a machine - Lack of human perfection in reading instruments and setting controls. - Voltage fluctuations and variation in temperatures. 	Some typical assignable causes of variation are: <ul style="list-style-type: none"> - Negligence of operators - Defective raw material - Faulty equipment - Improper handling of machines

1.4.1 Quality Control Techniques:

The five most common and commonly used tools are referred to as QC tools. They comprise the flow chart, check list, histogram, pareto analysis, and control charts. These are the fundamental seven tools for ensuring or raising the level of quality.

1. Flow Chart – A flow chart is a diagram that depicts a process's different steps. It assists in identifying the areas where a problem occurs or where improvement is potential. Comprehensive data can be gathered, analysed, and techniques for correction devised utilising flow charts.
2. Check sheet – Check sheets are used to keep track of the amount of flaws, the kinds of problems, the places and times they occur, and the workers who are responsible for them. The sheet records the occurrence frequencies in relation to potential defect-causing factors. Implementing a correction method in the location where the frequencies are higher is beneficial.
3. Histogram - Graphical depictions of data distribution are called histograms. They are typically used to store vast amounts of process-related data. They demonstrate the degree of variance and the number of peaks present in the pattern of distribution.



They show the number of peaks in the pattern of distribution as well as how much variation there is around the peak value. This aids in determining the severity of the issue. We can recognise the issue because the different kinds of visual patterns have been formed together with pertinent interpretations

4. Pareto analysis - The Pareto analysis is a method for categorising issues according to their level of relevance and focusing on the most crucial ones. The Pareto principle, which is linguistically expressed as "essential few; trivial many," is also known as the 80-20 rule because it is noted that 80% of the issues we face originate from 20% of the items. In the event that 184 assemblies experience issues in a single day and there are 11 potential causes, for instance, it is noted that 147 of them, or 80% of them, were brought on by just 2 or 3 of them. It will be simple to concentrate on these 2 or 3 and significantly minimise the amount of defects. When the causes of these faults are addressed, we will see that another problem starts to be more frequently seen, and if the process is sustained, we will eventually reach zero defects. In order to show the scope of each problem category in descending order of problem magnitude, Pareto diagrams are vertical bar charts.
5. Control charts - Control charts are instruments for examining process variability. They inform us whether a process is exhibiting stability or regular fluctuation. The control chart is based on the theory that unwanted changes in the process will be more obvious since the average of a sample of multiple things tends to cancel out the normal process variability.

A centre line, as well as upper and lower control limits, are shown on control charts. These control limits are normally positioned 3 standard deviations (of the sample statistic being displayed) above and below the centre line. The most common used control chart is \bar{X} and R charts for variables (fig 3).

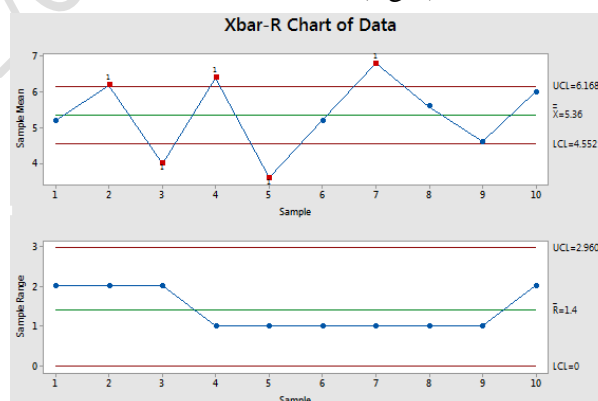


Fig. 3 \bar{X} and R charts for variables (<https://www.six-sigma-material.com/Xbar-R.html>)



The formulas used to establish six sigma control limits for \bar{X} and R charts are as follows:

Control limits for \bar{X} -chart:

$$\text{Upper control limit, UCL} = \bar{\bar{X}} + 3\sigma_{\bar{X}}; \text{UCL} = \bar{\bar{X}} + 3\frac{\sigma}{\sqrt{n}}$$

$$\text{Lower control limit, UCL} = \bar{\bar{X}} - 3\sigma_{\bar{X}}; \text{UCL} = \bar{\bar{X}} - 3\frac{\sigma}{\sqrt{n}}$$

Where

n = Sample Size

$\bar{\bar{X}}$ = Mean of the sample means

\bar{X} = Mean of a sample

$\sigma_{\bar{X}}$ = Sample standard error

Control limits for R-chart:

$$\text{Upper control limit, UCL}_R = R + 3\sigma_R$$

$$\text{Lower control limit, LCL}_R = R - 3\sigma_R$$

Where R = Range of a sample observations ; σ_R = Standard deviation of R

Another method of calculating control limits is using the sample range (which is a difference between the largest and smaller values of the sample). The formula for control limits (\bar{X}) in this case is as follows:

$$\text{UCL} = \bar{X} + A_2\bar{R}$$

$$\text{LCL} = \bar{X} - A_2\bar{R}$$

Where,

\bar{X} = Average of the sample means

\bar{R} = Average range of the samples

A_2 = Constant depending on sample size

The formula for control limits (\bar{R}) in this case is as follows:

$$\text{UCL} = D_4\bar{R}$$

$$\text{LCL} = D_3\bar{R}$$

Where,



\bar{R} = Average range of the samples

D_4, D_3 = Constant depending on sample size

Control Charts for Attributes

Quality measurements are frequently stated as qualities in these circumstances (good or bad etc.). The percent faulty chart (P-chart) or the number of defects per sample area (C-chart) are seen to be more appropriate control charts to regulate the quality in such circumstances.

Although the information conveyed by the two charts is similar, the P-chart is based on a normal distribution while the C-chart is based on a Poisson distribution.

P-chart:

P-charts are sometimes known as percent faulty charts. The purposes of this chart are summarised below.

- (a) To determine the typical percentage of nonconforming components or items submitted for inspection over time.
- (b) To alert management if there is a change in the level of average quality. The formulas for control limits are as follows:

The formulas for control limits are as follows:

$$\text{Upper control limit, UCL} = \bar{p} + 3\sigma_p; \sigma_p = \sqrt{\bar{p}(1 - \bar{p})/n}$$

$$\text{Lower control limit, LCL} = \bar{p} - 3\sigma_p; \sigma_p = \sqrt{\bar{p}(1 - \bar{p})/n}$$

Where

n = Sample size

\bar{p} = Mean of a sample

σ_p = Standard deviation of per cent defectives

C-chart:

This chart illustrates the prevalence of nonconformities in samples of fixed size. The number of nonconformities (defects) in each sample is represented by the variable C. The sample size is typically thought to be one. This graph's control limits are based on the Poisson distribution.

The following is a list of some C-chart applications:



- To limit the quantity of nonconforming rivets in a plane wing.
- To limit the number of flaws visible in a galvanised sheet.
- To limit the amount of surface blemishes on a large casting, such as a gear blank used to turn a kiln in cement factories.

The formulas for control limits are given below:

$$\text{Upper control limit, UCL} = \bar{c} + 3\sqrt{\bar{c}};$$

$$\text{Lower control limit, LCL} = \bar{c} - 3\sqrt{\bar{c}}$$

\bar{c} is the mean number of nonconformities

NUMERICAL CASE EXAMPLE

The following data were obtained over a five-day period to indicate X and R control chart for a quality characteristic of a certain manufacturing product that had required a substantial amount of rework. All the figures apply to the product made on a single machine by a single operator. The sample size was 5. Two samples were taken per day. Comment on the process using \bar{X} and R-charts.

Sample Number	Observations					\bar{X}	R
	1	2	3	4	5		
1	10	12	13	8	9	10.4	5
2	7	10	8	11	9	9.0	4
3	11	12	9	12	10	10.8	3
4	10	9	8	13	11	10.2	5
5	8	11	11	7	7	8.8	4
6	11	8	8	11	10	9.6	3
7	10	12	13	13	9	11.4	4
8	10	12	12	10	12	11.2	2
9	12	13	11	12	10	11.6	3
10	10	13	7	9	12	10.2	6

IN-TEXT QUESTIONS

16. Control charts are also called _____
17. _____ involves the inspection of final output by taking a random sample from it during the production process.



7.5 PROCESS CAPABILITY

A precise set of specification limits are established each time a product is initialised. For instance, if we are producing a white board duster, the production criteria, such as the duster's length and width, are predetermined. These restrictions ensure that a product will operate within the intended operating window. After the product has undergone a manufacturing process, the capabilities of the process must be matched with the requirements of the finished product. It is sometimes referred to as the "process capability" to indicate if a process can or cannot meet criteria.

A procedure designed to produce a good should be able to do so consistently within its limitations. The process variability is used to establish the operating ranges. (fig 4).

The following formula is used to calculate process capability:

$$C_p = \frac{USL - LSL}{6\sigma}$$

Where,

USL= Upper specification limit; LSL= Lower specification limit

If $C_p = 1$, process variability meets specifications

If $C_p \leq 1$, process variability is outside the range of specifications, which implies that the process needs to be improved

If $C_p \geq 1$, process variability is within the range of specification.

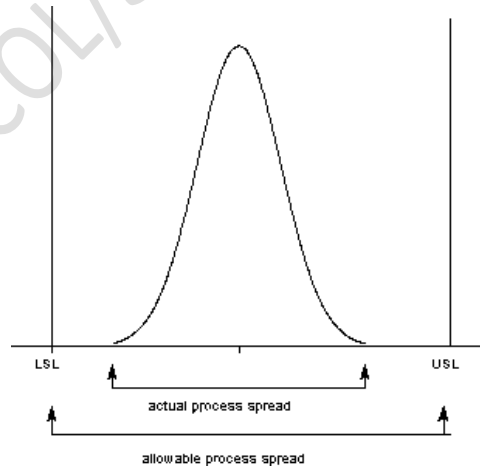


Fig 4. Variability of a Process Performance
(<https://www.itl.nist.gov/div898/handbook/pmc/section1/pmc16.htm>)



7.6 ACCEPTANCE SAMPLING

Suppose you go to a fruit market to buy a box of 100 apples. Then, out of the following two methodology, which one do you adopt for, in regular practice-

1. Inspect each and every apple before taking a final decision to purchase.
2. Randomly pick some apples from the box and on the basis of that selection, takes the decision to purchase the entire box or not.

Generally, we go with second methodology, because 100% inspection is not feasible within a certain limit of time and resources.

Similar is the process adopted by the organizations and consumers for product control and is called as acceptance sampling.

When the cost of 100% inspection is extremely high and it is not technologically feasible, then producers in order to ensure that the quality standards are being as per consumer specifications, goes for strategic lot checking methodology of sampling inspection plan. On the other hand, consumer too wants best quality of product. So, Acceptance Sampling is a statistical tool that is used to determine whether a production lot of material has chances of acceptance or of rejection.

Acceptance sampling is a statistical technique adopted in product control. In product control we want to ensure that the lots of manufactured goods do not contain large number of defective items. Accept in sampling is an inspection scheme to determine the acceptability of lots of manufactured items. In practice, a producer supplies a consumer a number of items and a decision to accept or reject the lot is made by determining the number of defective items in a sample from the lot. The lot is accepted if the number of defects falls below the acceptance number or otherwise the lot is rejected.

Acceptance sampling technique assures the quality of product which can be done for both variables and attributes. In case of Sampling by attributes, it is done on the basis of classification of good product or bad product as per specification laid by the consumer. And in case of sampling by variables one makes actual measurement to find out whether the product conforms to being a non-defective item or defective item.

Sampling Inspection follows the given steps-

1. Making inspection batches of the total quantity.



2. From each batch, drawing random samples of same size or varying size as per sampling plan.
3. Selecting a sampling plan technique and determining its parameters.
4. Performing quality check by careful inspecting the units of random sample.

1.6.1 Types of Sampling Plans:

Products' quality can be evaluated using a sample plan or a 100% inspection method. Although 100% inspection ensures a proper quality check; however, even then a sampling inspection plan is utilised because it provides the following benefits:

1. Lower Cost: Since a smaller number of random items are measured, the labour and time costs are lower.
2. Since 100% inspection is completely impractical for industries that go for mass production, sampling plans are thus the ideal technique for the same.
3. It simplifies the computational work.

There are primarily two types of sampling plans that can be used for inspection, with the warning that they won't identify all the faults. They are:

1. Single Sampling Plan (SSP)
2. Double Sampling Plan (DSP)

Single Sampling Plan: Single Sampling Plan: This term describes a sampling method in which a random sample is identified from the entire lot. Each sample item is marked with a good or bad label after assessment. The entire lot is either accepted or rejected depending on the quality of the products.

The maximum number of defects is identified in single sampling and based on the same, a sample chosen.

In single sampling, the maximum number of defects is defined based on which a sample is selected. The process of single sample plan is as follows:

- For examination, pick at random a sample from the lot.
- Check the sample for the required quality characteristics.
- Accept the lot if the number of defects in the sample is equal to or lower than the number provided by the parameters.
- Reject the lot in case the flaws in the sample are more than the allowed parameters.



In sampling, some errors are definitely going to be present. Using an Operating Characteristics Curve (OCC), we will explore the probabilities of these errors graphically in section 1.6.2.

Double Sampling Plan: With the single sampling approach, we can accept or reject the lot based on the sample's findings. But, the double sampling approach calls for taking a maximum of two samples before approving or rejecting a large quantity. The overall quality level of the samples serves as the basis for the final decision.

1.6.2 Operating Characteristic Curve

The sampling plan's capability to distinguish between good lots and bad lots is shown by the OC curve. According to the curve, a lot with a certain proportion of defects would be approved, based on the findings of a sampling inspection. In the curve, x-axis shows the percentage of defectives and y-axis shows the probability of the acceptance of the entire lot. Figure 5 shows the OC curve:

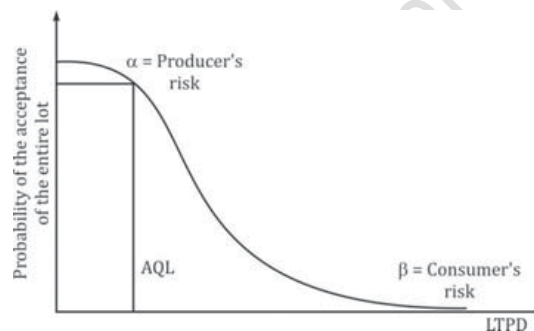


Fig.5. Operating Characteristic Curve

The OC curve is an S-shaped curve that suggests that as the number of faults decreases, the probability of acceptance rises. The OC curve has four parameters, which are discussed below:

Producer's Risk (α): It denotes the probability that sampling plan would reject a good lot (i.e. the non-defective lot). 0.01% to 10% is the risk of rejecting this lot.

Consumer's Risk (β): It denotes the probability that sampling plan would accept a bad lot (i.e. the one that contains a huge number of defects).

Acceptable Quality Level (AQL): It denotes the maximum percentage of defects which are acceptable to the consumers willingly. AQL is considered satisfactory.

Lot Tolerance Percentage Defective (LTPD): It denotes the percentage of defects exceeding the AQL, which are unacceptable to the consumers. Its probability of acceptance is low.



7.7 SIX SIGMA

The phrase "It is Six Sigma Certified" is sufficient to understand the effectiveness and efficiency of all processes, transactions as well as the tasks inside the firm. Because of this, businesses nowadays are making a lot of effort to obtain the "Six Sigma Certifications" badge.

Six Sigma was first conceptualised in the 1980s. Bill Smith, a Motorola engineer at that time, was not satisfied with the standards being utilised to gauge the quality level (like defects per opportunity, DPO).

Bill Smith thereby developed one of the most reliable methods for determining quality measures, where the Defects were quantified Per Million of the Opportunities (DPMO). As a result, the phrase "Six Sigma" was created.

Technically speaking, the origin of the term "Six Sigma" or " 6σ " lies in the statistical normal distribution curve. According to the standard normal distribution, six sigma level denotes 99.99966% confidence that the process was completed without errors. A process is deemed to be Six Sigma level, in the simplest terms possible, if it produces not more than 3.4 defects per million opportunities.

NUMERICAL CASE EXAMPLE

Defect per Opportunity vs Defect per million Opportunity

Six Sigma projects are designed to improve CTQ (Critical to Quality) characteristics.

Consider a system that has 5 parts, and in each part, there are 3 opportunities to defect. In this case, total defect opportunities are $5 \times 3 = 15$.

Now suppose 10 units are picked randomly and it was found that it had 2 defects.

Then, Defect per Opportunity (DPO) = $2 / (15 \times 10) = 0.0133333333$

This small figure is giving an impression that system quality can be thought of as good.

But if we convert it into norms of Six Sigma calculations, then Defect per million Opportunity (DPMO) will be-

DPMO = $0.0133333333 \times 1,000,000 = 13,333$

Which is quite a huge number.

Hence, Six Sigma is considered as a robust way for defining quality measure.



At its core, the Six Sigma objectives are twofold: first, to improve the process, and second, to lower the reduction in variation as much as possible. Six Sigma takes the following factors into account while aligning with these objectives:

1. To raise the quality of the product, which is the highest expectation of the client, it goes for process stability, meaning that it ensures predictable as well as constant procedures.
2. It is essential to take into consideration the qualities that are valued most by the client.
3. It pays more attention to the process and what can be produced.

To fulfil these goals, Six Sigma has primarily two approaches- DMAIC and DMADV, which is the next subject of our discussion. To comply these objectives Six Sigma broadly has two approaches- DMAIC and DMADV, which we will discuss next.

4.7.1 Approaches for Six Sigma:

Two basic methods inspired by Deming's Plan-Do-Check-Act Cycle are used in Six Sigma processes and projects. These techniques, which go by the abbreviations DMAIC and DMADV, each have five steps.

The DMAIC technique is used for projects whose goal is to improve an already-existing business process, whereas the DMADV methodology is used for projects whose goal is to create new products or business processes.

CASE STUDY

A dabbawala (one who carries the box), sometimes spelled dabbawalla, tiffinwalla, tiffinwalla or dabbawallah, is a person in the Indian city of Mumbai whose job is to carry and deliver freshly made food from home in lunch boxes to office workers. Tiffin is an old-fashioned English word for a light lunch, and sometimes for the box it is carried in. Dabbawalas are sometimes called tiffin-wallas. For the efficiency of their supply chain it has been claimed that this virtually achieves a six sigma performance rating. It may sound simple, but it's not. It is actually a highly specialized trade that has evolved in its current form over a century and has become integral to Mumbai's culture. There are employees about 5000 in number and deliver approximately 200,000 tiffin boxes every day. Study the Case and outline how dabbawalla meet Six Sigma performance.



DMAIC approach

The steps in this technique are as follows:

- Specifiable define the system, the customer voice, their needs, and the project goals.
- Assess important elements of the present process, gather pertinent data, and determine the 'as-is' Process Capability.
- Examine and confirm cause-and-effect relationships by analysing the data. Find out the relationships and make sure that all relevant elements have been taken into account. Find the source of the defect that is being looked at.
- To construct a new, future state process, enhance or optimise the current process based on data analysis employing methods like design of experiments, poka yoke or error proofing, and standard work. To determine the capability of the process, set up pilot runs.
- Manage the future state process to make sure that any deviations from the target are fixed before they become flaws. Employ control systems including production boards, visual workspaces, statistical process control, etc. and monitor the process continuously.
- In order to identify the problem to work on, some organisations include the Recognize step at the beginning, thereby producing an RDMAIC methodology.

DMADV approach:

In this approach, the following steps are included-

- Establish design goals that are in line with client needs and enterprise strategy.
- Assess product capabilities, production process capability, hazards, and CTQs (characteristics that are Crucial To Quality).
- Conduct analysis to create and develop alternatives
- Create a better alternative that best fits the analysis from the previous phase.
- Validate the design, carry out pilot runs, apply the production process and give it to the process owner.

7.8 SUMMARY

- In this chapter, you have learned the basic concepts related to quality management such as what is quality, dimensions of quality and cost of quality. After reading this



chapter you can classify the causes of variations in process, explain statistical control techniques and plot and analyse control charts. You learned Control Charts for Variables (X-bar and R chart) and attributes (p and c chart). The chapter covered sampling plan, operating characteristic curve, consumer's and producer's risk. Also, you have an understanding in describing the DMAIC and DMADV models in addition to the six sigma idea and its importance.

7.9 GLOSSARY

Quality System: A quality system works in tandem with the production process to guarantee that the latter yields items of the highest possible quality.

Statistical Quality Control (SQC) : A methodology that uses statistical methods to gather and analyse data in the determination and control of quality.

Chance Causes: Some 'stable pattern of variation' or "a constant cause system" is inherent in any particular scheme of production and inspection.

Assignable Causes: Variation attributed to any production process is due to non-random and is termed as preventable variation.

Quality Control: Refers to a management technique that aims at improving the quality of products and services of an organization

Process Capability: Helps in assessing the ability of the production process

Six Sigma: Refers to a strategy for achieving perfection in all the processes of an organization

7.10 ANSWERS TO IN-TEXT QUESTIONS

1	Dimensions (of Quality)
2	False
3	cost of conforming, cost of failure
4	Shewhart charts
5	Statistical Process Control

7.11 SELF-ASSESSMENT QUESTIONS

1. What is quality control?



2. What is operating characteristic curve. Explain in detail.
3. Define control charts. Explain control charts for variable and attributes.
4. Distinguish between 100% inspection and acceptance sampling.
5. Discuss the steps in constructing X-bar and R charts.
6. The following table gives the number of defects noted in a in 100 m cloth bundles.

Sample No	1	2	3	4	5	6	7	8	9
No. of Defects	14	13	26	20	9	25	15	11	14

Construct and examine C-chart

6. Design a single sampling plan with the following parameters.
Producer's risk = .05; Consumer's risk = .10; Acceptable quality level = 0.04 and Lot tolerance per cent defectives = 0.10.
7. What is Six Sigma? Explain its benefits, principles, and framework.
8. Distinguish between DMAIC and DMADV.
9. Assume a lot of size 2000 units and a desired AQL of 1.5%. Design a double sampling plan.

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LESSON 8 LEAN OPERATIONS

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STRUCTURE

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8.1 LEARNING OBJECTIVES

The main objective of this chapter is to deeply study about The Toyota Production System (TPS). TPS is known for its world-class operation at Toyota Motor Corporation. In this chapter, we discuss JIT, TPS, and lean operations as approaches to continuing improvement that drive out waste and lead to worldclass organizations.

8.2 INTRODUCTION

The Toyota Production System (TPS), with its emphasis on continuous development, respect for people, and regular work standards, is well suitable for assembly lines.

With continuous improvement, lean operations give the consumer exactly what they want, when they want it, and without wasting anything. Workflow that is started by the "pull" of the customer's order drives lean operations. JIT, TPS, and lean systems maintain competitive



advantage and produce higher total returns when used as part of a holistic manufacturing plan. The distinction between JIT, TPS, and lean operations:

- Forced issue solving is emphasised in JIT.
- In an atmosphere of an assembly line, TPS prioritises employee learning and empowerment.
- Lean operations have a strong emphasis on client comprehension.

However, in practice, there is little difference, and the terms are often used interchangeably. Leading organizations use the approaches and techniques that make sense for them.

In this chapter, we use the term lean operations to encompass all of the related approaches and techniques. Regardless of the label put on operations improvement, eliminating waste, removing variability, and increasing throughput are three concerns that managers must solve in order to implement good production systems. We first introduce these three issues and then discuss the major attributes of JIT, TPS, and lean operations. Finally, we look at lean operations applied to services.

Eliminate Waste

Remove Variability

improve Throughput

8.3 JUST-IN-TIME

By With focus on throughput and decreased inventory, just-in-time (JIT) is a method that solves problems in a continual and forced manner. The ultimate goal of JIT is a balanced, smooth and rapid flow of material through the system. This can be achieved by approaching the following supporting goals first;

- Zerodefects.
- Zeroinventories.
- Zeroset –up time.
- Zerohandling.
- Zerobreak–down.



Preparation for JIT

A new JIT system cannot be created that can be utilized successfully without changes.

Since every manufacturing process differs (for instance, in terms of Objectives, Product needs, Customer requirements, etc.), it is up to each organization to choose the final JIT application and evaluate to what extent it is appropriate.

Before establishing a JIT manufacturing system, it is crucial to outline the plan and objectives.

Defining the Planning

Understanding JIT's aims and objectives as well as the goals and objectives of the JIT system are necessary for defining the planning process for a JIT manufacturing system. The planning phase then include figuring out what is needed to achieve the production objectives once they have been determined.

A JIT strategy aims to create a system that enables a manufacturer to have only the tools, personnel, and materials on hand necessary to complete the work. Six fundamental goals are necessary to accomplish this goal:

- Including and improving each stage of the production process.
- Manufacturing high-quality goods.
- Lowering the cost of production.
- Making goods as needed.
- Increasing the adaptability of manufacturing.
- Maintaining connections and agreements established between customers and suppliers.

8.3.1 JIT and Kanban System

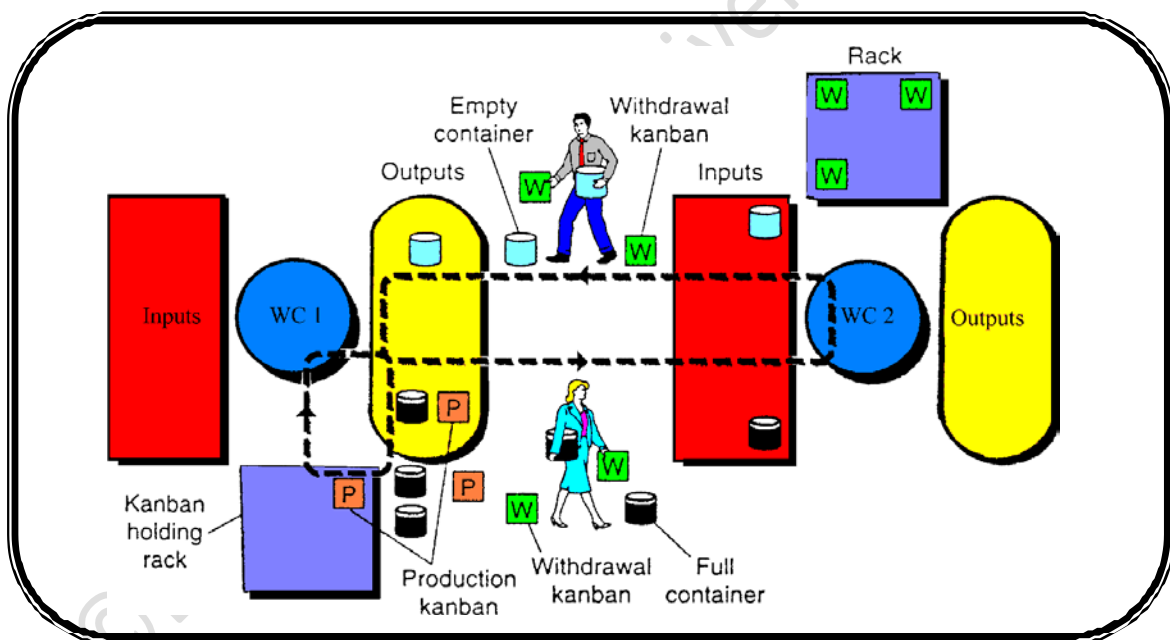
Sometimes the name "Kanban" is used interchangeably with JIT, but this is untrue. The Japanese word for "card" is kanban. The name "kanban" comes from the frequent use of cards to indicate the need for extra inventory. The kanban system is designed to only approve the manufacturing of materials when they are actually needed. This technique allows production to be "Pulled" via the system rather being "Pushed" out before it is required and then stored.



Part Description				Part Number	
Smoke-shifter, left handed.				14613	
Qty	20	Lead Time	1 week	Order Date	9/3
Supplier	Acme Smoke-Shifter, LLC			Due Date	9/10
Planner	John R.		Card 1 of 2		
			Location	Rack 1B3	

Figure (1): Kanban Card

A "withdrawal kanban" and a "production kanban" are the two cards typically used in a kanban system. The sole information on these cards, which also list the relevant work centres, storage location, and container capacity, is the part number and name. The strategy is shown in figure (2).



Figure(2)KanbanProcess

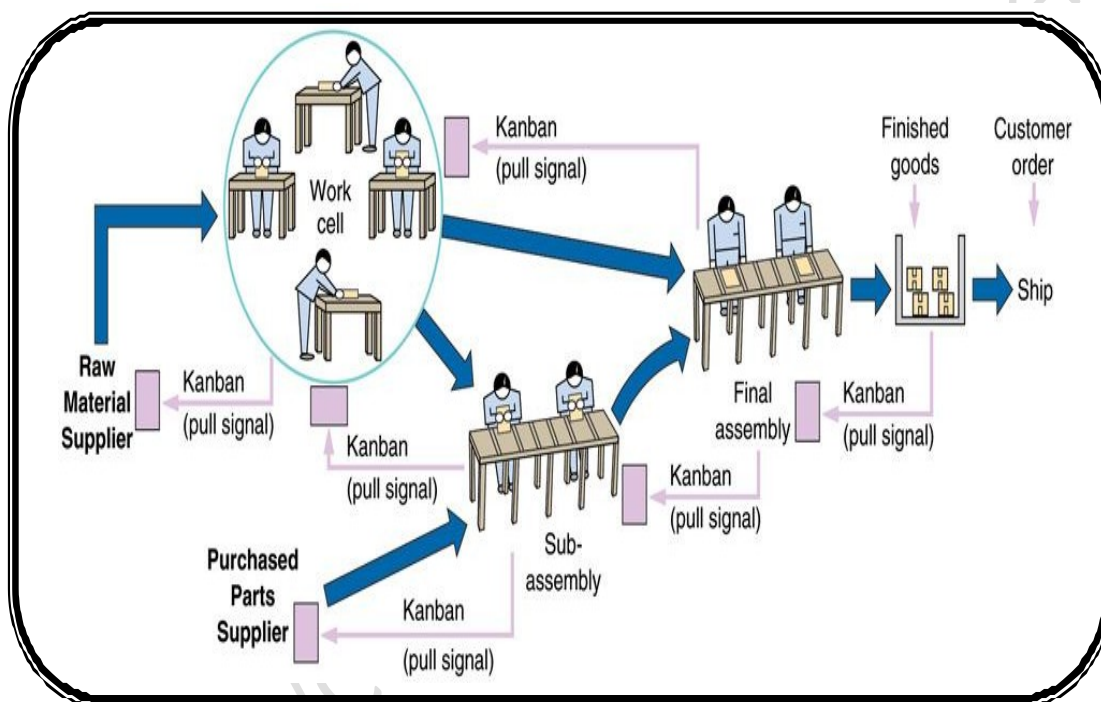
Assume, for example, that work flows are utilized to transfer output from Work Center No. 1 (WC1) to Work Center No. 2 (WC2), where it is used as input. When WC2 anticipates needing more input components, it returns to WC1 with an empty container and a withdrawal kanban. There it leaves the empty container. It finally withdraws the products from the



production team at WC1 and returns to WC2. It authorizes the creation of another container of parts by placing the production kanban in a rack at WC1. The withdrawal kanban is returned to its rack at WC2. Before it gets a production kanban approving more production, WC1 cannot start production and fill an empty container.

As a result, production kanban and withdrawal kanban both permit a work centre to produce more product and to remove more material from a work centre that supplies it.

Figure(3) displays the work of kanban system in manufacturing process:



Figure(3) work of kanban system in manufacturing process

Although the kanban system's key advantage is that it is implicit, it is inappropriate for many manufacturing situations and cannot be used without various prerequisites being prepared.

The goals of JIT

The following is a list of JIT's goals:

- Create flawless products.
- Make products with a short lead time.
- Produce products with only those attributes the buyer desires.



- Produce with no wastage of labour, supplies, or equipment; each action must have a specific goal in mind to ensure that there is no idle stock.
- Produce with approaches that allow for the development of individuals.

Conditions for the Effective Implementation of (JIT)

The following conditions must be satisfied for JIT to be successful:

1. The environment has to support it.
2. Step-by-step implementation of JIT is the best approach.
3. The best approach is a hybrid one that combines traditional and JIT. The conventional model will be employed as a backup plan if JIT is unsuccessful.
4. It's important to have a flexible management structure.
5. The JIT system's essential components must be in place. Some of them are:
 - (i) Good coordination between a small number of trustworthy suppliers.
 - (ii) Low inventories of finished goods, work-in-process materials, and raw supplies.
 - (iii) An appropriate material handling system, to prevent inventory of work-in-progress.
 - (iv) Limited lot sizes and quick lead times.
 - (v) Inexpensive setup

Advantages or Benefits of JIT

- Constant quality improvement.
- Price is decreased.
- Waste elimination.
- Production time is decreased.
- Increased output.
- Improved connections with suppliers.
- Production at low cost.
- Output without errors.



8.3.2 JIT LAYOUT

JIT designs minimise yet another form of waste movement. There is no value added by the movement of goods on a factory floor or by paper in an office. Thus, managers want adaptable layouts that limit both human and material movement. JIT layouts put the necessary content right where it is needed. To avoid having to send materials to a receiving department first and then move them again, an assembly line should be constructed with delivery points near to the line. The Wrangler Division of VF Corporation in Greensboro, North Carolina, implemented this; currently, denim is transported straight to the line. Toyota has taken this a step further by installing hardware and components in the chassis of every vehicle that is being built and is being moved down the assembly line. This is not only practical, but it also frees up space next to the assembly line that had previously been taken up by shelves. Reduced distance in a layout frequently results in labour and space savings for businesses, with the possible added benefit of removing potential sites for the accumulation of surplus merchandise.

Japanese industrial management technique known as "Just-In-Time" was created in the 1970s. Taiichi Ohno was the one who originally introduced it to Toyota manufacturing facilities. Meeting consumer expectations was the main priority at the time. A pull system is the just-in-time production process. The goal of the Just in Time (JIT) production philosophy is to eliminate causes of waste by obtaining the appropriate amount of raw materials and making the required amount of goods at the right location and time.

8.4 LEAN OPERATIONS

The main aim of lean management is to increase efficiency and productivity in manufacturing system. This is done through reducing the process waste and increase the product value.

Lean production starts with an exterior focus on the consumer, whereas JIT and TPS typically have an internal focus.

Lean production begins with knowing what the consumer wants and making sure they provide input and feedback.

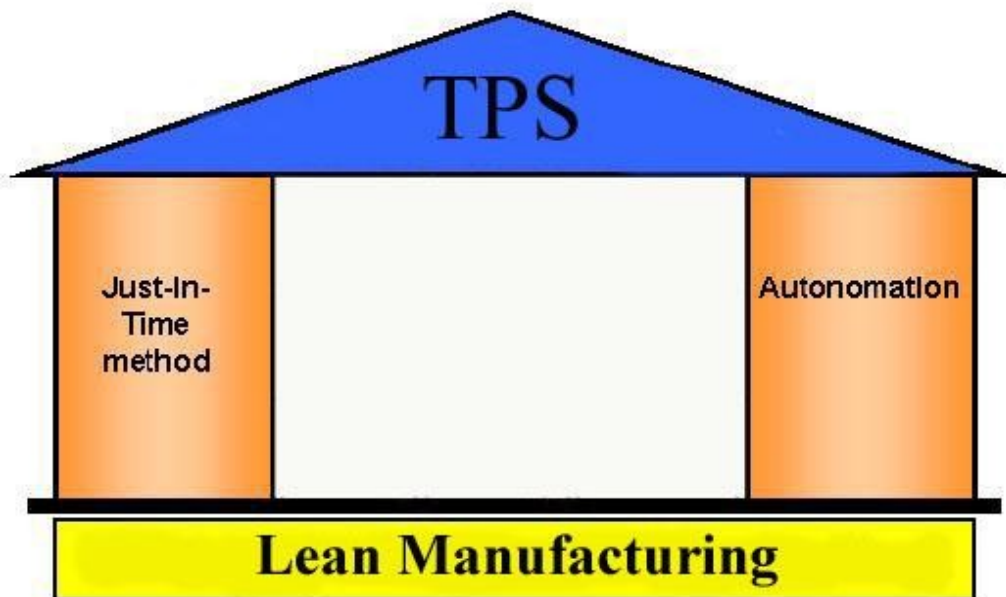
By examining all the steps necessary to manufacture a product, lean operations involves determining the customer value and then optimising the entire process from the customer's point of view.



Precision manufacturing Provide clients and consumers the goods or services they desire when they need them, in the most efficient manner with the fewest losses or omissions.

1.4.1 The Relationship Among JIT, TPS & Lean Manufacturing System

The Seven Wastes



A list of Seven Wastes

Waste is defined as something that does not add value from customers point of view. Waste is referred to as 'muda' in Japanese. Taichii Ohno identified seven types of waste in a manufacturing process. They are given as below:

1. Over-Production
2. Waiting
3. Transportation
4. Over processing
5. Inventory
6. Motion
7. Defective products

The Principles of Lean Manufacturing System

1. Reduced Setup Time
2. Value Stream Mapping,



3. Kanban system
4. Total Productive Maintenance
5. Cellular Production
6. Workplace organisation(5S)

1.4.2 Totalproductivemaintenance

In lean manufacturing, Total productive maintenance (TPM) is used to enhance equipment efficiency and effectiveness by greater involvement of employees in the process. TPM helps the organization in better maintenance and improvement of the equipment. TPM is regarded as a logical next step in the transition from run-to-breakdown to preventive maintenance in Japan, where it first appeared.

TPM incorporates some of the concepts of empowerment and teamwork, as well as a failure prevention strategy based on continuous improvement. Additionally, it views maintenance as a company-wide issue to which staff members can make some sort of contribution.

The main five goals of "TPM"

TPM attempts to implement good maintenance practises in operations by pursuing its five objectives:

- Increase equipment effectiveness by analyzing all losses that take place.
- Attain autonomous maintenance by giving staff members ownership over some maintenance duties and the enhancement of maintenance output.
- Create a maintenance plan that includes a thorough strategy for all maintenance tasks.
- Teach all employees the necessary maintenance abilities so that both operational and maintenance personnel are equipped to do their jobs.
- Attain early equipment management with "maintenance prevention" (MP), which entails taking maintenance issues into account during the equipment's design, production, installation, and commissioning.

The arrangement of the workplace (5S)

The 5-S acronym originated in Japan, and although it has only been roughly translated into English, it is commonly understood to stand for the following:



1. Sort (Seiri). Remove what is unnecessary and keep only what is required.
2. Place in order (Seiton). Place items where they can be quickly reached whenever they are needed.
3. Shine (Seiso). Keep everything clean and tidy; no garbage or dirt in the work area.
4. Standardize (Seiketsu). Keep everything nice and orderly at all times.
5. Maintain (Shitsuke). Get dedicated to upholding standards and take delight in doing so.

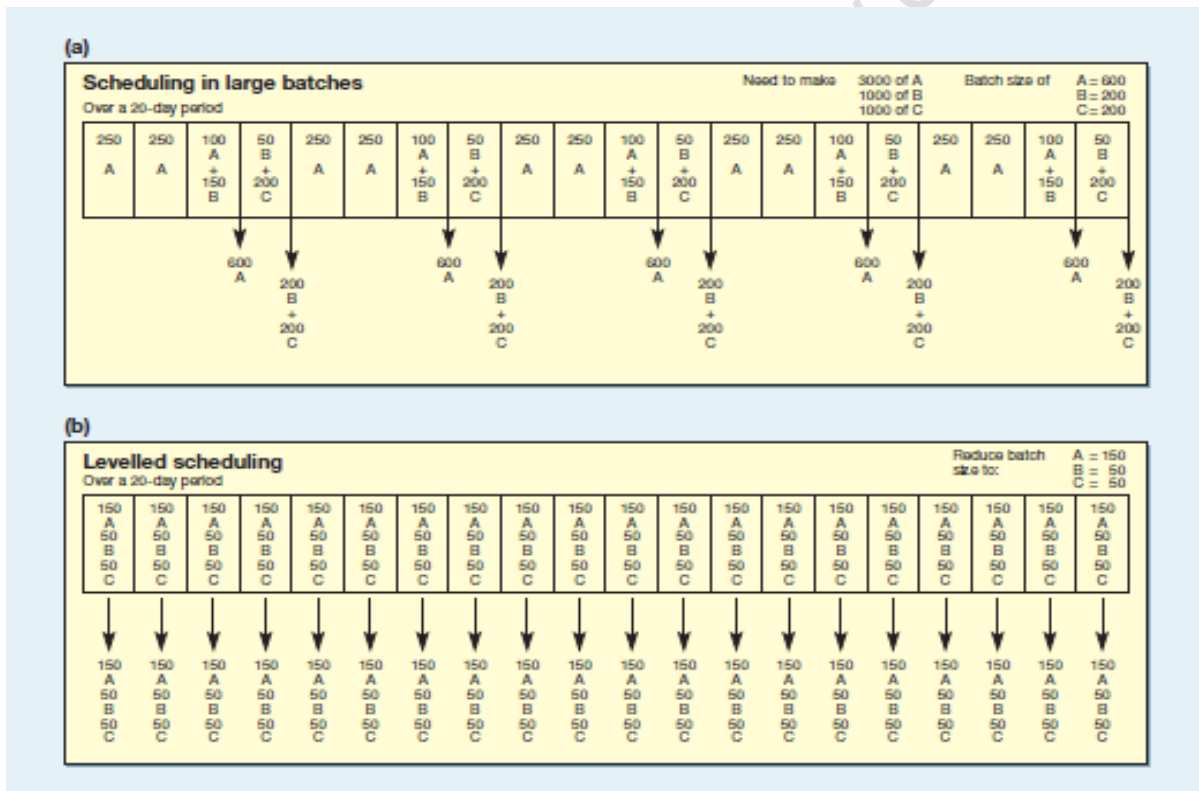
The 5S is a straightforward housekeeping system that emphasizes visual order, organization, cleanliness, and standardization in order to arrange work environments. It aids in removing any waste associated with ambiguity, waiting, looking for pertinent information, producing variance, and so forth. Clutter is decreased, important materials are always in the same location, and work is made easier and faster by getting rid of what is superfluous and making everything obvious and predictable.

JIT Environment with Levelled Scheduling

The Japanese phrase for levelled scheduling, heijunka, ensures that mix and volume are consistent over time. For example, levelling scheduling would force the operation to regularly produce just one piece each hour rather than 500 pieces in one batch, which would satisfy the needs for the following three months. Although the benefits of levelled scheduling can be significant, the requirements to put it into practice are rather onerous despite the levelled scheduling's simple theory. Figure(4) demonstrates the transition from traditional to levelled scheduling. Traditionally, a batch size would be established for each product and the batches would be produced in some order if a mix of items was needed in a time frame (often a month). Figure 4(a) shows three products (A, B and C) which are produced in batch sizes of 600, 200 and 200, respectively. Starting at day 1, the unit commences producing product A. During day 3, the batch of 600As is finished and dispatched to the next stage. The batch of Bs is started but is not finished until day 4. The remainder of day 4 is spent making the batch of Cs and both batches are dispatched at the end of that day. The cycle then repeats itself. Large batches have two negative effects: first, they cause the units to acquire a lot of inventory, and second, they cause most days to vary from one another in terms of the output they are expected to generate (in more complex circumstances, no two days would be the same).



If the flexibility of the process could be increased so the batch sizes were reduced to a quarter of their previous levels (see Figure 4 b), a batch of each product can now be completed in a single day. Smaller batches of inventory are moving between each stage, which will reduce the overall level of work-in-progress in the operation. Now, every day, the activity in the process is the same. This makes planning and control much easier. So, if on day 1 the daily batch of A was finished by 11.00 am and all the batches were successfully completed in the day, then the following day, if the process again completes all As by 11.00 am, it is on schedule. As every day is unique, it is impossible to answer the straight forward question, "Are we on?", by merely looking at the time. When does control become apparent and transparent to the schedule? requires some research. Progress can be hindered by the sameness of every day.



Figure(4) Levelled scheduling equalizes them ix of products made each day

Synchronization

Synchronization, which refers to the pacing of output at each stage of the manufacturing process to ensure the same flow characteristics for each part or product as it moves through each stage, is very similar to levelling scheduling. To do this, parts need to be categorized



according to the frequency with which they are requested. Making a distinction between runners, repeaters, and strangers is one way to do this:

Runners are goods or components that are produced regularly, such once a week.

Repeaters are goods or components that are regularly manufactured but at more spaced-out intervals.

Products or components that are created at irregular and possibly unpredictable intervals are known as strangers.

There are benefits to attempting to lessen timing interval variability. Synchronizing operations is the goal of creating runners and repeaters, giving the impression that manufacturing moves at a 'drum beat' pace. It may even be preferable to slow down quicker processes than to have them create more than what can be processed by the following process in the same amount of time. Output is made predictable and regular in this way.

Mixed Modelling

Mixed modelling, also referred to as the recurrent mix of parts, is associated with levelling scheduling. It implies that processes can eventually be created to be so flexible that they reach the JIT ideal of a "batch size of one". It was possible to gradually shorten the order in which each thing emerged from a process until a steady stream of each item was created. Hence, for instance, a constant mixed stream in the same ratio is created (**A A B A B C A B C A...** etc.) as opposed to **200 As, 120 Bs, and 80 Cs.**

Example 1

Suppose the number of products required in the 20 days period are: Product **A = 1920**

Product

$$B = 1200$$

Product **C = 960**

The cycle time for each product, or the amount of time between producing each unit of the same type of product, is as follows, assuming an eight-hour workday:

Product A, cycle time = $(20)(8)(60)/1920 = 5$ minutes
Product B, cycle time = $(20)(8)(60)/1200 = 8$ minutes
Product C, cycle time = $(20)(8)(60)/960 = 10$ minutes
So, the production unit must produce:

1 unit of A every 5 minutes 1 unit of B every 8 minutes 1 unit of C every 10 minutes



Alternatively, by identifying the same characteristic of 5, 8 and 10: 8 units of A every 40 minutes
5 units of B every 40 minutes
4 units of C every 40 minutes

This means that a sequence that alternates between eight units of A, five units of B, and four units of C and repeats every 40 minutes will result in the desired output. To create this blend, the goods will be sequenced in a variety of ways, such as: **BACABACABACABACAB...repeated...repeated**

Every 40 minutes, this process repeats itself and creates the right mixture of items to meet the monthly requirements.

Analysis for Number of Kanbans

The Kanban system aims to continuously reduce inventory. The number of kanbans is determined in the manner described below:

$$N = (D)(L)(1 + S) / C$$

Where

N: Number of kanbans or containers

D: Demand units (average number over a given time period)

L: lead period (time to replenish an order, expressed in the same time unit as expressed in demand)

S: Safety stock, based on service level and variation of demand throughout lead time, expressed as a percentage of demand during lead time.

C: Container size,

Container size may be kept much smaller (say 10 to 16%) than the average demand due to the necessity of a constant improvement process during the lead period.

Example 2: In a cellular manufacturing system for making auto parts, a production manager is employed. In the cell, he must typically process 250 pieces each hour. The capacity of each container is 30 pieces and one kanban is attached to all the containers. It takes 25 minutes to get fresh parts from the prior work centre. Factory keeps a 15% safety stock component. Establish how many kanbans the plant needs.

**Solution**

Given:

$$D = 250 \text{ parts per hour}$$

$$L = 25 \text{ minutes} = 25/60 \text{ hours} = 0.4167 \text{ hour} \quad S = 0.15$$

$$C = 30 \text{ parts}$$

Now, since number of Kanbans is $N = (D)(L)(1 + S)/C$

$$= (250)(0.4167)(1 + 0.15) / 30$$

$$= 3.993 \text{ kanbans or container} \sim 4 \text{ kanbans or containers}$$

D: Demand units (average number over a given period of time)

L: Lead time (time to replenish an order, expressed in the same time unit as expressed in demand)

S: Safety stock (as a percentage of demand during lead time), based on service level and variance of demand during lead time

C: Containersize

Container size would be kept much smaller (say 10 to 16%) than the average demand during the lead time, as this will continuously improve the process.

8.5 TOYOTA PRODUCTION SYSTEM

Toyota Motor's Eiji Toyoda and Taiichi Ohno are given credit for the Toyota Production System (TPS) (see the Global Company Profile that opens this chapter). Three core components of TPS are continuous improvement, respect for people, and standard work practice.

Toyota established an integrated socio-technical system called the Toyota Production System (TPS), which includes its management methods and philosophy. For the automaker, the TPS coordinates manufacturing and logistics, as well as interactions with suppliers and clients. It was created between 1948 and 1975.

Continuous Development

Building an organisational culture and instilling in its workers a value system that emphasises that processes can be improved—indeed, that improvement is an inherent part of every



employee's job—are key components of continuous improvement under TPS. This process is formalized in TPS by kaizen, the Japanese word for change for the good, or what is more generally known as continuous improvement. In application, it means making a multitude of small or incremental changes as one seeks elusive perfection. (See the OM in Action box “Kaizen at Ducati.”). Instilling the mantra of continuous improvement begins at recruiting and continues through extensive and continuing training. One of the reasons continuous improvement works at Toyota, we should note, is because of another core value at Toyota, Toyota’s respect for people.

Respect for People

People are hired, trained, and treated like knowledge workers at Toyota. With the use of vigorous cross-training and minimal job classifications, TPS challenges employees to use both their cerebral and physical capacities to improve operations. The workforce is empowered. They have the authority to implement changes. They are empowered to stop machines and processes when quality problems exist. Indeed, empowered employees are a necessary part of TPS. This means that those tasks that have traditionally been assigned to staff are moved to employees. Toyota recognizes that employees know more about their jobs than anyone else. TPS shows respect for its employees by allowing them the chance to improve both their lives and their jobs.

Standard Work Practice

These guiding principles are part of Toyota's standard working procedures.

- Work is completely stated as to content, chronology, scheduling, and outcome.
- Direct links between internal and external customers and suppliers that describe individuals, methodologies, time, and quantity.



Toyota Production System Principles

1. Constant development.
2. Root cause investigation.
 3. Visualization.
 4. A proof error.
 5. Set work standards.
 6. Respect for workers.
 7. Simplification.
8. Always addressing underlying issues.

8.6 SUMMARY

JIT, TPS, and lean operations are philosophies of continuous improvement. Lean operations focus on customer desires, TPS focuses on respect for people and standard work practices, and JIT focuses on driving out waste by reducing inventory. But all three approaches reduce waste in the production process. And because waste is found in anything that does not add value, organizations that implement these techniques are adding value more efficiently than other firms. The expectation of these systems is that empowered employees work with committed management to build systems that respond to customers with ever-lower cost and higher quality.

8.7 GLOSSARY

5S

The 5s approach is used to arrange the workspace:

- Sift your items and get rid of everything unnecessary.
- Arrange remaining elements in a straight line.
- Shine: tidy up and examine the workspace.
- Standardize: Create guidelines for the aforementioned
- Maintain: consistently uphold the principles



Study of bottlenecks

Bottleneck analysis identifies the manufacturing process step that restricts overall throughput and works to enhance that step's efficiency.

Jidoka (Autonomation)

Jidoka is developing machinery that will allow for some partial automation of the production process (partial automation is often significantly less expensive than complete automation) and will halt operations automatically in the event of a defect. Kaizen (Continuous Improvement).

“Employees actively collaborate under the kaizen strategy to enhance the manufacturing process on a regular basis.”

Kanban (Pull System)

A way of controlling the flow of goods between the factory and external suppliers and customers is called kanban. Utilizing signal cards that automatically replenish stock when additional commodities are required.

8.9 SELF-ASSESSMENT QUESTIONS

1. The six attributes of lean organization are _____.
2. Lean applies to services:
 - a) only in rare instances.
 - b) except in terms of supply chain.
 - c) except in terms of employee issues.
 - d) except in terms of both supply chain issues and employee issues.
 - e) just as it applies to manufacturing.
3. What are the seven wastes identified in a manufacturing process?
4. What is lean methodology?
5. What are Muri, Mura and Muda?

8.10 REFERENCES



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LESSON 9

THEORY OF CONSTRAINTS

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STRUCTURE

- 9.1 Learning Objectives
- 9.2 Introduction
- 9.3 Theory of constraints
- 9.4 Critical Chain Project Management
- 9.5 Project Management Processes
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9.1 LEARNING OBJECTIVES

The objectives of the lesson will indicate the idea of management Guru Eli Goldratt's. He proposed the idea that managing "constraints" is the key to maximizing the throughput and efficiency of business processes.

He argued that a manager should focus on managing the resource that most limits the process from achieving its goal. This resource is called the "bottleneck" and nothing can be achieved beyond the capability of the bottleneck.



9.2 INTRODUCTION

In 1980, Goldratt noted that many manufacturers were not managing their inventories and resources effectively. To improve this situation, he and his associates at Creative Output developed software that enables them to schedule their jobs through the various processes of their operations. This method, known as OPT, was then introduced to help firms comply with their production schedules.

Recognizing the importance of constraint theory in today's business environment, Goldratt expanded his scope and created the "Theory of Constraints," a practical approach that can be used to solve problems. In figure 9.1, we introduce the basics of understanding this concept.

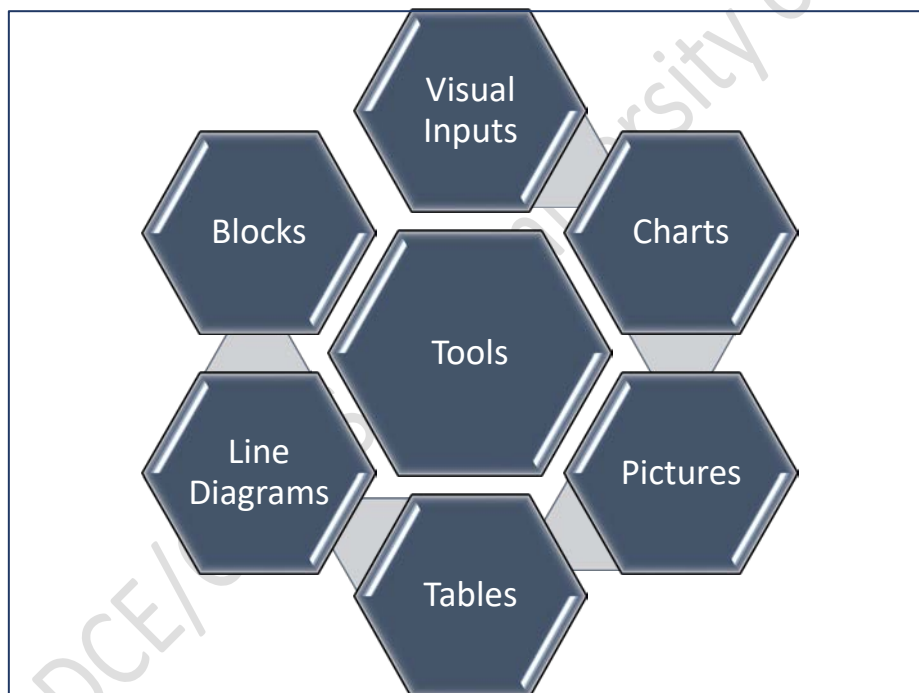


Fig 9.1: Tools to create interest among learners(Source: www.abcd.com)

9.3 THEORY OF CONSTRAINTS

The Theory of Constraints states that limitations determine how well a system functions. A limitation is something that prevents a system from improving in relation to its goal. The concept of constraints was first applied in the context of business networks. Dr. Goldratt



believes that the objective of a for-profit organisation is to increase profits both now and in the future.

Limitations on resources include things like a person or department's inability to satisfy market demand. If the division could raise production, it would boost sales and bring in more money. If all divisions are able to satisfy customer demand, there is a market restriction. The business would make more money if more could be sold because the ability to produce more already exists. There are also policy limitations and dummy constraints. A management choice or company mindset that restricts the system is referred to as a policy constraint. For example, the plant featured in Goldratt's novel, *The Goal*, had a resource constraint.

This resource was initially unavailable between lunchtime and shift changes, costing four to five hours per day spread across three shifts. This rule imposed restrictions. The plant's throughput was raised by utilising the resource fully at all times. A resource constraint that can be broken easily is called a dummy constraint. For example, in *The Goal*, the setup crew was a limitation since the resource that was the constraint occasionally went down. Because the cost of a setup team is so low compared to the thousands of dollars per hour that would be lost if the constraint was inactive, it is a dummy constraint. This fictitious constraint was broken by applying a dedicated setup crew to the resource constraint. It is helpful to contrast the theory of constraints with two other well-liked methods of continuous improvement, Six Sigma and lean manufacturing. Both Six Sigma and lean methodologies place a strong emphasis on lowering costs through the elimination of waste and the reduction of variability at each stage of a process or in light of each individual system component. The TOC five-step technique, in comparison, is more narrowly applied. It concentrates its improvement efforts solely on the operation that is impeding a crucial procedure or on the system as a whole's least reliable element. If these elements are adequately managed, the system will perform better overall in relation to its objective, increasing the likelihood that it will be accomplished..

9.3.1 Goldratt's Rules of Production Scheduling

Here we discuss some basic rules of production as follows:

- Do not balance capacity - Balance the flow.
- The level of utilization of a no bottleneck resource is determined not by its own potential but by some other constraint in the system.
- Utilization and activation of a resource are not the same.



- An hour lost at a bottleneck is an hour lost for the entire system.
- When there is no bottleneck, an hour spared is a mirage..
- Bottlenecks govern both throughput and inventory in the system.
- The transfer batch may not, and many times should not, be equal to the process batch.
- A process batch should be variable both along its route and in time.
- Priorities can be set only by examining the system's constraints. Lead time is a derivative of the schedule.

9.3.2 Goldratt's Theory of Constraints (TOC)

There are five steps for theory of constraints which has given by Goldratt's and shown below:

- (i) Identify the system constraints. (No improvement is possible unless the constraint or weakest link is found.)
- (ii) Decide how to exploit the system constraints. (Make the constraints as effective as possible.)
- (iii) Subordinate everything else to that decision. (Align every other part of the system to support the constraints even if this reduces the efficiency of no constraint resources.)
- (iv) Elevate the system constraints. (If output is still inadequate, acquire more of this resource so it no longer is a constraint.)
- (v) If, in the previous steps, the constraints have been broken, go back to Step 1, but do not let inertia become the system constraint. (After this constraint problem is solved, go back to the beginning and start over. This is a continuous process of improvement: identifying constraints, breaking them, and then identifying the new ones that result.)

9.3.3 Evaluate bottleneck scheduling problems by applying TOC principles

The purpose of this, the analyse bottleneck resources and apply TOC principles to controlling a process. A bottleneck is defined as any resource whose capacity is less than the demand placed upon it.

A bottleneck is a constraint within the system that limits throughput. It is that point in the manufacturing process where flow thins to a narrow stream. A bottleneck may be a machine, scarce or highly skilled labour, or a specialized tool. Observations in industry have shown that most plants have very few bottleneck operations.



Bottleneck, a resource that restricts the process's capacity or utmost output. If there isn't a bottleneck, there is excess capacity, and the system needs to be changed to add a bottleneck (perhaps with more setups or a smaller capacity), as we'll address later.

Here the meaning of capacity is defined as the available time for production. This excludes maintenance and other downtime.

Any resource whose capacity exceeds the demand put on it is said to be at a bottleneck. Therefore, a no bottleneck shouldn't be operating continuously because it can create more than is required. A no bottleneck contains idle time. "No bottleneck Any resource whose capacity is greater than the demand placed on it (Goldratt's definition)".

Another important concept in TOC, a capacity-constrained resource (CCR) is one whose utilization is close to capacity and could be a bottleneck if it is not scheduled carefully. For example, a CCR may be receiving work in a job-shop environment from several sources.

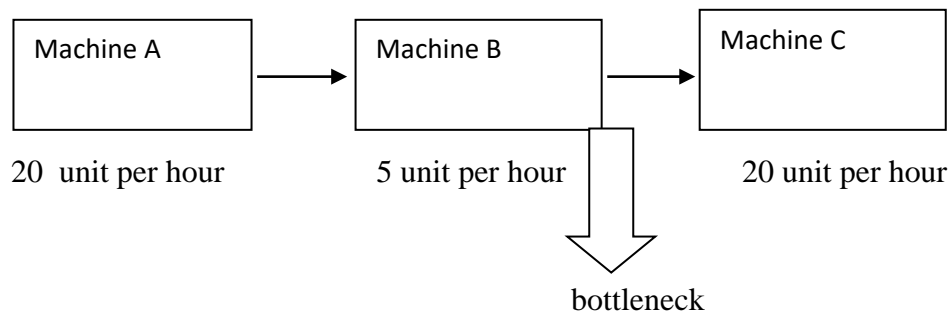
If these sources schedule their flow in a way that causes occasional idle time for the CCR in excess of its unused capacity time, the CCR becomes a bottleneck when the surge of work arrives at a later time. This can happen if batch sizes are changed or if one of the upstream operations is not working for some reason and does not feed enough work to the CCR. Thus to increase the throughput, one must focus on identifying and improving the bottleneck or constraint.

Suppose if there are bottlenecks in your operation then first identifying the all bottlenecks becomes essential, because it leads to the loss in revenue increased waiting time between different operations and loss the customers and finally the poor quality of product will be produced so identify them and fixing and try to remove them

Basically bottleneck leads to:

- Loss in revenue.
- Increase waiting time.
- Poor quality product.
- Loss of customer .

Let us take one manufacturing example here, so in this example machine A has a capacity of 20 units per hour and machine B has a capacity of 5 units per hour and for machine C has 20 per hour, now in this case the machine A can process more parts but machine B is not efficient enough to produce that much part that is why machine B is a bottleneck in the example.



Types of Bottleneck

There are two types of bottleneck the first is short-term bottleneck and second one long - term bottleneck.

The sort-term bottleneck are caused by temporary problems it will only remain shorter period of time. It could be the operator is missing for certain period of time, resulting in the lot of pileup of works or delay in receiving materials from another vendor or it could be the obstruction in your supply chain or limited staff due to some festival holidays.

The long-term bottleneck are which are reoccurring it remains for a long time or it effects your production line, your capacity by huge margin and they may also result in the loss in the revenue. Thus that is consider as a major bottleneck, it could be because of the lack of appropriate technologies limited funds and resources are organised workforce, less trained workers and lean manufacturing techniques which are not applied.

Bottleneck Analysis

Basically, The bottleneck analysis is a process of identifying "bottleneck"

Bottleneck analysis tools:

- 5 why root cause analysis
- Fishbone diagram
- Theory of constraints (TOC)

Common causes of bottleneck:

- Poor line balancing
- Inadequate process control

How to dealing with bottleneck:

- Increase additional capacity
- Eliminate non-value-added steps
- Add additional workforce
- Balance production line



Bottleneck Analysis and Theory of constraints

- Each work area can have its own unique capacity
- Capacity analysis determines the throughput capacity of workstation in a system
- A bottleneck is a limiting factor or constraints
- A bottleneck has the lowest effective capacity in a system

Process Time for Stations, System and Cycles

- The **process time of a station** is the time to produce a unit at that single workstation.
- The **process time of a system** is the time of the longest process in the system or the bottleneck.
- The process cycle time is the time it takes for a product to go through the production process with no waiting

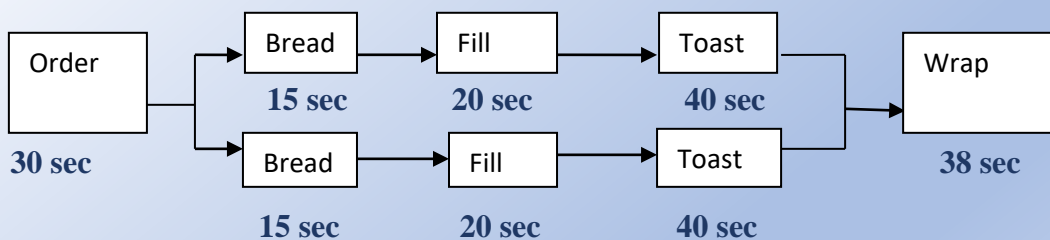


Fig. 9.3: Process of making Sandwich capacity per hour

In the fig: 9.3, two identical sandwich lines and these lines have two workers and three operations and all completed sandwich are wrapped.

- Toast work station has the longest processing time - 40 seconds
- The two lines each deliver a sandwich every 40 seconds so the process time of the combined lines is $\frac{40}{2} = 20$ seconds
- At 38 second, wrapping and delivery has the longest processing time and is the bottleneck
- capacity per hour is 3600 seconds so $\frac{3600}{38} = 95$ sandwich per hour
- The process cycle time is $30 + 15 + 20 + 40 + 38 = 143$ seconds.



9.4 CRITICAL CHAIN PROJECT MANAGEMENT

In 1997, Dr. Eliyahu M. Goldratt created the Critical Chain Project Management or (CCPM) concept. The theory of constraints, another one of Dr. Goldratt's theories, and CCPM have a strong relationship. Using the concept of constraints, you can identify the main bottlenecks or limiting factors hindering the successful completion of your project. The hypothesis holds that every project has a single major constraints that could lead to its failure by severing its weakest link.

Using the critical chain project management (CCPM) methodology, you can prioritise dependent tasks within a project and keep an eye on key resources. Discover how to implement this framework to aid in resource management and project completion for your business.

Consider yourself a young child playing with blocks. You have a limited quantity of blocks at your disposal, but you can construct anything you like. You draw your resources from the available stockpile of blocks as you progress. However, what happens if you exhaust all of your options? How can you be confident that the blocks you have will allow you to construct what you want to? Basically this is the concept behind critical chain project management (CCPM).

What is critical chain project management (CCPM)?

Critical chain project management is a project management methodology that helps you monitor essential resources and prioritize dependent tasks - Now you can complete projects as efficiently as possible. If you and your team is looking to carefully monitor the usage of resources, the critical chain project management (CCPM) is more good strategy to keep track of those resources.

1.4.1 Critical chain method (CCM) vs Critical path method (CPM)

Although there is a significant variation between these two project management models, they are fairly similar. The critical path technique focuses on the single set of concurrent tasks that must be finished for a task to be completed. The critical path emphasises all of the actions that are absolutely essential for the project's completion, even when other tasks may still need to be finished. Teams can use this method of project management to determine the best procedure to use when developing a project timeline. All jobs are given a lower priority if they are not on the critical path. The success of a project depends on whether or not certain crucial activities are finished by a specific deadline.



1.4.2 Components of a critical chain

A critical chain is composed of the critical path, the feeding chain, and resource buffers as its three primary components. All components of critical chain briefly explain below:

- (i) **The critical path:** The critical route is the lengthiest chain of related tasks that must occur in order to finish a project. In other words, it consists of all the activities that must be carried out in a specific order in order for a project to succeed. It's crucial to comprehend that there are several levels of dependencies while using the critical chain approach. The critical path, also known as the project critical path, has the highest degree of dependencies or project critical activities. If a job has no bearing on the critical path, it is transferred to another path, also known as the feeding chain.
- (ii) **The feeding chain:** The critical path must operate concurrently with a secondary chain of dependent tasks known as the feeding chain. The critical path finally combines with each feeding chain. This is so because just one of the jobs on the critical path is impacted by the series of events in the feeding chain. To avoid any delays on the critical path, the feeding chain must operate concurrently with the critical path.

Let's look at a straightforward example of the critical path and the feeding chain. Imagine you are organising a work party. Your critical route appears as follows:

- Decide on a theme
- Send out party invites
- Find a venue
- Host event

Even though there are still key route steps, there are some feeding chain chores that must be completed simultaneously with the critical path. For instance, the group must decide who to invite to a party before sending out invitations. Prior to hosting the event, they must set up the venue and buy decorations that fit the theme. These are all illustrations of feeding chain tasks.

- (iii) **The resource buffers:** Buffers are safety measures incorporated into the critical chain's resources to guarantee a project's success. These buffers, like bumpers in a bowling lane, are intended to provide projects more leeway in the event that anything doesn't go as planned. Mainly we have three types of buffers which are commonly used in the critical chain project management methodology:
 - **Project buffers** - "The extra time that's placed between the final task and the end of the project. Adding an extra chunk of time before the expected due date gives team



members a chance to catch up on any outstanding project tasks they couldn't get to earlier".

- **Feeding buffers** - Some times, we placed the extra time between the feeding chain (also called as the non-critical chain) and the critical chain. "Adding this buffer into the timeline prevents any delays from the feeding chain affecting the critical chain."
- **Resource buffers** - The resource buffers are literal resources, you set aside in case the critical chain is in need of extra supplies - like extra team members to have on hand, additional more equipment, or help from a third-party.

We have four steps for using the critical chain project management process

If you are using first time the critical chain project management process, we can use the following four steps to get you started.

Step1: First identify the critical path

The critical path is the backbone of your entire project when you use the critical chain methodology. Finding out which specific tasks make up that core chain is crucial because it forms the basis of all planning.

Step 2: Predict the exact amount of resources your project requires

Here, the term "resources" can refer to the time required by your team members, the real materials and equipment your team needs to produce the finished output, or the actual people required to finish a task. If you can, estimate how many resources you will need to complete this project. Also estimate how many people it will take to complete a specific task on the critical chain, and approximately how long it will take them. We have to do this for every task laid out on the critical chain. According to on these calculations, do you have enough resources to finish this project?

If we have any known resource constraints in advanced, such as team members leaving due to vacation, we can plan around those constraints. This is one of the major helpful of using the critical chain methodology, the bulk of the project planning happens before the project even begins.

Step 3: Place your buffers

It is much simpler to decide where to place buffers and how much time or resources your buffers should contain once the resources needed for the critical path and feeding chains have been established. This will give you an opportunity to count the buffers you should build



based on the requirements you have already calculated when creating the critical path. When a project manager is handling buffer management, they can help maintain resource availability and prevent any bottlenecks.

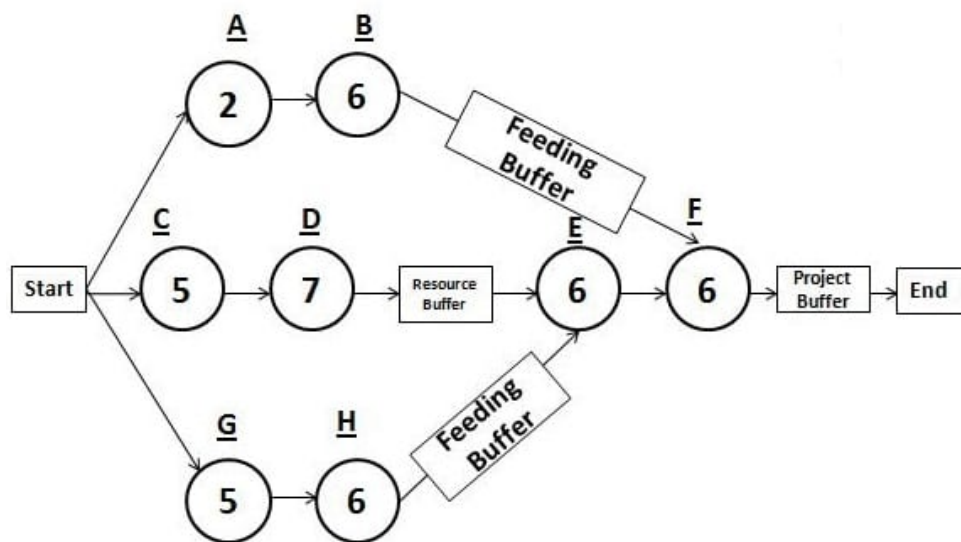
Step 4: focused on team members

The worst enemy of your team is multitasking. It may be more difficult for all of your team members to perform work at their usual high rate and high quality when they are required to switch between numerous jobs or projects.

Firstly, ensure your team members have to stay on track with the project schedule, do not assign one person into many different tasks. If you keep them oriented on one task or one project, they are more likely to stay focused. To ensuring team members are not working on too many different projects at once can also help prevent context switching, which can be lead to stress and burnout.

9.4.3 Critical Chain Method or (CCM)

Before discussing CCM, let’s first we understand the critical chain. When activity interdependence and resource limitations are taken into account, the critical chain is "the longest path in the network diagram."



(Path “Start→ C→ D→ E→ F→End” is the critical chain.)

Now we come to the Critical Chain Method



A modernised version of the Critical Path Method is the CCM. Here, when you create the project timeline, take resource availability into account.

Instead than using a float, the Critical Chain Technique employs a buffer. These buffers eliminate the concept of float or slack.

The critical path is a unique instance of the critical chain that occurs when a project has infinite resources.

Critical Chain Method Illustration

Consider receiving a project to build a structure. You begin the job after creating a schedule using the Critical Path Technique.

But, when this project is being carried out, you learn that:

- There is a scarcity of cement, or
- Equipment from your project is assigned to some other projects, or
- Management has pulled one team member for some essential job.

What will occur next?

Naturally, this will make your project take longer.

Where then was the issue?

The resources your project needs may not have been identified by the critical route.

No, the resources for your activities were determined by the critical path.

Where then was the issue? What happened?

The distribution of resources was the issue. Despite the fact that the critical path identified the resources, it did not take into consideration their limited availability.

It was assumed that all resources would be accessible at all times while creating the project schedule. Sadly, this was not possible, which caused a delay in the schedule. To remedy these problems, you add resource limitations to your critical path, which results in a more realistic model called a critical chain network diagram.

You may now finish your job with more assurance.

Let's review a few crucial elements of critical chain management, which are listed below:

- The model is deterministic.



- It prevents improper slack or float management.
- It maximizes the use of available resources.
- The completion of projects using the critical chain technique is 10% to 30% faster than using the critical path method.
- It is a more practical approach.
- It increases output.

9.5 PROJECT MANAGEMENT PROCESS

One of the most important processes in any project is the project management. This is because the primary process that brings all other project activities and procedures together is project management. There are several project management activities to choose from. These numerous project management tasks can be divided into five primary stages, though.

Let's take a closer look at each of the five primary project management processes.

- (i) **Project Initiation:** Any project must begin with project initiation. All of the steps necessary to win a project are taken during this procedure. The pre-sale is typically this phase's primary activity. During the pre-sale period, the retailer proves the eligibility and ability of completing the project to the client and eventually wins of business. Then, this is the detailed requirements gathering which comes further.

During the requirements gathering activity, all the client requirements are gathered and analysed for implementation. In this activity, negotiations may take place to change certain requirements or remove certain requirements altogether.

- (ii) **Project Planning:** One of the primary project management processes is project planning. The project's subsequent phases could suffer greatly if the project management team makes a mistake at this stage. Therefore, the project management team will have to pay detailed attention to this process of the project.

In this process, the project plan is derived in order to address the project needs such as, requirements scope, budget and timescales. The project schedule is created after the project plan has been determined.

Afterwards, the resources are assigned to the project based on the budget and the timeline. When it comes to project cost and effort, this phase is the most crucial.



(iii) Project Execution: At this phase, the project management puts the plan into action to accomplish the project's goals after all the paperwork is completed.

When it comes to execution, each team member completes their respective tasks by the deadline specified for each activity. The thorough project schedule will be utilised to monitor project development.

Many reporting tasks must be completed throughout the project's execution. The company's senior management will need status updates on the project's advancement every day or every week.

Additionally, the client might also want to monitor the project's development. Tracking the effort and cost of the project is essential to determining whether or not it is moving in the right direction during project execution.

During the project's execution, there are numerous deliverables that must be performed in addition to reporting. Project deliveries are typically not one-time items given at the project's conclusion. Instead, the deliveries are spaced out across the course of the project's execution and are made according to schedule.

(iv) Control and Validation: The project activities should be meticulously regulated and validated throughout the project life cycle. Following the early procedures, such as the project plan, quality assurance test plan, and communication strategy for the project, can be done in large part to control.

There may occasionally be situations that fall outside the purview of such protocols. When this occurs, the project manager should take the appropriate and required measurements to keep things under control.

The supporting activity of validation lasts from the first to the last day of a project. Each and every activity and delivery should have its own validation standards to ensure that the intended result was achieved or that the task was successfully completed.

(v) Closeout and Evaluation: It's time to hand over the implemented system and wrap up the project once all of the project requirements have been met. The project will be formally accepted and paid for by the customer if the project deliveries meet the client-defined acceptance criteria.

After the project has been completed, it's time to review it as a whole. The errors made by the project team will be documented in this review, and the necessary actions will be taken to avoid them in future projects. The service provider may discover during the project evaluation phase that they didn't achieve the projected margins and may have gone beyond the initial timetables.



In these situations, the service provider's project is not entirely successful. As a result, it's crucial to carefully evaluate these incidents and take the necessary safety measures to avoid them in the future.

9.6 SUMMARY

Eli Goldratt put forth the notion that managing "constraints" was essential to increasing throughput and business process effectiveness. A manager should concentrate on the "bottleneck," or weakest resource, that prevents the business from reaching its objective. Find the bottleneck, make the necessary improvements, and then repeat the previous steps for each iteration.

Goldratt and collaborators created a programme called "optimized production technology" or (OPT) that scheduled tasks throughout the manufacturing process. This distinction between bottleneck and nonbottleneck processes served as the foundation for the logic, which adhered to Goldratt's nine production scheduling rules. By adhering to the aforementioned rule, a production process is referred to as synchronous manufacturing when it coordinates to cooperate in order to accomplish the objectives of the company.

A more realistic method for creating the project timeline is the Critical Chain Technique. When laying out the network, it takes into account the resources that are available.

One of the most significant recent advancements in project management is the Critical Chain Technique. This approach boosts productivity, addresses numerous flaws in the Critical Path Method, offers a realistic schedule, and motivates team members to work well.

9.7 GLOSSARY

1. Financial Measurements

Net Profit: Absolute measurement in dollars.

Return on investment: Relative measure based on how much invested for the net profit

Cash Flow : Survival Measurement as cash necessary for daily operations and to pay bills.

2. Operational Measurements

Throughput: Rate at which money is generated by the system through sales. specifically defined for goods sold. Actual sales must happen. Defined this way to prevent illusion that goods might be sold.



Inventory: Inventory is the total amount of money spent by the system on items it plans to sell. Only the expense of raw materials was valued. Ignoring labour expenses and machine hours. This eliminates the problem of separating direct from indirect expenses.

Operating Expense: The cost incurred by the system to convert inventory to throughput. Includes administrative expenses as well as production costs like labour, inventory-carrying costs, etc.

3. Time Components

The following kinds of time make up production cycle time

Setup time: The time that a part spends waiting for a resource to be set up to work on this same part.

Processing time: The time that the part is being processed.

Queue time: The time that a part waits for a resource while the resource is busy with something else.

Wait time: The time that a part waits not for a resource but for another part so that they can be assembled together.

Idle time: The unused time; that is, the cycle time minus the sum of the setup time, processing time, queue time, and wait time.

4. The Goal of the Firm

Goldratt has a very straightforward idea about the goal of any firm:

"THE GOAL OF A FIRM IS TO MAKE MONEY".

From an operations standpoint, the goal of the firm is to increase throughput while simultaneously reducing inventory and reducing operating expense.

5. **Bottleneck:** Resource whose capacity is less than demand placed upon it. It limits the capacity or maximum output of the process.
6. **Nonbottleneck:** Resource whose capacity is more than demand placed upon it.
7. **Capacity-constrained resource (CCR):** Resource whose utilization is close to capacity and could be bottleneck if not scheduled properly.



9.9 SELF-ASSESSMENT QUESTIONS

1. In the theory of constraints, the pace of a non-bottleneck production operation is controlled by the pace of
 - (i) the previous (upstream) operation.
 - (ii) the next (downstream) operation.
 - (iii) a bottleneck operation.
 - (iv) another non bottleneck operation..
2. One of the key ideas in Goldratt's theory of constraints is to maximize throughput by
 - (i) balancing the production line, i.e., equal capacity at each operation.
 - (ii) balancing the flow of work in the plant.
 - (iii) maximizing production at each operation.
 - (iv) a and b.
3. An objective in the theory of constraints is to
 - (i) balance the capacity of each operation in the plant so that all operations will produce at the same pace.
 - (ii) balance the flow of work by allowing the most binding constraint to set the pace for the plant.
 - (iii) balance the capacity of each operation by recognizing the variability within the system.
 - (iv) balance the flow of work by allowing each operation to produce at it's own pace.
4. Which of the following is not correct critical path method (CPM) used in project scheduling?
 - (i) The path with the longest time sequence the critical path.
 - (ii) For each activity earliest start time and latest start time are computed.
 - (iii) The length of the critical path determines the minimum time in which the entire project can be completed.
 - (iv) The path with the shortest time sequence is the critical path



5. Critical path method is good for

- (i) Small project only.
- (ii) Large project only.
- (iii) Both small and large projects equally.
- (iv) Neither small nor large projects.

Answers: 1. (iii) 2. (ii) 3. (ii) 4. (iv) 5. (ii)

6. What are the name of software Goldratt developed to implement his idea of TOC ?

7. What are the term that refers to the entire production process working in harmony to achieve the profit goals of the firm ?

8. Describe the Project Management briefly?

9. what is critical chain project management?

9.10 REFERENCES

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9.11 SUGGESTED READINGS

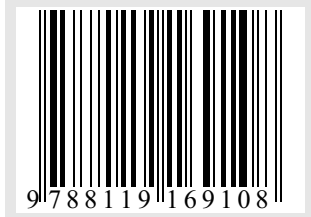
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