

UNIT - I

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INTRODUCTION TO PRODUCTION AND OPERATION MANAGEMENT

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NOTES**UNIT - I****INTRODUCTION TO PRODUCTION AND OPERATION MANAGEMENT****1.1 INTRODUCTION**

This unit starts with a definition of a system. In this unit production system and its objectives are explained along with the components of a system. The history of operations management is portrayed. The various functions of production system and their interlinking are explained through a flow chart. The components of computer, integrated manufacturing and their purpose are dealt. Finally, the recent trend in the operations, namely, **Global Supply Chain** is introduced in this unit.

1.2 LEARNING OBJECTIVES

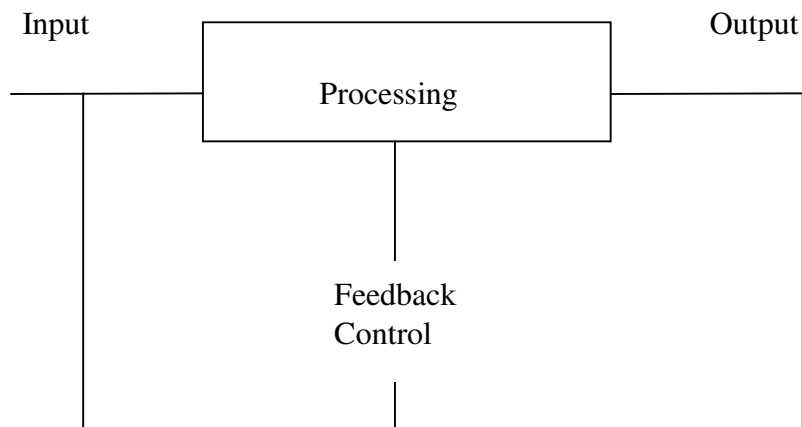
- To know the importance of the production system in an organization.
- To understand the link between various activities of the production system.
- To comprehend the history of operations management.
- To understand the components of computer integrated manufacturing

1.3 SYSTEM

It consists of elements or components. The elements or components are interlinked together to achieve the objective for which it exists. Eg: human body, educational institutions, business organizations.

Components of a system:

The input, processing, output and control of a system are called the components of a system.

Figure 1.1 - Components of a system

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Control:

There are two types of control, namely **Proactive Control and Reactive Control**.

Proactive Control:

When an operation is carried out on a product in a workstation, the quality inspector goes to the workstation and inspects the product. When the samples that he has taken for the inspection are not confirming to the quality, he stops the machine and identifies the reason for the deviation and corrects the problem, so that the produced product thereafter conform to the specifications. This type of control prevents any major quality setback after the production. This is an example for proactive control.

Reactive Control:

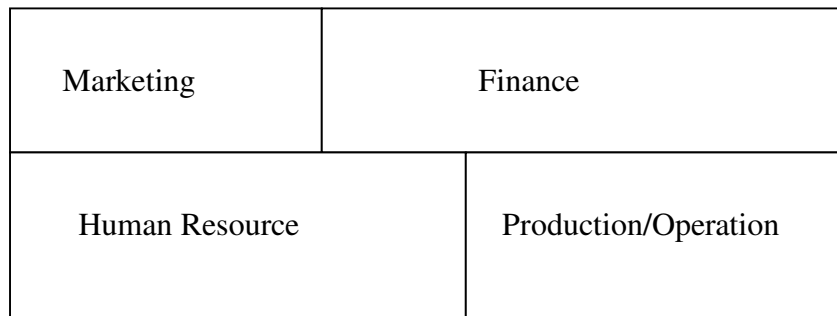
In a planning period, usually the quality target is fixed. Suppose, an organization feels to fix 5% defective is safe in the targeted production quantity and assumes that at the end of the planning period it finds that the defective output exceeds the targeted defective products. Then, it has to find out the reason for the deviations, namely, whether the problem is due to the method of doing the work or the resources used in the process. Then the planner uses this knowledge to prevent any problem in the future. Thus a Reactive Control is a post mortem case.

1.3.1 Business System:

The business organization is classified into different subsystems based on the functions like marketing, production/operation, finance and human resource etc.

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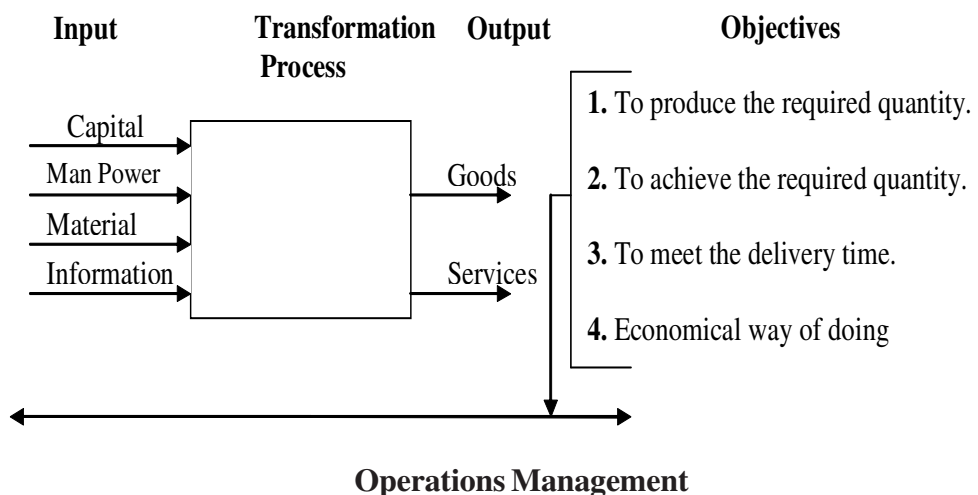
Figure 1.2 – Business System



Each subsystem will have more sub subsystems.

1.3.2 Production / Operation System

Figure 1.3 – Production / Operation System



Operation system is either manufacturing sector or service sector. The input requirements are shown in figure 1.3. The transformation process, in which part of the value addition takes place to get the required quantity of the product or services with the targeted quality within the specified time period, is carried out in a most economical way. Operation Management Plan coordinates and controls all the activities in the operation system to achieve the stated objectives.

Thus (the activities listed in the diagram) the Operations Management activities, ensure the objective of quantity, quality, delivery time and economical way of doing work. The communication link between the various activities are shown in the figure 1.3.

Each activity is dealt in detail in different sections of this material. This figure (figure 1.3) will be very much appreciated after getting a clear understanding of all the activities.

1.3.3 What is operation management (OM)?

Operation Management is a way or means through which the listed objectives of an operating system is achieved. There is always a confusion between the word OM & PM (Production Management). It is accepted norm that OM includes techniques which are enabling the achievement of operational objectives in an operation system.

The operation system includes both manufacturing sector as well as service sector, but when you use the word PM, you should be careful to note that it refers to the manufacturing sector but not the service sector. Suppose, you are designing a layout for the hospital you should say that you are applying Operations Management Technique not the Production Management Technique.

When you design a layout for a manufacturing sector you can say that you are applying Production Technique or Operation Technique or vice versa.

From, the above discussion we can come to a conclusion that production management is a subset of Operations Management.

Review questions –

1. What are the components of a system?
2. What are the differences between the Production Management and the Operations Management?
3. List the objectives to be fulfilled by an Operation System.

1.4 HISTORY OF OM

Table 1.1 – History of OM

Year / Period of Concept	Concept/Tools and System Used	Developers/ Originators
(14-16) Century	Evolution of Production system	
18 th Century	New Technology for Production Process Management	Adam Smith and harles Babbage
1895	Scientific Management Principles (Work Study) Motion Study for Psychological Factors Activity Scheduling Chart Gantt	F.W.T. Taylor Frank & Lillian Gilbreth Henry
1935	Hawthorne Studies of Worker Motivation	Elton Mayo
1950's	Operation Research for Decision Making Long term Medium term, Short term decision by	Many Researcher

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	Critical Path Method (CPM), Program Evaluation and..... Technique (PERT), Waiting-Line Theory	
1970's	Computers for Inventory Control Material Resource Planning (MRP)	IBM, Joseph Orlicky, Oliver Wiegert
1980's	Just In Time (JIT), Total Quality Control (TQC) Kanban System, CAD/CAM, Computer Integrated Manufacturing (CIM) Flexible Manufacturing System (FMS)	Toyota
1990's	1. Total Quality Management (TQM), Concurrent (CIM), Engineering, Value Engineering 2. Business Process Engineering 3. Supply Chain Management	Asqc(U.S.). IOS (England), Michael Hammer Oracle, SAP (Germany)
2000's	Logistics, Enterprise Resource Planning (ERP), E-Commerce, E-Business	

Review questions -

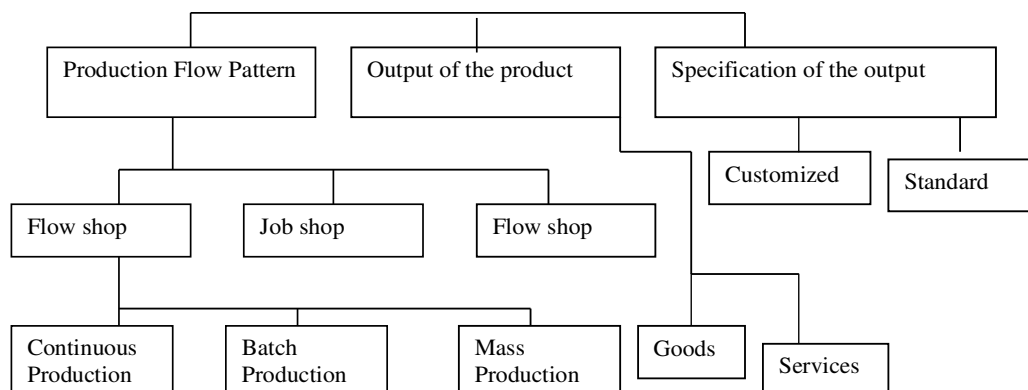
1. What is the contribution of GANTT?
2. Who is the father of Scientific Management?

1.5 TYPES OF OPERATION SYSTEM

The type of Operation System to be adopted should be known to the people, and then only you may choose the system based on the nature of the product that you are going to manufacture. The types of operation system are classified based on the following criteria.

Product flow pattern in conversion system
Output of the product
Specification of the output

Figure 1.5 - Types of Operation System



The characteristics of the Operation System based on the product flow pattern:**NOTES****1.5.1 Flow Shop**

In this kind of production, the productive resources are arranged according to the sequence of operation required by the product design.

Assume that you are engaged in the ready to wear clothing, if you want to adopt the flow shop production, then the productive resources are kept according to the sequence of operations required by the product like

Cutting

Joining by sewing

Adding, buttons, zippers etc

Quality checking

Packaging

Mostly Flow shop production are adopted when there is untapped market for the product, customers are price sensitive and more competition in the market.

Flow shop production as shown in the figure is further divided into **Continuous Production**, **Mass Production** and **Batch production**.

1.5.1.1 Continuous Production

The industries involved in the following activities are classified as Continuous Production

- Oil refining.
- Fertilizer production.
- Chemical processing etc.
- In this type of production the product flows continuously without much interruption.
- This type of production lacks in flexibility.

1.5.1.2 Mass Production

The industries involved in the following activities are classified as the Mass Production Industries:

Auto Manufacturing

TV Manufacturing

Cigarettes

This kind of **flow shop** produces the same type of output, it has little flexibility compared to **Continuous Production**.

1.5.1.3 Batch Production

The industries involved in the following activities are classified as the **Intermittent Production**.

- Shoe manufacturing
- Bottling plant
- Cloth manufacturing

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Here the basic design of the product is the same but the specification of the product differs. The production gets interrupted when the system switches over to other type of the product specification. The products are similar in nature but not identical.

The Characteristics of Flow Shop Production:

Refer Table 1.2

Table 1.2 - The Characteristics of Flow shop Production

Product	The products are standardized.
Conversion	Special purpose equipments, designed for the specific
Resources	process of the product.
Work force	Specialized people, doing the repetitive jobs.
Workforce Job satisfaction	Job satisfaction among the employee is low because of the repetitive nature of job, results in boredom, more turnover and absentees.
Work-in-progress inventory	Productive resources are balanced that result in less work in progress inventory.
Cycle time	Cycle time per unit is relatively low
Cost of production	Cost of production per unit is relatively low.
Quantity of production	Comparatively quantity of production is more
Varieties	Products to be produced of less variety.
Flexibility	This kind of production lacks in flexibility.
	Small change in the product design needs the change in production system abnormally.
Production planning and control	Since less varieties of product are produced for longer period, the production planning and control activities are inbuilt in the system itself, so the production planning and control activities are not a complex one.

1.5.2 Job Shop

In the case of Job Shop Production, the products are mostly customized products. Based on the customer requirements, the products are produced. The productive resources are kept according to the function.

The industries involved in the following activities are classified as the Job Shop production:

- Auto repairing
- Hospital
- Machine shop

The Characteristics Of Job Shop Production.

Table 1.3

Product	The products are of order based mostly non standardized.
Conversion of Resources	General purpose equipment, grouped according to their functions.
Work Force	Skilled people, doing multi skilled work.
Work force satisfaction	Job satisfaction among the employee is high because the operator role is multifaceted.
Work in Progress Inventory	There is lot of waiting time for the product to be manufactured in the system that results in more in process inventory.
Cycle time	Because of more waiting time for the product in the production line that results more manufacturing cycle time comparatively.
Cost of Production	Cost of production per unit is relatively high.
Quantity of production	Since it is order based production, quantity produced per unit type is relatively less.
Varieties	The production system capable of producing more type of products.
Flexibility	This system has more flexibility any change in the design of the product could be incorporated without much problem.
Production Planning and Control	The arrival, the operations demanded and the operations time required by the order mostly uncertain. This makes the jobs of production planning and control difficult.

1.5.3 Project Production

This refers to the industries involved in the production of one type of complex products like, ship construction, dam construction, bridge construction, research and development etc.

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Project production consists of many activities where the activities are interlinked, time phased and resources committed.

In this kind of production, scheduling the activities is important so that you can complete the project within the time and budget constraint. The resources, namely, manpower, machines, material are brought to the workplace where the product is manufactured. There is no movement of the product.

Review Questions

1. Which type of the production system in the process inventory is less?
2. In which type of production system flexibility is more?
3. Tell the important characteristic of Batch Production about the product?
4. In which type of production system there is no product movement?

1.6 COMMUNICATION IN POM

As it is mentioned in the above section, operation management is meant to achieve the objectives for which the operation system is intended for. Based on the objective set by the top management, the system design is established. The system design involves designing the product and process, designing the methods, measuring the work, identifying the location, and designing the layout. By keeping the system design as a framework in the aggregate planning various production alternatives are analyzed and the best feasible production alternatives are chosen.

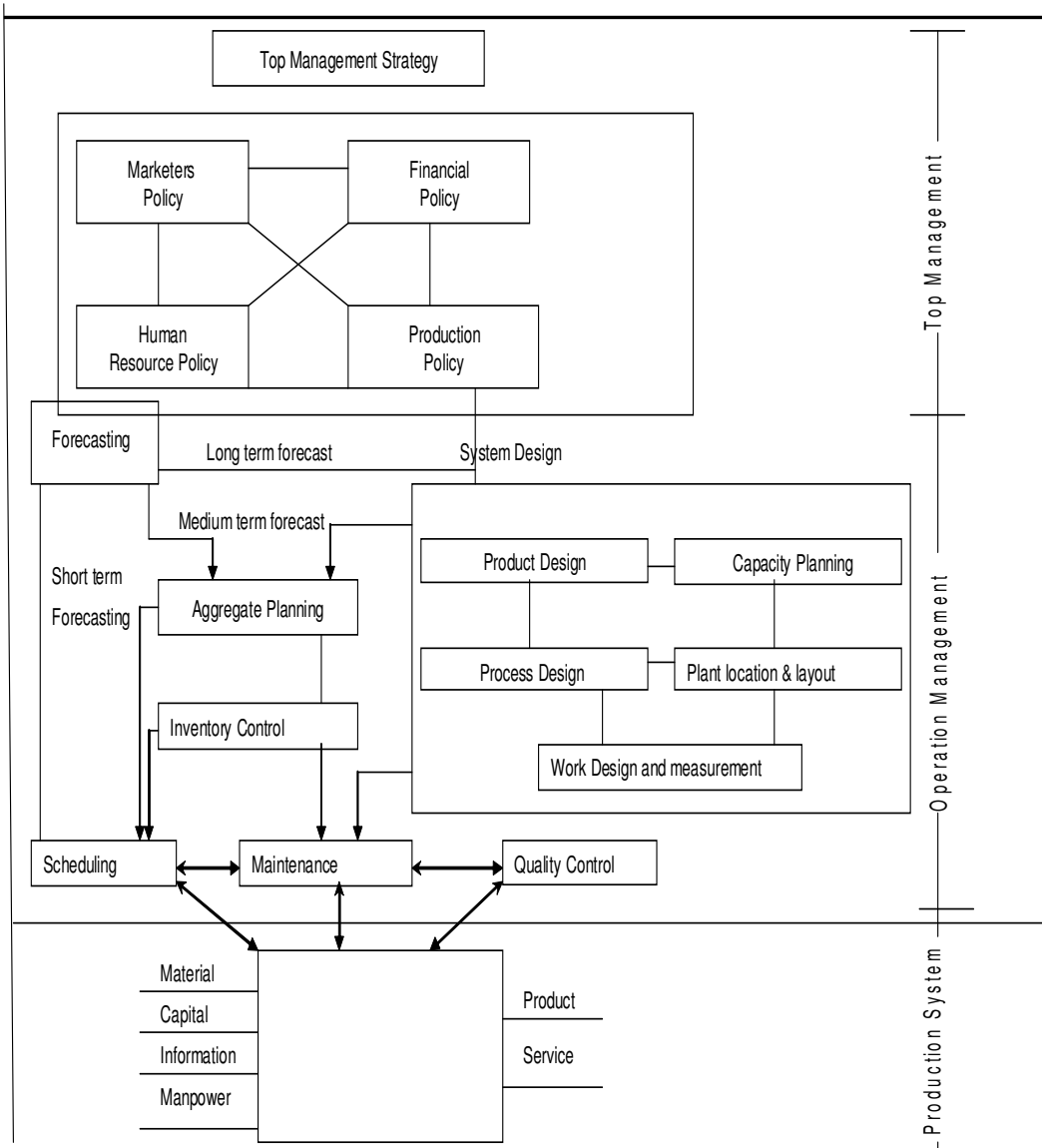
Then keeping the aggregate planning as a input, resource allocation and sequencing of day to day activities are done. The inventory also kept at minimum to satisfy the organization's inventory objectives. The maintenance activity ensures the availability workstations. Quality control ensures the quality in the input, processing and output stages of production system. (See figure 1.4- Communication in POM).

Review Questions-

1. List the activities in system design?
2. What are the phases of scheduling?

Figure 1.4- Communication in POM**NOTES**

External: Socio, Political, Economic environment

Figure1.4

1.7 COMPUTER INTEGRATED MANUFACTURING AND SERVICE SYSTEM

Computer Integrated Manufacturing (CIM), a strategic thrust, is an operating philosophy. Its objective is to achieve greater efficiencies within the business, across whole cycle of product design, manufacturing and marketing. International competition has intensified the requirement for high quality products that can compete in the global market place. As a result of this increased competition, the pace of development has been quickened and thus forcing manufacturers to enter into an era where the continuous

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quality improvement is maintained as a matter of survival, not simply being competitive. As the time scale of product life cycle has decreased and the demand for the quality increased, attention has focused on improving the product quality and promoting the competitive ability of industries through better design, manufacturing, management and marketing.

Global manufacturing industry is now undergoing a rapid structural change. As this process is continuous, manufacturing industry is encountering difficulties as it confronts with a more changed and more competitive environment and also the market place. In order to share the international market, manufacturers need to implement two strategies. The first is, to improve the Enterprise Management. The second one is, to develop and apply a Systematic and Scientific Technology, i.e., CIM.

With the rapid growth of the complexity of manufacturing process and the demand for high efficiency, greater flexibility, better product quality and lower cost, industrial practice has approached the more advanced level of automation. Nowadays, much attention has been given by both industry and academia to CIM.

Currently, most of the industries have highly automated facilities. To stimulate industrial companies for utilizing the newest manufacturing technology, this has compelled to develop a system architecture that does not only replace the existing manufacturing facilities, operational environments, but effectively utilizes the knowledge and facilities that are available in the industry.

To overcome the difficulties and solve the problems mentioned above automatic techniques and methodologies should be Introduced into real industrial manufacturing.

1.7.1 CIM Subsystems

Significant progress has been made in the manufacturing technology in recent years. Numerically control machine tools, automated material handling systems and controlled systems have been widely used in industrial companies. The Flexible Manufacturing System (FMS), Computer Integrated Manufacturing (CIM) or Systems or Automated Manufacturing Systems (AMS) can be attributed to an increasing number of companies. The advancing manufacturing and computer technology has brought new challenges to the designers of products, processes and system as well as to the managers. The traditional design and management tools can not effectively cope with problems arising in the modern manufacturing systems.

1.7.2 Functional areas of CIM

CIM system has emerged as a result of the development in manufacturing and computer technology. The computer plays an important role integrating the following areas of CIM system.

- **Part (component) and product design**
- **Tool and fixture design**
- **Process planning**
- **Programming of numerically controlled (NC) machines, material handling system (MHS), etc.**
- **Production planning**
- **Machining**
- **Assembly**
- **Maintenance**
- **Quality control**
- **Inspection**
- **Storage and retrieval**

To emphasize the computer aspects, the terms **Computer Aided Design (CAD)**, **Computer Aided Process Planning (CAPP)**, **Computer Aided Manufacturing (CAM)**, **Computer Aided Quality Control (CAQC)**, **Automatic Storage Retrieval (ASR)**, have used. Each term refers to one or more of the listed functional areas. **CAD** refers to the part and product design and tool and fixture design, **CAPP** refers to Process Planning, **CAM** refers to the programming of manufacturing hardware, production planning machining, assembly and maintenance, **CAQC** refers to the quality control and inspection and **ASR** involves the storage and retrieval of raw materials, finished products work in process inventory.

The computer plays a leading role in the automation and integration of hardware component i.e. machines, material handling carriers and the software components of manufacturing systems. In order to understand the CIM subsystems and the importance of integrating them, it is first necessary to explore the functional areas by these subsystems.

1.7.2.1 Computer Aided Production Planning

Production planning involves establishing production levels for a known length of time. This forms the basis for the following two functions:

1. Material requirement planning
2. Loading and scheduling

Based on the information regarding the type and quantity of parts or products to be manufactured, the materials required to produce the parts or products must be ordered with an appropriate lead time to ensure their availability for production. This function constitutes material requirement planning. Based on the material required, capacity- for example, machine hours and labor hours can be calculated.

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Machine loading involves assignment of parts and products to machines and machine cell in order to distribute the production loads. Scheduling determines the sequence in machines perform the operations.

1.7.2.2 Computer Aided Process Planning

Process planning for a part involves the preparation of a plan that outlines the routes, operations, machines and tools required to produce the component. Since the process is a tedious task, there has been a trend to automate it. As a result, a number systems have been developed. There are three basic approaches to the automated process planning. They are -

- a. Variant Approach
- b. Generative Approach
- c. All based Approach

CIM Subsystems

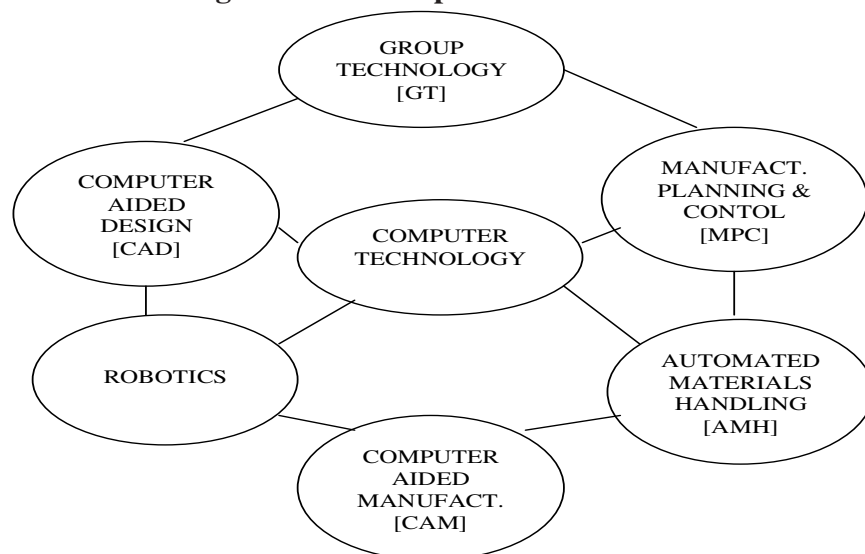
Intelligent Manufacturing

Development in artificial intelligence has had an impact on the manufacturing systems. All most all the areas of the computer integrated manufacturing have been effected by the artificial intelligence. Researchers and engineers are developing the intelligent systems ranging from application in machining and assembly to long term planning.

1.7.3 Conceptual framework of CIM

The conceptual framework of CIM is shown in Figure.1.6 are six major being integrated by computing technology. Note that one of these is Group Technology (GT).

Figure 1.6 – Conceptual framework of CIM



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According to Arthur D. Little and Co., GT is the important technology among the others and it will play a major role in the factory of the future. The GT concept is considered a center road towards a higher level of CIM.

1.7.4 Group Technology

Group technology (GT) is a concept that is currently attracting a lot of attention from the manufacturing community. GT offers a number of ways to improve productivity in the batch manufacturing. The essence of GT is to capitalize on similarities on recurring tasks. GT is, very simply, a philosophy to exploit similarities and achieve efficiencies grouping like problems.

1.7.4.1 Definition of GT

“Group technology is the realization that many problems are similar and that, by grouping similar problems, single solution can be found to a set of problems, thus saving time and effort”

1.7.4.2 History of GT

Prior to 1913, the era of Henry Ford and his model T, all machining models were similar to our present job shop techniques with machines laid out usually in lines or blocks of similar machines. The work was loaded onto the machines usually by the manual progress control system. Ford introduced the assembly line and that, in turn, led to automated transfer machines. However, the majority of engineering do not produce items in quantity that justify such methods and so the jobbing shop philosophy continued. GT is mainly a coordination of normal good engineering practices. It is impossible to say who first practiced GT. There are reports of it having been used in Germany in the 1930s.

In an international Conference held in Stockholm in 1947, the basic groups were explained by C.B. Nanthorst. In Italy M. Patrignany was an early exponent of this technology. However, little of this appears to have been in English. First published work was from the USSR by S.P. Mitrofanov in 1959 and there after subsequent books were published by F.S. Denyanyuk and E.K. Ivanov. The first reported work on GT outside Russia was done by a French Forges et Ateliers de Construction Electriques de Jeurmont - and this was about in Machinery in 1962. Subsequently, several British companies conducted considerable work in this field. There have also been considerable studies done by various consultants in the Universities. The significant contribution by J.L. Burbidge in the 1960s led to GT as A total Manufacturing Philosophy.

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1.7.4.3 Advantages of GT

According to Burbidge, following are the advantages after introducing GT in manufacturing.

- a. Short throughput times because machines are closed together.
- b. Better quality because groups complete parts and the machines are closed together under one foreman.
- c. Lower material handling costs because machines are closed together under one foreman.
- d. Better accountability because machines complete parts. The foreman can be made responsible for costs, quality, and completion by due date.
- e. Training for promotion for promotion since GT provides a line of succession, because a group is a mini-department.
- f. Automation GT is a first evolutionary step in automation.
- g. Reduced set up time since similar parts brought together on the same
- h. Morale and job satisfaction since most workers prefer to work in groups.

Studies undertaken by N.L.Hyer indicate the following significant savings after implementing GT Snead prepared a summary matrix, listing the benefits listing benefits achieved for the various GT.

Table 1.4 - Advantages of GT

Applications implemented set up time	20-60%
Planned labor	15-25%
Tooling	20-30%
Rework & scrap	15-75%
Machine tool expenditures	15-75%
WIP carrying costs	20-50%

1.7.4.4 Organizational suitability for GT

The suitability of a firm for the introduction of GT depends on several factors. The survey of Willey and Dale give a tentative description of a company profile likely to achieve the greatest benefits from GT, some of these are:

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- a. The company must be a relatively small organization with a reasonably small machine tools, and manufacturing equipment.
- b. The company should not be typified by either large or small component variety.
- c. The batch sizes and the batch size range of products of the companies it is relatively small.

Athersmith and Crookall Rajagopal and Smith Gupta Andand Grayson have suggested another way of finding out the suitability of GT for a batch production industry. Computer simulation has been used by the effect of introduction of GT in the batch production industries based on the parameters such as throughput time, WIP inventory and plant utilization Further GT is considered a desirable stepping stone for establishing Just-In-Time production.

1.7.4.5 Group Technology in CIM

One may question whether a cellular concept is applicable to CIM systems. Some studies have shown that grouping machines to machine cells may limit the manufacturing system flexibility. However, industrial applications have proven that it is virtually impossible to implement a large scale CIM subsystem using a cellular concept. Here after, the automated manufacturing systems that cellular approach can be called as, Cellular Automated Manufacturing (CAMS). Four crucial factors of CAMS as identified by Kusiak are:

1. Volume of information

Volume of information a large-scale CIM subsystem is typically large, and it is too expensive to effectively process information without the system's decomposition.

2. Material handling system

In a typical CIM subsystem, automated material handling carriers are used (AGVs and Robots). Each of the two carriers can tend a limited number of machines.

3. Technology Requirement

Some machines have to be grouped together due to technological requirements. For example, a forging machine and a heat treatment section.

4. Management

Although in most of the currently CIM subsystems, the degree of automation is higher than in classical manufacturing systems, humans will be, for a long time, an integral

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part of these new manufacturing systems. Due to limited size of each machine cell, a CAMS is easier to manage than the entire system.

Review Question:

Following stands for :

1. CRM 2. FMS 3. AMS
4. AS/RS 5. CAD 6. GT

1.8 GLOBAL SUPPLY CHAIN

Even though the countries fought for border issues, but there is no trade barrier for the trade is concerned. GATT agreements and WTO paves the way for the **Global Supply Chain in trading**. (See Figure 1.7).

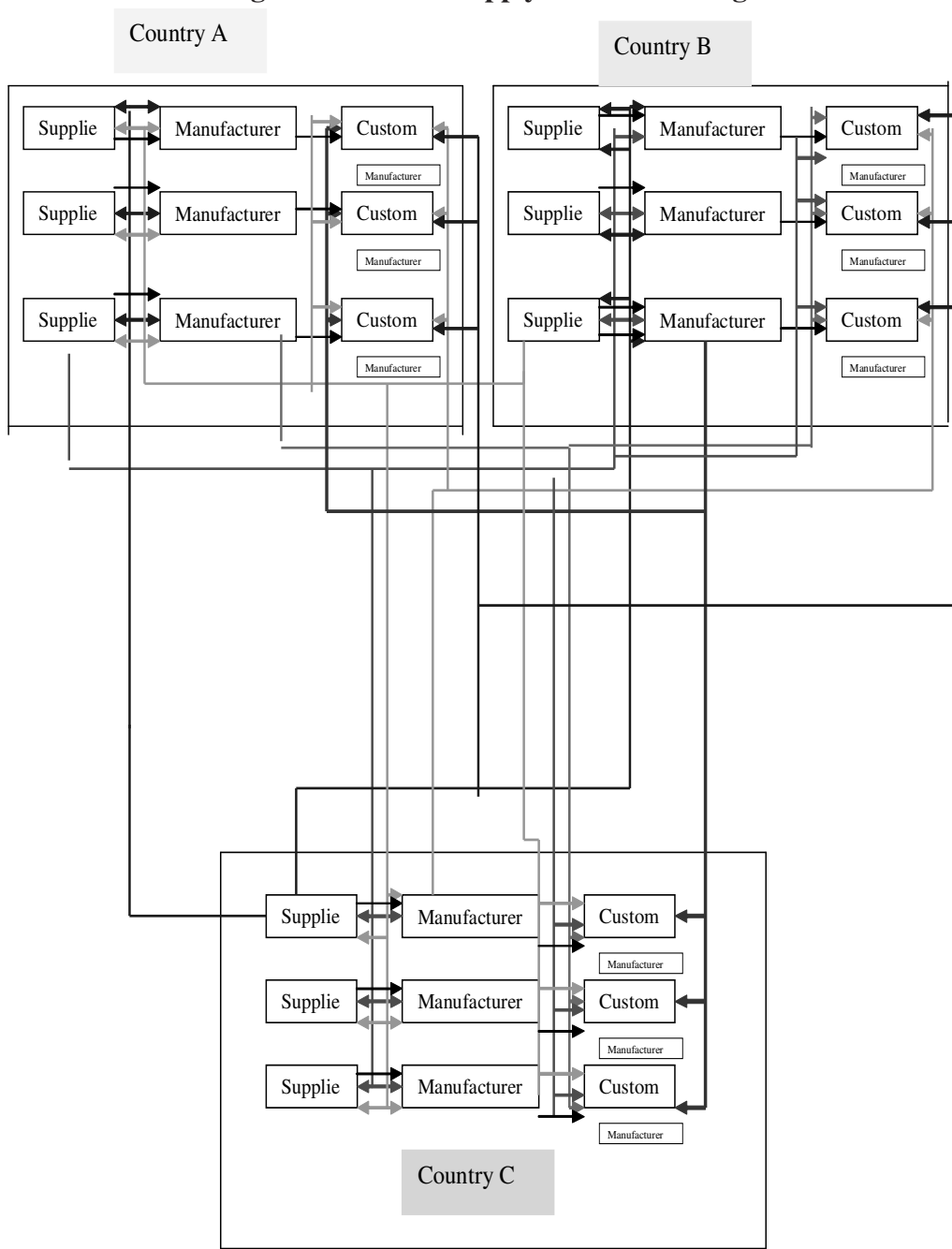
Overall Objective of Global Supply

The objective of global supply chain configuration is in meeting or exceeding worldwide customer (internal and/or external) expectations at the lowest cost.

Specific Objectives and Expectations of Global Supply

Achievement of the transformation of supply chains into value chains will normally include some combination of the following objectives and expectations:

- Leverage spend (across business units and geographic boundaries).
- Align Incentives for integration of activities (buyers, suppliers, end-users) to support organizational goals and strategies.
- Optimize supply chain operation (no. of members, capabilities, costs).
- Reduce inventories across the chain.
- Reduce all costs (item costs and supply chain operational costs).
- Assurance of supply of right quality items to support operations.

Figure 1.7- Global Supply Chain in trading

For simplicity only one supplier, manufacturer and customer of each country is taken in the above diagram, same can be possible for others.

1.8.1 Global Complexities

If the supply/value chain involves sourcing in multiple countries, additional considerations need to be addressed. Some of these include:

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- ~ Currency exchange and risk.
- ~ Counter trade opportunities and requirements.
- ~ Varying laws and jurisdictional questions.
- ~ Cultural differences.
- ~ Language differences.
- ~ Labor and training availability, practices, laws, regulations.
- ~ Transportation, packing, shipping, storing, import, export, customs.
- ~ Security: materials, products, personnel, intellectual property.

Challenges and Barriers to Transforming Global Supply Chains into Value Chains

In the varying environments encountered internationally, there are a number of challenges and barriers involved in building global supply chains. Many of these are rarely concerned with the domestic supply chains. Some of these include:

- ~ Uncertain political stability, self-serving governments.
- ~ Lack of infrastructure in some countries (roads, port facilities, trained labor, utilities, communications).
- ~ Lack of critical market mass in particular countries.
- ~ High transaction costs.
- ~ Requirements to use in-country agents or partners and local content requirements.
- ~ Lack of potential for repeat purchases.
- ~ Slower adoption of e-business than in the domestic market.
- ~ No or limited free trade zone availability.
- ~ Partner/contract limitations requiring bidding for all procurement activities and alliance-building.
- ~ High logistics and transportation costs.
- ~ Different time zones (communication difficulties).
- ~ Financial risks are higher, e.g. potential for war, terrorism, government changes.
- ~ The nature of global activity (may be fragmented and/or scattered).
- ~ Long/unpredictable supplier lead times.
- ~ Protectionism (tariffs, duties, quotas, inspections).
- ~ Limited number of qualified global suppliers.
- ~ Difficult to link global project work to “run and maintain” global activities.
- ~ Limited availability of trained personnel for purchasing or supply management positions inhibiting.

1.8.2 How to Transform Global Supply Chains

Improve the quality/cost ratio of your supply chain. Strive for the highest quality at the lowest cost.

Leverage value across the supply chain

Understand what constitutes value and to whom it is valuable in your supply chain. Identify and evaluate trade-offs between value added and profitability. Leverage knowledge to create and deliver the value. Where commodity markets are involved, be proactive in initiating change that will benefit you.

Redefine the boundaries of business

Redefine the boundaries of your business in the context of what provides continuing competitor and customer advantage. Evaluate any existing vertical integration structures and replace with virtual sourcing if value can be added by doing so. Evaluate what to insource and what to outsource. Use all capabilities of existing or potential supply chains in the development of new products.

Develop relational competence

View relationships with other members of your supply chains as a continuum ranging from spot relationships to strategic alliance or co-ownership but recognizing that most relationships will be somewhere between these extremes. Determine where more competition will add value and where more collaboration will add value and seek the best combination of competition and collaboration.

Manage at the right level

Determine which strategies and activities best add value with global management and which best add value with local management. Determine the best level of autonomy for local management within supply chain activities. Analyze supply chains for each category of material or service that is significant to the organization to determine the best value -adding approach for management and control.

Develop supply chain responsiveness

Determine how the degree of responsiveness to customer needs such as re-supply time or product mix adjustment matches with customer requirements in each such area. Consider techniques such as supplier managed inventory, supplier integration,

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and consignment stocking. Pay particular attention to the quality of demand forecasts throughout the supply chain. Drive down purchase costs. Capture cost saving opportunities and share benefits with contributing supply chain members. Pay attention to the differing cost management and purchase strategy needs of various categories of purchases. For example, commodities, specialty items, custom-made items, MRO materials. Service purchases can be similar.

Bring About Change

Change Management 1-1. It refers to transforming supply chains which involves a collateral change management. Consider purchases in the broadest possible sense - do not exclude anything which is purchased by the organization, material or service effort. This includes the following activities:

- ~ Seek Top Management mandate with visible support.
- ~ Identify the local sponsors and supporters of the supply chain, change early in the transformation process.
- ~ Use coordinated communication efforts to develop a dialog about the benefits and obstacles for implementation.
- ~ Target quick wins and immediate opportunities.
- ~ Focus on overcoming obstacles to implementation by creating a cross functional approach (Team) to address issues.
- ~ Perform a competitive advantage review in order to leverage the core competencies of the supply chain members .
- ~ Develop a supply chain agenda, manage the overall program and frame goals to address major gaps in supply chain performance.
- ~ Develop a business plan that will integrate the activities of the supply chain members.
- ~ Formulate key performance metrics and measurements, tracking quarterly.
- ~ Review results and make modifications as necessary to achieve supply chain optimization.

Summary

- This unit helps the reader to understand the importance of the production / operation system in an organization.
- Characteristics of the different production / operation system are detailed out in addition to when one should prefer what type of system.
- The components of computer integrated manufacturing system and the introduction of Global supply chain network are highlighted.

Review Questions:

1. State any five Global Complexity.
2. Give any three steps to develop Global Value Chain?

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NOTES**UNIT II****MATERIAL AND INVENTORY
MANAGEMENT****2.1 Introduction****2.2 Learning objectives****2.3 Materials Management**

2.3.1 Definition and Scope

2.3.2 Objectives

*2.3.2.1 Primary objectives**2.3.2.2 Secondary Objectives***2.4 Material Handling**

2.4.1 Introduction

2.4.2 Robotics

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2.4.3 Automatic Storage and Retrieval system (AS/RS)

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*2.4.4.1 Component of AGV**2.4.4.2 Applications of AGV***2.5 Just In Time (JIT)**

2.5.1 Problems of Conventional Production System

2.5.2 Conventional vs. JIT attributes

2.5.3 JIT as a waste elimination tool

2.5.4 KANBAN production control system

2.5.4.1 Working of KANBAN

2.5.5 Uniform loading

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2.6.1 Kind of Control

2.7 Inventory models

- 2.7.1 Need for Inventory
- 2.7.2 Types of Inventory
- 2.7.3 Inventory costs
- 2.7.4 Deterministic model
 - 2.7.4.1 EOQ model
 - 2.7.4.2 EBQ model
 - 2.7.4.3 Quantity discount model
- 2.7.5 Probabilistic model
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2.8 Material Requirement Planning (MRP)

- 2.8.1 Introduction
- 2.8.2 Overview of MRP system
- 2.8.3 Inputs of MRP system
- 2.8.4 MRP Process
- 2.8.5 MRP output

2.9 Manufacturing Resource Planning (MRPII)

- 2.9.1 Introduction
- 2.9.2 Closed loop MRP system
- 2.9.3 Master Production Schedule
- 2.9.4 Capacity planning
- 2.9.5 Forward scheduling and backward scheduling
- 2.9.6 Benefits of MRPII
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2.10 Enterprise Resource Planning (ERP)

- 2.10.1 Need for ERP
- 2.10.2 Evolution of ERP
- 2.10.3 Advantages of ERP system
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2.11 E-Business and E-Commerce**NOTES**

NOTES**UNIT - II****MATERIAL AND INVENTORY
MANAGEMENT****2.1 INTRODUCTION**

In this unit the productivity of material resources is discussed. The role of materials management in an organization and the latest material handling devices like Automated Guided Vehicle (AGV), Automatic Storage and Retrieval System (AS / RS) and Robots are illustrated. The deterministic and probabilistic inventory models are illustrated with examples. Detailed discussions are carried out about material requirement planning and manufacturing resource planning. The evolution of ERP system is dealt. In addition, introduction about e-business and e-operation strategies are also explained.

2.2 LEARNING OBJECTIVES

- To know the importance of material resources.
- To understand functions of materials management.
- To understand the computer controlled material handling devices.
- To know the importance of deterministic and probabilistic inventory models.
- To know the working of MRP – I and MRP – II systems.
- To highlight the E-business and e-operation strategies.

2.3 MATERIAL MANAGEMENT**2.3.1 Definition and Scope**

We can define Materials Management as the function responsible for the coordination of planning, sourcing, purchasing, moving, storing and controlling materials in an optimum manner so as to provide a pre-decided service to the customer at a minimum cost.

2.3.2 Objectives

However, within the broader management objectives of any industry or business, Materials Management's contribution towards objectives may be divided into two categories:

1) Primary and

2) Secondary.

The former contributes directly to the Materials Management function and the latter, helps other departments to achieve their objectives.

2.3.2.1 Primary Objectives

Purchasing:

Materials play a vital part in the field of cost-control and operating expenditure of any organization and therefore, materials have a direct bearing on the cost of a product, manufactured. If the Materials Department can reduce the overall materials cost through an efficient system of buying, it can directly contribute its share to the enhancement of profit. Thus lower prices, lower procurement and possession costs are important objectives of Materials Management. Price consciousness or less materials cost means more profit as embodied in the phrase, "Purchasing for Profit" which is readily recognized by Management. It is therefore a prime functional responsibility of the Materials Management department.

Stores and inventory management:

Arriving at the right balancing point in the inventory investment like investment in any other capital assets has always been a perplexing problem to industries. Inventory Management function is more complex, more subtle and the balance of costs and gains is much more difficult to find out. Briefly, Materials Management objective here is to have the correct quantity and right quality of material on hand at the time required with a minimum of investment expenditure, consistent with business experience. When inventory turnover is high, storage and carrying costs are low.

Continuity of supply:

This is an other important objective of Materials Management. Specially in automated processes, where costs are rigid and are not easily amenable to reduction due to lack of production materials, the question of continuity of supply gains prominence. This foreshadows all other objectives, because idle-time costs of men and machines push up overall costs of production and expediting supply means additional transport costs.

Quality of materials:

Where quality of materials presents cost plus production engineering problems, it may well become one of the prime objectives of Materials Management, where other objectives are sacrificed at quality-cost.

Good supplier relations:

A good supplier relation, on which depends much of the product-reputation of the company, is also one of the key objectives of Materials Managers. Suppliers respond

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to fair treatment but are uncooperative and unwilling if indifferently treated. The Materials Management department can improve relations by providing the required stimuli for their better performance.

2.3.2.2 Secondary Objectives

Secondary objectives are so varied that they limit the possibility of listing exclusively in one breath. In one way or the other, they help to achieve the primary objectives, but different organizations put different emphasis on them. The following are a few examples.

Make-or-Buy decisions:

Since the Materials Management department is immediately concerned with the selection of supply sources, materials-cost, procurement-cost and the availability of materials, it influences heavily the Make-or-Buy decision. Often, this is a Committee action where other departments are also involved. However, the Materials' department's contribution is still substantial and more direct.

Value analysis and Value engineering:

Any item that is produced or bought is to serve a specific purpose. Before making or buying any material or equipment, engineers and buyers must decide what purpose they are to serve in order to find out whether a lower-cost design would work well or a less costly item could fill the need. Both engineering department and purchase department may watch the specifications for the best value of the money spent.

'Value engineering' and Value Analysis' are close to the same thing. They are approaches to cost-saving goals that deal primarily with product design. The first usually refers to what the engineering department is doing in this direction and the second usually refers to the work that the buyer is doing in this area. If value analysis is designed to reduce the cost of an item, standardization may often eliminate the item entirely.

Standardization:

Standardization is essential to a mass production system which is defined as "that which has been established as a model to which an object or action can be compared". However, one should take note that even when a substitute is technically feasible, it is not always economical to use it. The economics of standardization is not necessarily so complex.

All that is required is to compare costs of acquisition and carrying before the substitution was made with the costs after it was made. A standardized program is primarily designed to root out unneeded inventories. The buyer who knows who made the original components, need not pay a premium price for it to another equipment manufacturer for the same thing.

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The Engineering department is primarily responsible for standards and specifications. However, the Materials department can promote incorporation of standard components into product design to reduce cost. The fewer the items that need be managed, the simpler and more efficient is the Materials Management process, so that the Materials Management department can periodically review the stock to suggest weeding out of non-standard items.

Product development and new products:

Since the discovery and improvement of materials frequently lead to a new product and lower costs on existing products, the Materials department can suggest materials and components that will do better or equivalent jobs at lower cost. Product efficiency is basically a compromise between engineering design and economic objective of Management. The Materials Manager's economic knowledge can supplement the technical skill of engineering through a product change for bigger profits. Again, a program designed to find ways and means of utilizing the by-products or wastes is always profitable and here the Materials department can render substantial help by adding new products to the existing product-line.

Price, demand and requirements forecasting:

In large concerns this is a functional responsibility of economists. They make forecasts both for sales and purchases. Materials Management personnel translate them into specific purchase actions. Because of their intimate knowledge of the market conditions through daily contacts with suppliers, in medium or small-size organizations, Materials Management departments do this job. By analyzing and interpreting data of past sales, seasonal variations in prices, availability and demand for materials, they forecast future trends and plan material requirements accordingly.

An organization structure is an essential tool of management:

As a system of responsibility and of formal interrelations, it is concerned with two of the elements, namely, planning and coordination. Its chief purpose is to ensure smooth and balanced working of the organization. Obviously the size of the unit must affect the way in which management and other activities are carried out. Clearly, a large organization will be able to use and will need to use techniques and procedures of a different kind and higher degree of complexity than those of the medium or smaller firm. In other words, there will be differences in methods or routines according to differences in size, but the fundamental principles of management and the approach necessary for the attainment of effective management are the same, irrespective of size.

1. The determination of the basic objectives:

The basic objectives of an organization determine the organization structure for they determine the type, stability, structure and permanency of the organization. The

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objectives of an organization play, therefore, a vital part in determining how quickly the structure should be developed, what it should look like, its operating cost and permanency. What we want to accomplish should be kept clearly in mind while determining and setting up its structure. Obviously, the organization structure of a large corporation is much more complex, and therefore, slowly developed. Here too, objectives affect the structure. Once the objectives are clearly determined, the development of structure will follow the natural path dictated by the desire to reach these objectives. An organization structure should never hinder the achievement of these objectives; instead it should facilitate the mechanism that will enable the organization to accomplish things more easily and effectively than when left in unorganized things more easily and effectively than when left in an unorganized fashion. Thus, if it is decided that the company should add to a new line of product, and therefore, expand its marketing territory, such an objective and its concomitant Materials Management activities would necessarily affect the final structure of the organization.

2. Determination of the areas of activity:

Organization itself is nothing but the application of the universal law of specialization. Through organization, a person's actions and responsibilities are narrowed to one or a few functions, specializing in these few and thereby, increasing efficiency.

Specialization by division of work into functional areas enables one to understand his job more thoroughly. Therefore, effective organization must include specialization as an element of efficiency for the performance of one or a very few leading functions. As far as possible, similar functions should be combined into one position. Although its advantages are universally recognized, yet it has its limits which should not be exceeded.

3. Determination of the ideal structure to accomplish the desired activities:

Physical listing of activities will in itself suggest possible areas within which it needs to consolidate work. Each of the groupings will then lead to an 'ideal' organization structure to carry out the functions. Products, tools and processes may be considered as possible areas of functional activities. This 'ideal' structure may then represent the long range or ultimate organization with available personnel, funds, etc., so as to reconcile the 'ideal' with the 'working' organization.

4. Authority and Responsibility:

Authority is the right to give orders and the power to exact obedience. Authority is not to be conceived apart from responsibility, that is, apart from sanction – reward or penalty, which goes with the exercise of that power. Delegation of authority is the key point of organization. Without delegation there would be no organization and this is the core of all formal processes of organization. A major task of top management is the delegation of authority to proper individuals in order to secure appropriate actions. But often, we hear of responsibility being delegated without power to command or act.

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Such an organization set-up makes for ease and efficiency in determining responsibility and delegating necessary authority. Since it would not be just to hold a person responsible for performance of a task without first giving him the authority, responsibility should always be coupled with commensurate authority. Here, authority can be delegated, responsibility cannot.

5. Span of Control:

By span of control, we mean the number of individuals one supervises and directs. There is a definite limit to this number and this, to a great extent, determines the units of an organization. There may be a tendency to over supervise and this may, in effect, mean scant or ineffective supervision.

On the other hand, when too few report to one supervisor, his time is not effectively used. However, no hard and fast rule can be established and it depends upon the type of work performed.

6. Personal Ability:

Simply assigning jobs to individuals does not mean that they will be accomplished. Individuals differ in capacity and ability and these differences as well as personal limitations should be considered before placing an individual in an organization. In developing an organization, therefore, proper regard should be paid to the personal ability of individuals assigned to various components. An organization is referred to the people and its structure reflects the ability of its members which again largely determines the structure.

7. Unity of Command:

For any action whatsoever, an employee should receive orders from one superior only. Such is the rule of unity of command. No one in any organization should report to more than one line supervisor and everyone should know to whom he reports and who reports to him. In fact, receiving directions from more than one individual may easily result in confusion, conflict, lack of action and poor morale. Each member of an organization, therefore, should receive directions from only one boss, his immediate superior and should be responsible to him alone.

8. Job Assignment:

Logical groupings or related functions should be made in developing the organization structure. It is often desirable to have the responsibility for each of these functions assigned to specific individuals with these persons turning to the leader charged with the accomplishment of the overall function.

9. Regulations:

Rules and regulations aid improper operation of an enterprise. A complete statement of the operating objective of an enterprise as well as the responsibility and

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the authority of each individual should be formulated and should be made available in writing to all personnel in the organization. They may be broad and specific. Even detailed methods manuals to describe how the tasks are to be carried out may be valuable. They define the authority which certain individuals have over particular functions.

10. Two way communication:

Despite the fact that line of authority provides channels downward and upward, they are often used only to pass directives downward and never as a means of communicating attitudes, feelings or ideas upward. Such blocks in communication occur in a great many organizations. In fact, one of the most immediate and costly results of poor organization is the breakdown of intra-organizational communication. In as much as an organization is developed to aid in accomplishing an objective, good communication is necessary if all employees are to know what to do to reach this objective.

11. Flexibility:

The environment in which an organization exists and the individuals who make it up are constantly changing. Organizations change because of technological, economic or personnel changes or changes in the objectives. An organization possessing flexibility withstands minor pressures, but gives way to the demand for genuine change permitting their expansion or contraction without seriously altering the basic functions of various segments of the structure.

12. Line and Staff activity:

Line and staff functions should not be combined in one individual where separation of functions is possible. Line functions, as has been said before, are those which directly affect the product or service. Staff functions are those that aid the line or, are auxiliary to the line function. Because confusion may result, line and staff functions should be separate wherever possible. Staff specialists are useful and there will always be a need for them. Especially in large materials organizations, where materials management is treated as an integrated activity, there should be less need for staff experts in a variety of functions. Among the major staff services value analysis, economic forecasting and administrative planning may be essential. A staff expert on 'trade relations' is also a common feature in large-scale industrial purchasing.

Leadership Question:

Leadership is obviously more than personal ability and skill. Leadership is important to the effective set up and operation of every organization because leadership is the one force that charts and makes possible the economic accomplishment of the objectives. A 'weak' organization structure with effective leaders will probably accomplish more than a so called 'strong' organization with weak leaders.

Structural balance:

An organization conceived and developed along the principles detailed above, will more than reward its leaders, as well as its members. In the process of forming a new organization structure or of reorganizing an existing one, these principles should be considered. But the consideration of these principles, rules and types will not in itself result in the development of a new organization. Instead a new organization structure must be visualized and developed step by step. Although no series of rules can assure an effective organization, this objective can be approached in a systematic fashion without much difficulty. In a balanced organization, each function of the structure should be large enough, but not overly developed in relation to other functions of the organization. Without such a balance, the objective of the organization cannot be achieved economically.

Review Questions:

1. List any two Primary functions.
2. List any two Secondary functions.

2.4 MATERIAL HANDLING**2.4.1 Introduction**

For an ideal operation system, material handling is not a desirable activity. The reason is it does not add any value to the product but it adds only cost to the product. So when you design a layout you should see that the movement of materials should be minimum. The material handling equipment used mostly depends upon the type of production system to be adopted. In the case of flow line production system, the following material handling equipments are used.

Conveyors

1. Slat conveyor
2. Pusher bar conveyor
3. Roller conveyor
4. Belt conveyor
5. Wheel conveyor
6. Screw conveyor
7. Pivoted bucket conveyor
8. Apron conveyor
9. Spiral chute
10. Pneumatic conveyor
11. Trolley conveyor

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In the case of **job order/intermittent type production systems**, the material handling equipment used are

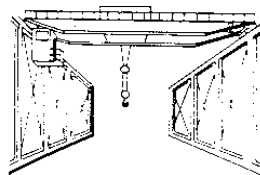
1. Fork Truck
2. Platform Truck
3. Industrial Truck
4. Straddle carrier
5. Hand operated vehicles

In addition, CRANES and HOISTS are also used in the production system. Thus is not specifically related to particular system. All types of production system uses this kind of material handling equipment.

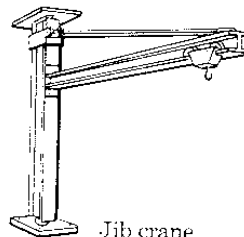
The types of CRANES and HOISTS are :

1. Overhead traveling bridge cranes
2. Jib crane
3. Gantry crane
4. Air hoist
5. Electric Hoist
6. Chain hoist

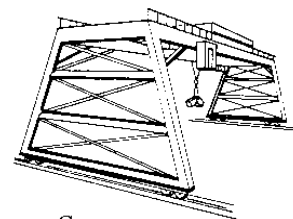
There is no hard and fast rule that particular material handling system used only by the particular production system. But you can find that the trucks used in the flow line. Production as well as the conveyors used in the job order and intermitted production system.



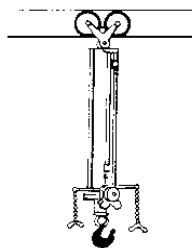
Bridge crane



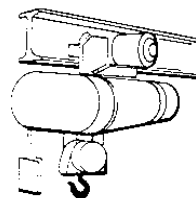
Jib crane



Gantry crane



Air hoist

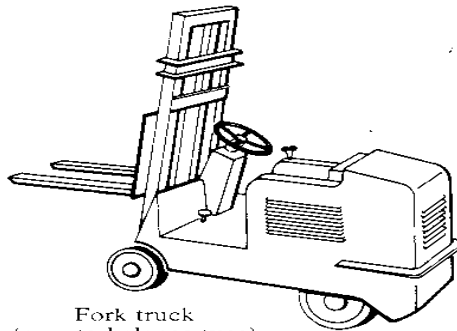


Electric hoist

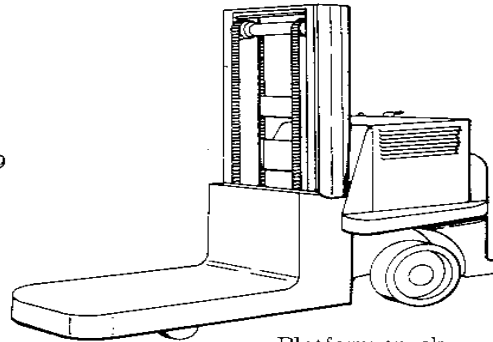


Chain hoist

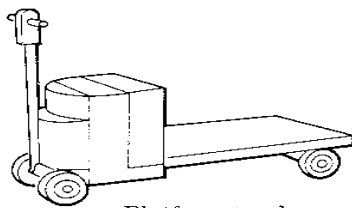
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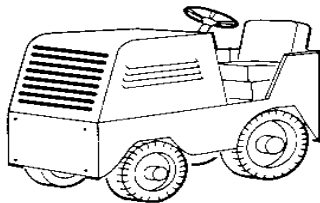
Fork truck
(counterbalance type)



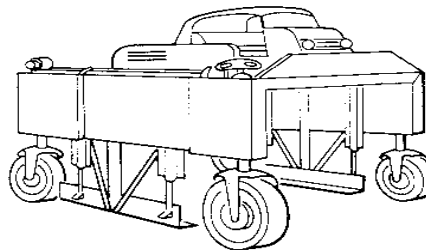
Platform truck
(high-lift type)



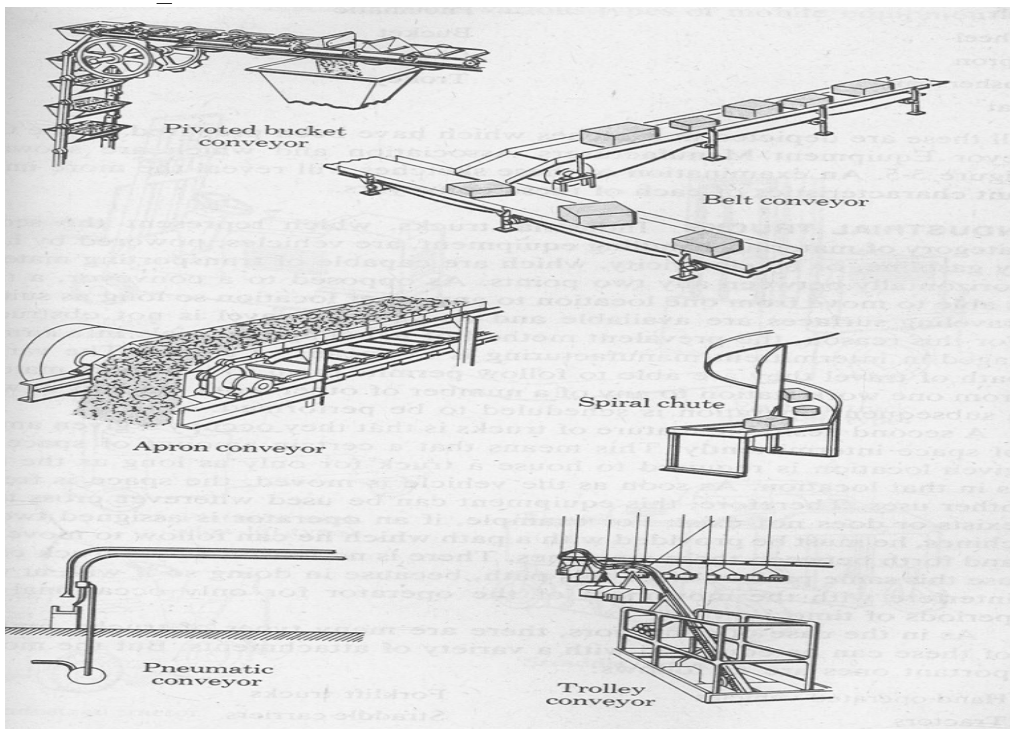
Platform truck
(low-lift type)



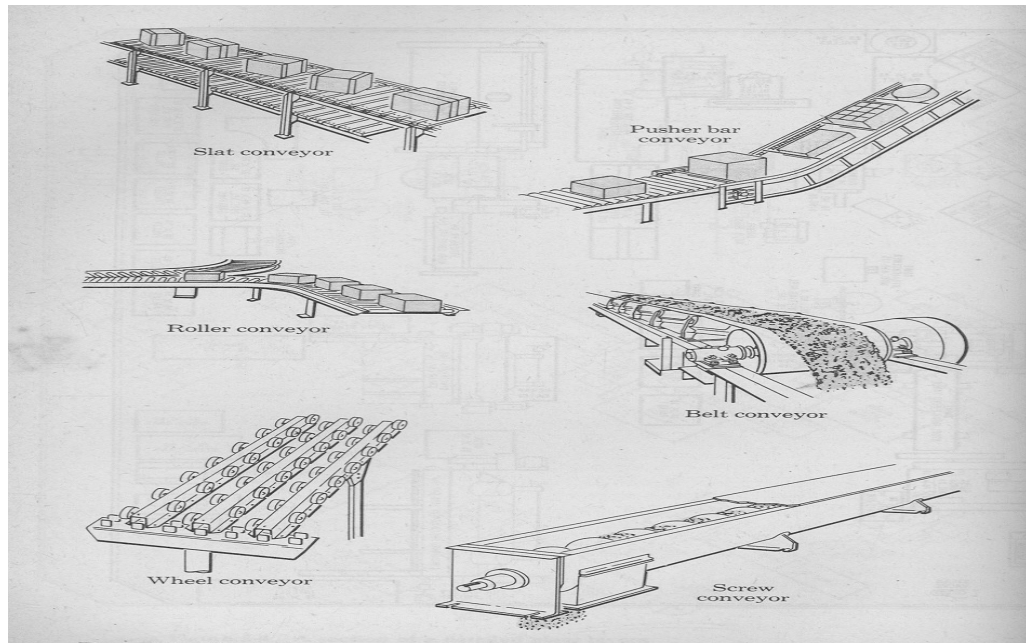
Industrial tractor



Straddle carrier



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2.4.2 Robot

The word “robot” is also used in a general sense to mean any machine that mimics the actions of a human, in the physical sense or in the mental sense. It comes from the word *robota*, labor or work. The word robot first appeared in Karel Capek’s science fiction play R.U.R. (Rossum’s Universal Robots) in 1921. The word was brought into popular Western use by famous science fiction writer Isaac Asimov.

A robot is an electro-mechanical or bio-mechanical device or group of devices that can perform autonomous or preprogrammed tasks. A robot may act under the direct control of a human or autonomously under the control of a programmed computer. Robots may be used to perform tasks that are too dangerous or difficult for humans to implement directly, such as radioactive waste clean-up, or may be used to automate mindless repetitive tasks that should be performed with more precision by a robot than by a human, such as automobile production. Robot can also be used to describe an intelligent mechanical device in the form of a human, a humanoid robot.

The word robot is used to refer to a wide range of machines, the common feature of which is that they are all capable of movement and can be used to perform physical tasks. Robots take on many different forms, ranging from humanoid, which mimic the human form and way of moving, to industrial, whose appearance is dictated by the function they are to perform.

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Asimov proposed three 'laws' which for many years were recognized as principles in the use of robotics:

A robot must not harm a human being or, through inaction, allow a human to come to harm.

A robot must always obey human beings unless this is in conflict with the first law.

A robot must protect itself from harm unless this is in conflict with the first or second law.

Robots can be grouped generally

Mobile robots (e.g. autonomous vehicles)

Manipulator robots (e.g. industrial robots)

Self reconfigurable robots, which can conform themselves to the task at hand.

An industrial robot has been defined as:

"A reprogrammable multifunctional manipulator designed to move material, parts, tools, or specialized devices through various programmed motions for the performance of a variety of tasks".

The definition says the robot is a reprogrammable and multifunctional. The reprogrammability means, through computer the programmed instructions can be written fed and also can be edited. Multifunctional is in the sense of its versatility. It can perform various activities.

2.4.2.1 Advantages of Robots in Industry:

We can analyze the various advantages of robots in three perspectives.

Technical factors:

When comparing robot and human performance it is generally considered that humans cannot match the speed, quality, reliability, endurance and predictability of robotics systems. However, robots cannot compete with hard automation if the cycle times are short and flexibility is not an important factor. Robots therefore provide a link between the rigidity of dedicated automation and the flexibility of the human operator, in that they offer:

High flexibility of product type and variation.

Lower preparation time than hard automation.

Better product quality.

Fewer rejects and less waste than labor-intensive production.

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Economic factors:

Major factors in considering the possible implementation of robotics systems include:

- The need to increase production rates to remain competitive.
- Pressure from the marketplace to improve quality.
- Increasing costs.
- Shortage of skilled labor.

In general, robotics can increase profitability by:

- Providing maximum utilization of capital-intensive production facilities for up to 24 hours per day, seven days per week;
- Reducing production losses due to absenteeism and skilled labor shortage, reducing the amount of inventory which is being processed with resulting savings in work in progress.
- Reducing the manufacturing lead time of the product or processes;
- Reducing scrap and increasing product quality, with resulting reduction in the number of customer complaints.

Social factors:

- Robots are employed to do mindless, repetitive tasks so that the human capital can be utilized in more interesting work.
- Many low-level tasks can be carried out by robots.
- Robots can be utilized to perform undesirable work in dangerous or hazardous environments and work requiring heavy physical effort.

E.g.: spot-welding car bodies, applying spray paint.

- Robots are successfully implemented in the nuclear industry for carrying out the maintenance work on reactors and for the handling of dangerous waste products.

2.4.2.2 Components of a robot:

A robot has many components which include:

A base- fixed or mobile.

A manipulator with several degrees of freedom (DOF).

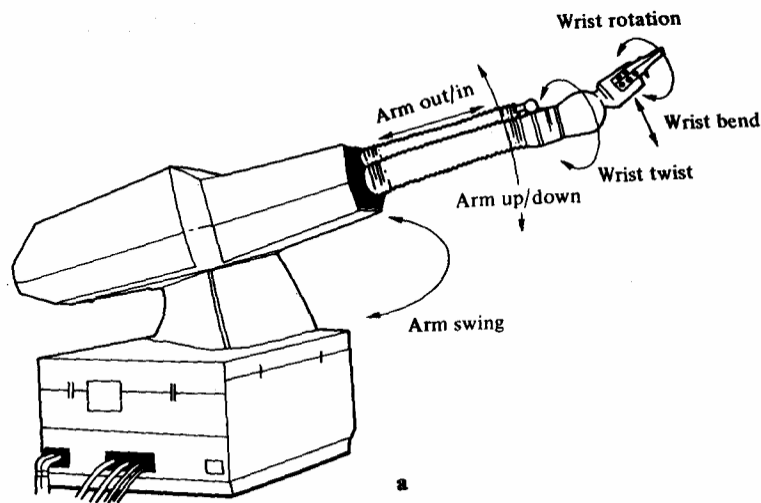
An end-effector or gripper for holding a part or a tool.

Drives or actuators causing the manipulator arm or end-effector move in a space.

Controller with hardware and software support for giving commands to drivers

Sensors to feed back the information for subsequent actions of the arm as well as to interact with the environment in which the robot is working.

Interfaces connecting the robotic subsystems to the external world.

Figure 2.2 – Movements of a Robot**NOTES****2.4.2.3 Industrial applications of robotics:****Material handling:**

Depalletizing/palletizing
 Transporting components
 Transfer of components/tools
 Bottle loading
 Parts handling

Machine loading and unloading components:

Loading parts to CNC machine tool
 Loading a punch press
 Loading a die casting machine
 Loading electron beam welding and laser beam welding machines
 Loading/orientating parts to transfer machines
 Spray painting
 Loading parts on the test machine
 Painting of trucks/automobiles
 Painting of agricultural equipment
 Painting of appliance components
 Arc welding
 Spot welding
 Arc welding
 Seam welding of variable width
 Machining
 Drilling

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Deburring
Sanding
Grinding
Cutting
Forming
Assembly
Mating components
Riveting small assemblies
Inspection
In-process measuring and quality control, searching the missing parts
Others
Heat-treatment, applications of adhesives etc.

2.4.2.4 Applications of robotics in other fields:

1. Hazardous environments

Mining
Exploration
Search and rescue
Tunneling for main roadways
Operations in short passages
Municipal services

Fire fighting
Underground (dangerous gas-filled)
Sewer clearing
Maintenance of atomic reactors
Space
Space vehicles
Undersea
Oil/mineral exploration
Salvage operations

2. Medical

Rehabilitation engineering for handicapped
Non-invasive diagnostics
Surgery

3. Distribution

Warehousing
Retailing (for food industry or for retail industry)

4. Agriculture

5. Hobby/household purposes

6. Military applications of robots may be in both manufacturing and non-manufacturing areas.

2.4.2.5 Dangers and disadvantages:

Although robots have not developed to the stage where they pose any threat or danger to society, fears and concerns about robots have been repeatedly expressed in a wide range of books and films. The principal theme is the robots' intelligence and ability to act could exceed that of humans that they could develop a conscience and a motivation to take over or destroy the human race.

Currently, malicious programming or unsafe use of robots may be the biggest danger. Although industrial robots may be smaller and less powerful than other industrial machines, they are just as capable of inflicting severe injury on humans. However, since a robot can be programmed to move in different trajectories depending on its task, its movement can be unpredictable for a person standing in its reach. Therefore, most industrial robots operate inside a security fence which separates them from human workers.

Even without malicious programming, a robot, especially a future model moving freely in a human environment, is potentially dangerous because of its large moving masses, powerful actuators and unpredictably complex behavior.

Designing and programming robots to be intrinsically safe and exhibit safe behavior in a human environment is one of the great challenge in robotics. Some people suggest that developing a robot with a conscience may be helpful in this regard.

2.4.3 Automated Storage and Retrieval System (AS/RS)

An integrated FMS, AGVS, and AS/RS system provides an efficient and effective production system for manufacturing. Receiving, identification and sorting, dispatching, placing in storage, retrieving from storage, packing, shipping, and record keeping have traditionally been considered the functions of storage systems. An AS/RS attempts to achieve these functions by automating most of these procedures in a cost-effective and efficient manner.

An automated storage and retrieval system is defined as:

A combination of equipment and controls, which handles, stores and retrieves materials with precision, accuracy and speed under a defined degree of automation.

Different operations of AS/RS:

- Automatic removal of an item from a storage location
- Transportation of this item to a specific processing or interface point

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- Automatic storage of an item in a predetermined location, having received an item from a processing or interface point.

An automated storage and retrieval system comprises the following:

- A series of storage aisles having storage racks.
- Storage and retrieval (SIR) machines, normally one machine per aisle, to store and retrieve materials
- One or more pickup and delivery stations where materials are delivered for entry to the system and materials are picked up from the system.

2.4.3.1 Types of AS/RS

Several types of AS/RSs are distinguished based on certain features and applications.

Some of the important categories include:

1. Unit load
2. Miniload
3. Person-on-board
4. Deep-lane
5. Automated item retrieval system

1. Unit Load AS/RS

The unit load AS/RS is used to store and retrieve loads that are palletized or stored in standard-size containers. In general, a unit load system is computer controlled; having automated machines designed to handle unit load containers. Each machine is guided by rails in the floor. These are the load-supporting mechanisms that moves loads to and from storage locations and the pickup-and-deposit stations.

2. Miniload AS/RS:

A miniload system is designed to handle small loads such as individual parts, tools, and supplies. The system is suitable for use where there is a limit on the amount of space that can be utilized and where the volume is too low for a full-scale unit load system and too high for a manual system. A smaller investment and flexibility of handling small items make it a popular choice in industry.

3. Person-on-Board Systems

The person-on-board system allows storage of items in less than unit load quantities. A person rides on a platform with the S/R machine to pick up individual items from a bin or drawer. This provides in-aisle order-picking ability, which can reduce the time it takes to fill an order. The operator can select the items and place them in a tote or module, which is then carried by the S/R machine to the end of the aisle or to a conveyor to reach its destination.

4. Deep-Lane AS/RS:

The deep-lane AS/RS is another variation on the unit load system. The items are stored in multideep storage with up to 10 items per row rather than single or double deep. This leads to a high density of stored items, permitting high usage of the unit.

Each rack permits flow-through of items; that is, an item is deposited on one side of the storage rack and removed from the other side. The S/R machine is similar to the unit load S/R machine, except that S/R machines have specialized functions such as controlling rack-entry vehicles.

5. Automated Item Retrieval System:

This system is designed for automatic retrieval of individual items or cases for storage. The storage system consists of items stored individually in a flow-through system that can be automatically released from storage and automatically brought to a required point. The items are stored from the rear, as in the deep-lane system, and are retrieved from the front.

2.4.3.2 Technical and Economic Benefits of AS/RS

There are several benefits of AS/RS for an organization, which include:

- An AS/RS is highly space efficient. Space now occupied by raw stock, work in process, or finished parts and assemblies can be released for valuable manufacturing space.
- Increased storage capacity to meet long-range plans.
- Improved inventory management and control.
- Quick response time to locate, store, and retrieve items.
- Reduced shortages of inventory items due to real-time information and control.
- Reduced labor costs due to automation.
- Improved stock rotation.
- Improved security and reduced pilferage because of closed storage area.
- Flexibility in design to accommodate a wide variety of loads.
- Flexibility in interfacing with other systems such as AGVS, FMS, and inspection systems such as coordinate measuring machines.
- Reduced scrap and rework due to automatic handling of parts.
- Reduced operating expenses for light, power, and heat.
- Helps implement just-in-time (JIT) concepts by getting the right parts, tools, pallets, and fixtures to the right place at the right time because of automatic control of storage and retrieval functions and accurate inventory management.

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2.4.4 Automated Guided Vehicle

Automated Guided Vehicles (AGV), popularly known as battery-powered driverless vehicles. AGVs are becoming an integral part of automated manufacturing systems. They are with programming capabilities for destination, path location, and positioning. The AGVS belong to a class of highly flexible, intelligent versatile material-handling systems used for materials loading and unloading throughout the facility.

Automated Guided Vehicle (AGV) is the advanced material handling applications. AGV play an important part in automating the manufacturing unit because they not only connect all faces of the factory by the horizontal movement of materials, but allow management to control and direct manufacturing processes.

The AGV can be defined as a vehicle equipped with automatic guidance equipment, either electromagnetic or optical. Such a vehicle is capable of following prescribed guidepaths and may be equipped for vehicle programming and stop selection, blocking, and any other special functions required by the system.

One of the interesting feature of AGVs is the collision avoidance capability. That is, the vehicle comes to a dead stop before any damage is done to personnel, materials, or structures.

2.4.4.1 The Components of AGV

There are four main components of an automated guided vehicle system:

1. The vehicle: It is used to move the material within the system without a human operator.
2. The guide path: It guides the vehicle to move along the path.
3. The control unit: It monitors and directs system operations including feedback on moves, inventory, and vehicle status.
4. The computer interface: It interfaces with other computers and systems such as the mainframe host computer, the automated storage and retrieval system (AS/RS), and the flexible manufacturing system (FMS).

AGV's Control Systems

There are three types of AGVS control systems. They are 1-1

• Computer-controlled system:

In this system, all the transactions and AGVS vehicle movements are controlled and monitored by the system controller. The guide path controller controls the guide path of the AGVS and transfers the information to the AGVS process controller. The AGVS process controller directs the movement of the AGVS vehicles.

• Remote dispatch control system:

In this system a human operator is required to issue instructions to the vehicle through a remote control station. The control system sends destination instructions directly to the vehicle. Therefore, the human operator does not have any direct control over the AGVS vehicle.

• Manual control system:

In the manually controlled system, the operator gives commands to AGVS. The operator gives instructions like loading the vehicle, entering a destination and unloading. A manually controlled system is simple and the least expensive of all control systems. The efficiency of the system depends on the skill and performance of the operator.

2.4.4.2 Applications of AGVS

AGVS have numerous applications and have already been applied by many manufacturing plants and companies. New applications are being developed as technology improves and as experience is gained. Some of the most common applications of the AGVS are:

- Raw material storage
- Finished goods storage
- Assembly operations
- Flexible manufacturing systems
- Manufacturing operations

Technical and Economic Benefits of AGVs

- *Economic Justification:* AGV systems are proving to be the most economical method of moving material.
- *Interface with Other Systems:* AGV systems are designed to interface with other material-handling systems including conveyors, automatic storage/retrieval systems, production lines, and other devices.
- *System Accountability:* Computer control means planned delivery, transaction audit records, on-line interface to production and inventory control systems and management information on the vehicle and workstation production.
- *Reduced Labor/increased Productivity:* In cases where driverless vehicles are used, substantial savings are realized due to labor reduction.
- *Guide path Easily Expanded:* As material movement needs change or plant size increases, AGV systems can be expanded or modified quickly and at low cost.

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- *Expandable System Capacity:* As material movement needs an increase, load movement capacity in the AGV system is easily accomplished by adding one or more vehicles.
- *Unobstructed Aisles:* Control wires for AGV systems are installed in the floor and therefore, leave no 'above-floor obstructions'.
- *Destinations Unlimited:* AGV systems can be designed with an unlimited number of pick-up and delivery points.
- *Less Equipment Damage:* There is less product and equipment damage when AGV systems are used to move material because the vehicles travel on a predetermined route.
- *Reliable System Control:* All automatic guided vehicles are equipped to allow manual override for the special material or vehicle movement situations.
- *Energy Conservation:* AGV systems require very little energy to operate.
- *Ease of Installation:* AGV systems can be installed in less time than most other material handling systems.
- *Installation in Existing Buildings:* AGV systems can be installed in existing buildings with minimum interference to ongoing operations.

Review Questions:

1. Name any two Conveyors.
2. List any two component of Robotics.
3. Name any two trucks.
4. Name any two cranes.
5. State any two advantages of Robots in Industry.
6. Name any two components of Robots.
7. List three benefits of AS/RS.
8. Expand AGV.

2.5 JUST IN TIME

Just In Time (**JIT**) is a philosophy, wherever an organization adopts this philosophy to strive for excellence in their activities. **JIT** is considered to be a production strategy which enables to identify the non value added activities and eliminate those activities. The activities include the activities starting from the design to delivery of the product. **JIT** helps in achieving the listed objectives like.

- *Zero defects*
- *Zero lead time*
- *Zero Breakdowns*
- *Zero Handling*
- *Zero Set uptime*
- *Zero lot excesses*
- *Zero Surging*

2.5.1 Problems of Conventional Production Systems:

The well known Conventional Production Systems like Continuous Production System and the Intermittent Production System have their own limitations as you have read in the previous sections. The continuous production system has the shortcomings like for eg; this kind of system is not suitable for variety production. If there is a change in the product design, this system needs to be changed as it lacks in flexibility. The work forces are specialized work forces. But the workstations are properly balanced, comparatively you need less work in progress inventory. The manufacturing cycle time is comparatively low. In the case of intermittent production system, the system is more of process based. Since, it does the variety of products. The product has to wait for long time in the queue for the processing. This results in more in process inventory. But this system has the advantage of producing more no of variety production. Flexibility is in built in this system.

Since the traditional system have these kinds of problems, so we need a system incorporating flexibility, balanced work station with multi skilled work force, with less waiting time of the products.

JIT provides solution for the problems of conventional production system.

2.5.2 Conventional Vs. JIT Attitudes

Table 2.1 - Conventional Vs. JIT Attitudes

Conventional Attitudes	JIT Attitudes
Some defects are acceptable	Zero defects are necessary and attainable
Large lots are efficient (more better)	Ideal lot size is one (less is better)
Fast production is efficient	Balanced production is efficient
Inventory provides safety	Safety stock is a waste
Inventory smoothes production	Inventory is undesirable
Inventory is an asset	Inventory is a liability
Queues are necessary	Queue should be eliminated
Suppliers are adversaries	Suppliers are partners.
Supply sources lead to safety	Sources of supply lead to control
Breakdown maintenance is enough	Preventive maintenance is essential
Long lead time is better	Short lead time is better
Setup time is given	Setup time should be zero
Management is by edict	Management is by consensus
Work force is specialized	Work force is multifunctional

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The above table illustrates the difference between Conventional System and JIT system. JIT is also considered as Inventory System in addition to considering it as production strategy. The reason for considering JIT as an Inventory System is that the main emphases of the JIT is the product, should flow in the production system without any impediments.

But Inventory hides much type of impediments like:-

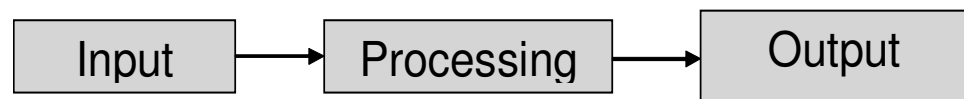
- Bad raw materials-
- Machine break downs-
- Poor quality-
- Worn tools-
- Delayed deliveries
- Unavailable material handling equipment
- Unavailable inspectors or setup persons

If you have Inventory, the above problem will not come to the lime light very much. So JIT focus on mainly on inventory reduction to pave the way for the smooth flow of product in the system.

2.5.3 JIT as a waste elimination tool

As it is mentioned, JIT emphasis on the inventory reduction. You can see in this section what re-engineering by the JIT requires in the input, processing and output sides of an operation system.

Figure 2.3 - JIT as a waste elimination tool



- | | | |
|------------------------|--------------------------|------------------------|
| - Customer order | - Group Technology | - Customer order |
| - Accurate Forecasting | - Uniform plant loading | - Accurate forecasting |
| - Reliable supplier | - Kanban type production | |
| | - Control system | |
| | - Quality Control | |

Raw Material inventory reduction:

The following situations lead the organization to invest less in Raw Material inventory.

- The exact proportion of the input requirement is known, provided the organization produces the product based on customer order.
- Accurate finished good forecasting enables the organization to stock less.
- Fewer but better suppliers.
- Partnership with the supplier.

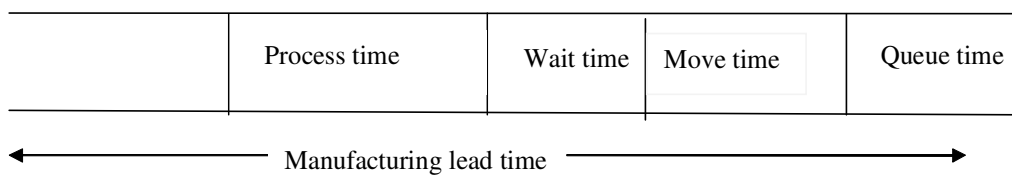
- More local suppliers to reduce lead time.
- Frequent delivery of parts directly to the point of use.
- Quality at the source by preventing defects and doing it right the first time.

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Work in Progress reduction:

Work in Progress is the result of long manufacturing lead time, improper balance of the workstations. First let us analyze the constituents of manufacturing lead time. Manufacturing lead time consists of

Figure 2.4 - Work in Progress reduction



Except process time, all other times are non value added times. The organization should re-engineer first to reduce non value added times.

Setup time:

It is the time to setting up the machine. It involves the time included

- in bringing the raw material and tools to the work place.
- in cleaning and lubricating the machines.
- in changing the die and jigs & fixture etc.

The relationship between setup time, setup cost and production is given below:

Setup time is **Proportional** to Setup cost.

Production quantity = **f** (Setup cost)

So, reduction the set up time in enables the reduction in set up cost. This in turn reduces the economic production quantity to be produced. So JIT advocates one unit, is the economic production quantity. The setup time reduction is Possible through adopting the following means:

- **Method analysis**
- **Quick disconnects**
- **Tinged bolts**
- **Clamps**
- **Roller platforms**
- **Tool carouses**

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Process time:

It is the actual operation time on a product. This usually contributes less than 10% of the total manufacturing time.

Wait time:

This is the waiting time of the product to be moved for the next operation. This time is reduced provided the movement of material and the completion of operation are synchronized. This time is reduced through proper material handling planning.

Move time:

This is the movement time from one work station to another work station. This time is lessened if the work stations are adjacent.

Queue time:

This represents major portion of the manufacturing cycle time. This is the idle time of the product, waiting for the operations because the machine center from which the processing sought for, engaged by another product. This time depends upon the routing procedure adopted, priority rule assigned for the product.

If you reduce the non value added times by the way and means mentioned above, the investment on, namely, the material, labor and manufacturing overhead in work in progress, inventory gets reduced. This is possible by adopting the group technology principle, Kanban production control, assuming machine reliability through preventive maintenance.

Finished Good Inventory Reduction:

Finished good inventory is reduced if you reduce the uncertainty related with the timing and the quantity of the customer requirement. The means for the uncertainty reduction:

- Production based on the customer orders.
- Accurate forecasting or free from errors .
- Through better customer relationship, retaining the customer helps in executing agreement.
- To fulfill the customers future requirement.
- Retaining the customer through better customer relationship enables the organization in executing agreement to fulfill his future requirement.

Group Technology:

This is already explained in the previous unit's section (1.7.4 Group Technology)

2.5.4 KANBAN Production control system:

KANBAN is a Japanese word, meaning, CARD. There are two types of KANBAN one is called CONVEYANCE KANBAN and the other one is PRODUCTION KANBAN. CONVEYANCE KANBAN acts as a move order authorizing the movement of material from one center to another work center. PRODUCTION KANBAN acts as a work order authorizing the work center to start production. You can understand the working of KANBAN Production control systems by considering intermediary work centers $n-1$, n and $n+1$ in a manufacturing.

2.5.4.1 Working of KANBAN

1. The production centers know in advance the production schedule.
2. The operator in the production center ' $n+1$ ' goes with conveyance KANBAN to the production center ' n '. Where a container have the parts required for the production center ' $n+1$ '. Then he removes the production KANBAN and keeps it in the rack of the production center ' n '.
3. Then he keeps the conveyance KANBAN in the container and move with the container to his work station $n+1$.
4. The order in which the production KANBAN in the rack gives indication to the operator in the work center ' n ' about the priority based on which the product have to be processed in the centre ' n '.
5. In the production center ' n ' based on the production schedule, when the time for starting his operation reaches.
 - He goes with conveyance KANBAN to the production center ' $n-1$ '.
 - Remove the production KANBAN in the container and keep it in the rack of center $n-1$ and keep the conveyance KANBAN in the container and move with the container to the workstation ' n ' to start further processing on the product.

The whole sequences of activities are portrayed in the figure 2.5.

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Figure2.5 - Working of KANBAN

From the above sequence you can understand that the JIT operates in the **pull system** basis. That is the down stream pulls the components from the upper stream for the production. But, in the case of traditional production system, it operates, based on

the **push system**. In this case, whether the down stream requires the component at the time or not, the upper stream simply pushes the component to down stream as and when it completes the component that results in comparatively more work in progress inventory.

2.5.5 Uniform Loading:

You can understand the concept of uniform loading through an example, suppose a product 'x' of 2000 quantity is required in a month. Assume that the organization works for 20 days in a month, then $2000/20 = 100$ units, the organization has to produce in a day. Uniform loading means, the organization never produces the product excess of 100 units in a day even though there is an idle capacity available in a day. This means that JIT insists not on the efficiency (Utilization of resources) because if the product is produced faster than the required, then it adds more costs to the organization through the following:

- Containers are needed to hold them.
- Trucks are needed to move them.
- Warehouse space is needed to store them.
- Money is needed to finance the inventory.
- Accountants are needed to keep track of it.
- Schedulers are needed to indicate when to produce more.

Quality Control:

In JIT, as far as in process inspection concerned, the worker act as a inspector and he is responsible for the quality. As it is mentioned, the work force is a multi 1-1 skilled workforce. The worker is trained in the inspection process also, if there is any problem regarding the quality, the whole production stops. After, the quality problem is rectified, the production starts. In JIT, the quality improvement is done through **Total Employee Involvement (TEI)**, quality circles. The emphasis is more on the quality but not on the quantity. Workers are responsible for feeding only good quality parts to the downstream operations. The machines are kept in good working conditions so that it produces good quality part. The worker acts as a maintenance man to get defect free product. JIT operates on the policy of prevention better than cure.

Review Questions:

1. What does JIT aim for?
2. How do you achieve flexibility and less work in progress inventory?

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3. What is meant by wait time?
4. What is meant by queue time?
5. What does KANBAN stand for?

2.6 ABC ANALYSIS (ALWAYS BETTER CONTROL)

Any organization usually deals with lots of items. It is very difficult to exercise control over all the items. Controlling means transactions related to inventory, degree of control, type of records to be maintained, lot sizes, frequency of review, size of safety stock to be maintained etc.

ABC analysis helps to classify the thousands or even millions of individual items into three groups namely items belonging to A group, B group, C group items respectively. ABC analysis is done based on the Pareto's principle. Consumption value is the basis for ABC classification. Consumption value is the product of unit price and consumption.

Mechanism of doing ABC classification:

Steps involved:

1. Collect previous year consumption and unit price for each item.
2. Multiply the consumption and unit price for each item to get the consumption value.
3. Rank the items corresponding to the consumption value.
4. Calculate cumulative consumption value against each item.
5. Find the percentage of cumulative consumption value.

Usually to classify the items into 'A' class there is leverage available. The leverage is 60 to 70 percentage of the consumption value. This means the cut-off value can be fixed in between 60 to 70 percentage of consumption and the corresponding items which contribute up to the cut-off value are classified as a class items.

Similarly, to classify the items into B class, there is a leverage of the consumption value to the extent of 10 to 20 percentage of the consumption value.

To classify the items into C class, there is a leverage of the consumption value to the extent of 5 to 10 percentage of the consumption value.

Table 2.1

Class of items	Cut-off % of Consumption Value
A	60-75
B	10-20
C	5-10

Illustrated Example: 2.1

1. Bulchand & Co. company inventories 20 items. The company decides to setup an ABC inventory system with 10 % of A items, 20% of B items and 70% of C items. The company records provides the information, which is as follows:

Table 2.2

Item Code	Annual usage in units	Cost per unit (Rs)
G	2,500	150
H	15,000	90
I	12,000	100
J	8,000	50
K	1,00,000	50
L	25,000	300
M	80,000	500
N	2,000	300
O	3,000	70
P	6,500	60
Q	10,000	75
R	6,000	20
S	20,000	50
T	40,000	90
U	1,20,000	350
V	20,000	200
W	1,500	350
X	4,000	100
Y	4,500	200
Z	7,000	40

Analyze the above items into ABC categories on the basis of the information and prepare a report showing your findings with comments.

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Table 2.3**

Item code	Annual usage in units	Cost per unit (Rs.)	Consumption Value	Ranking
G	2,500	150	3,75,000	17
H	15,000	90	13,50,000	7
I	12,000	100	12,00,000	8
J	8,000	50	4,00,000	14
K	1,00,000	50	50,00,000	4
L	25,000	300	75,00,000	3
M	80,000	500	400,00,000	2
N	2,000	300	6,00,000	12
O	3,000	70	2,10,000	19
P	6,500	60	3,90,000	16
Q	10,000	75	7,50,000	11
R	6,000	20	1,20,000	20
S	20,000	50	10,00,000	9
T	40,000	90	36,00,000	6
U	1,20,000	350	420,00,000	1
V	20,000	200	40,00,000	5
W	1,500	350	5,25,000	13
X	4,000	100	4,00,000	15
Y	4,500	200	9,00,000	10
Z	7,000	40	2,80,000	18

Table 2.4

Ordered Ranking	Item Code	Consumption Value value	Cumulative consumption consumption	Percentage of Cumulative value	Class
1	U	420,00,000	420,00,000	37.90	A
2	M	400,00,000	820,00,000	74.14	
3	L	75,00,000	895,00,000	80.92	B
4	K	50,00,000	945,00,000	85.44	

5	V	40,00,000	985,00,000	89.05	
6	T	36,00,000	1021,00,000	92.31	
7	H	13,50,000	1034,50,000	93.53	C
8	I	12,00,000	1046,50,000	94.62	
9	S	10,00,000	1056,50,000	95.52	
10	Y	9,00,000	1065,50,000	96.33	
11	Q	7,50,000	1073,00,000	97.01	
12	N	6,00,000	1079,00,000	97.55	
13	W	5,25,000	1084,25,000	98.03	
14	J	4,00,000	1088,25,000	98.39	
15	X	4,00,000	1092,25,000	98.75	
16	P	3,90,000	1096,15,000	99.10	
17	G	3,75,000	1099,90,000	99.44	
18	Z	2,80,000	1102,70,000	99.70	
19	O	2,10,000	1104,80,000	99.89	
20	R	1,20,000	1106,00,000	100	

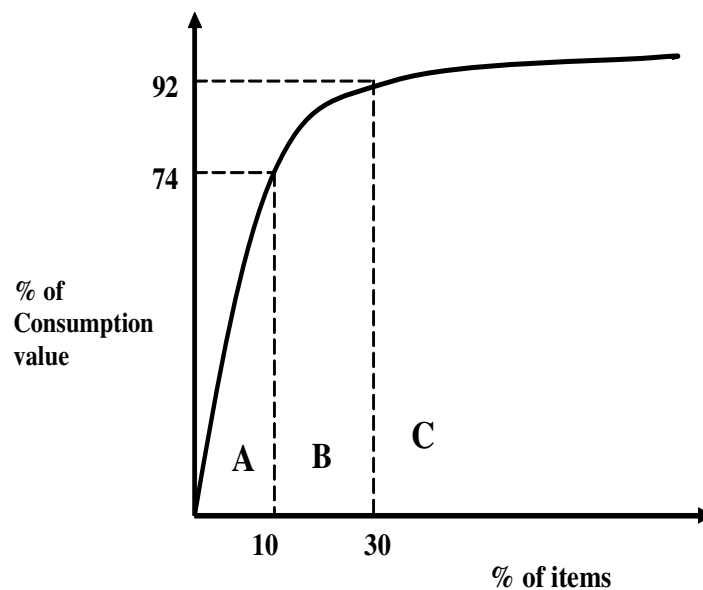
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Table2.5

Class	No. of items	% of items	Consumption Value in Lac Rs.	Cut-off % of Consumption value
A	6	30	450	73.48
B	7	35	120	19.59
C	7	35	42.25	6.9

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Figure 2.6 - Graphical representation of ABC analysis



2.6.1 Kinds of Control

Purpose of classifying the items into ABC is to control over each item. The degree of control required for A class is not same for B and C class items. The following table helps the material manager in the kind of control to be exercised on these items.

Advantages of ABC Analysis:

1. Better exercise of control over all materials.
2. The capital invested in inventory can be reduced to minimum levels.
3. Warehouse and storage costs can be reduced.

Limitations of ABC Analysis:

- ABC analysis mainly provides a guideline for inventory management. It needs to be supplemented by basic understanding and judgment as there are certain items which may fall into category C or category B due to their low usage value but are otherwise very critical for the production process of the firm. Their inventory levels have to be carefully monitored.
- The ABC analysis, to be effective, needs to be constantly undertaken and periodically reviewed by the management, as the number of items and value of items keep on undergoing changes.
- The practical problem in the usage of ABC analysis is that generally, thousands of items fall in category C, as a result, a lot of time is spent on managing inventory of items of this category (even if it needs simple control). The time left for controlling the inventory stocks of categories A is therefore much shorter than that required for their effective management.

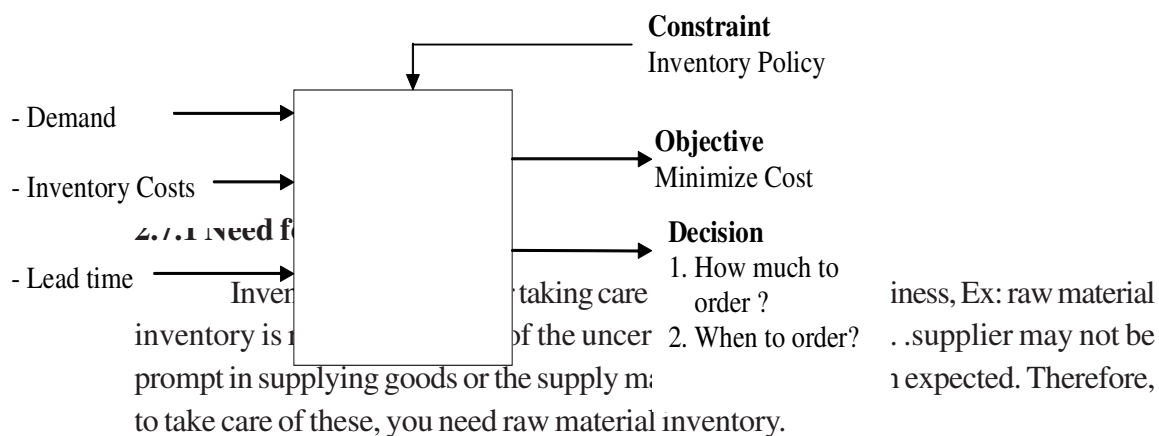
Review Questions:

What is consumption value?

2.7 INVENTORY MODELS**Inventory:**

Organizations spend lot of money in materials. Material cost represent 20 to 60 percent of the cost of production, even a small saving in material will reflect in profit. Idle scarce material resource is called inventory. Since we invest lot of money in materials and if materials are idle for long time, it is not good for the health of the organization. So it is a must to exercise a control over **Idle Scarce Resources**, otherwise, lot of money is tied in inventory. So had you not invested this money on material, it would have fetched return from the other source. Therefore, an opportunity of earning the return is lost by investing in the inventory, you can see now how can you control the inventory.

Figure 2.7 – Inventory System

**2.7.2 Types of inventory**

1. Raw material inventory.
2. Work in process inventory.
3. Finished goods inventory.
4. Supplies.
5. Pipeline inventory.
6. Buffer stock or Safety stock.
7. Decoupling inventory.

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1,2,3,4 are the basic types of Inventory whereas others are named based on their usage.

Supplies:

Materials which are used other than those used for production of finished goods.

Ex: lubricants, pencil, pen, paper, spare parts.

Pipeline inventory:

It can be raw material, work in progress or finished goods inventory. Ex: Assume supplier is far away. Consumption per day is 20 units, 5 days for transportation

$20 \times 5 = 100$ units are required for the period of transportation.

So if you keep 100 units in your stock it becomes your pipeline inventory.

Decoupling inventory

Inventory “**decouples**” in different stages. It might be raw material, WIP, finished goods inventory. Ex: customer has inventory for 10 days for the consumption. For 10 days the customer is decoupled from the producer.

So, decoupling inventory is the one which decouples the customer and the producer.

Safety stock:

This stock may be raw material, WIP or finished goods which are extra stock required to take care of fluctuation or uncertainties in the demand or lead time.

Usually in a business organization two things are uncertain namely,

- Demand
- Lead time

Inventory models adopted by organizations depend upon the level of uncertainty with the lead time or demand. The following table portrays the type of inventory model of organizations has to be adopted against the lead time and demand situations.

Table 2.6 – Demand and lead time in different types of model to be adopted

Situations	Demand	Lead time	Type of Model to be adopted
1	Constant	Constant	Deterministic Model
2	Constant	Variable	Probabilistic Model
3	Variable	Constant	Probabilistic Model
4	Variable	Variable	Probabilistic Model

Lead time:

There are two types of leadtime

- Supply lead time
- Manufacturing lead time

Supply lead time:

This time refers to the time lapse between placing of order with the supplier and receiving it by the customer.

Manufacturing Lead time:

The average time consumed by the product in the plant.

Supply lead time (l)

$$L = T_1 + T_2 + T_3 + T_4 + T_5$$

T_1 = order genesis time and transit time (selection of supplier).

T_2 = manufacturing time of the product by suppliers.

$T_2 = 0$ If the product is readily available with the supplier.

T_3 = inspection time.

T_4 = transit time.

T_5 = receiving time.

If L is high, more inventory is needed to take care of high lead time.

2.7.3 Inventory cost:

Types of inventory cost are

- Ordering cost / setup cost.
- Carrying cost.
- Shortage cost / Back ordering cost.
- Purchase cost.

Inventory cost varies according to decisions namely.

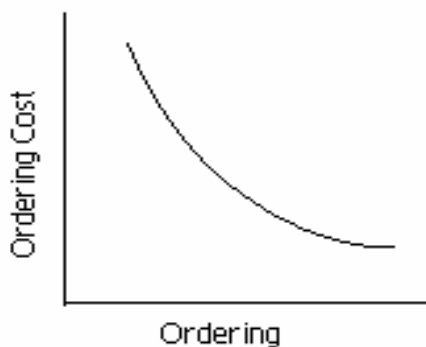
Ordering quantity

Ordering cost: (Co)

It is measured per order.

Fig: Ordering Cost behavior against the Ordinary Quantity.

Figure 2.8 – Ordering Cost Curve



Component of Ordering Cost

- Tender and Bidding Cost
- Purchase negotiations
- Selection of vendor
- Preparation and sending of order etc.

NOTES

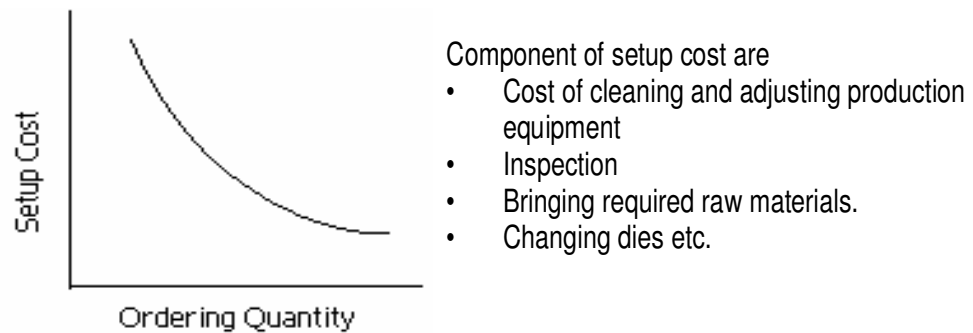
NOTES

Suppose we produce internally without ordering, then there is no ordering cost . It becomes Setup cost.

Setup cost: (Co)

It is measured per setup.

Figure 2.9 – Setup cost Curve



As we have seen in both cases, it varies with decision making i.e. how much to order?

Carrying cost: (Cc)

It is the penalty cost which organization incurs because of carrying inventory.
Components of carrying cost:

- Capital Cost
- Storage Cost
- Insurance
- Obsolescence
- Deterioration
- Tax etc

Cc = cost of holding one unit per unit time* avg. amount of inventory held per unit time.
Carrying cost is measured in terms of percentage.

Example 2.2

Assume that the average inventory in a year for an item = 2000 units

Price of the item = Rs. 100

$$\begin{aligned}\text{Average Investment on Inventory} &= 2000 \times 100 \\ &= \text{Rs. 2, 00,000}\end{aligned}$$

By having the average inventory, the organization involves the following additional Cost.

NOTES

Capital Cost (Opportunity Cost)	= 500
Storage = 1000	
Insurance	= 5000
Obsolescence	= 1000
Deterioration	= 4000
Tax = 4000	
Total = 20,000	

Rs. 20,000 contributes 10 percent of the Average investment of Rs, 2,00,000.

So the inventory carrying cost for this organization is valued at 10 percent (10 percent of Rs. 100) per unit per year.

Figure 2.10 – Carrying Cost Behavior



Carrying Cost Behavior
against the
ordering cost

Shortage Cost (C_s)

Shortage cost is the result of the customers demand not met from the existing stock. Shortage costs are of two types, the one is lost sale and another is the back ordered. In the case of the lost sale the customers demand is not met. But in the case of the back ordering the customers demand is met at delayed date.

The components of shortage cost are the –

1. cost involved in taking steps to expedite the procurement of the purchased material.
2. cost involved in rearranging the shop schedule to permit the earlier completion of order under consideration.
3. cost involved in working overtime and so on.
4. loss of customers goodwill because of not meeting the customer requirement (future profit loss).
5. present profit loss etc.

NOTES

Some of the components of the shortage cost is difficult to quantify but roughly it is possible to estimate the shortage cost.

$$\text{Shortage cost} = [\text{shortage cost per unit time}] * [\text{average shortage per unit time}]$$

$$= C_s \cdot I_s$$

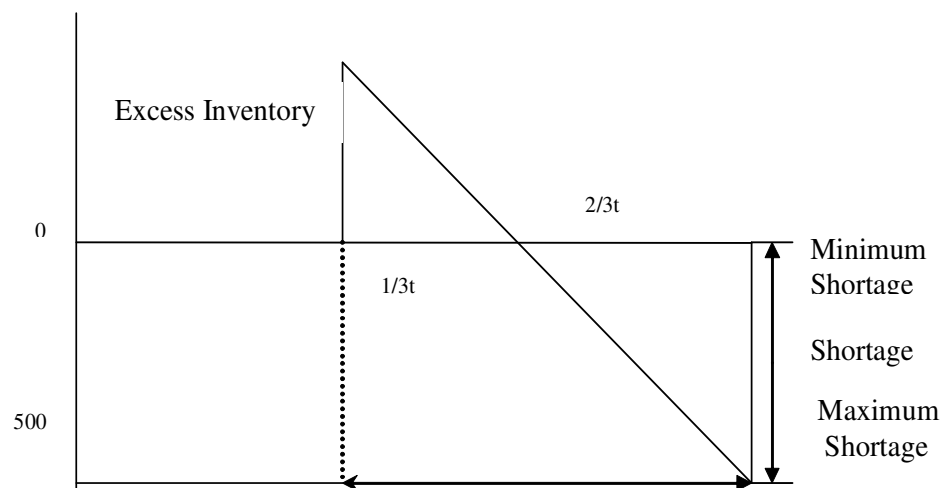
C_s = shortage cost per unit time

I_s = average shortage per unit time

Example 2.3

Assume that the average shortage cost is calculated per ordering cycle

Figure 2.11 – Inventory level fluctuations for determining average shortage



Suppose t is the ordering cycle.

Assume that in that ordering cycle $2/3t$ time the demand is not met from the stock.

The average shortage in the cycle =

$[(\text{minimum shortage during cycle} + \text{maximum shortage during cycle})/2] \times [\text{Proportion of time shortage occurs during cycle}]$

$$= (0+500)/2 \times (2/3t)/t$$

$$= 500/3$$

Assume that shortage cost per unit time = Rs. 9

$$\text{Shortage cost} = 9 \times 500/3$$

$$= 1500$$

Purchase Cost (C_p)

Purchase cost is the cost of purchase/price of product to be produced. C_p becomes the production cost if it is produced inside the organization.

Decision

The decision regarding inventory will be mostly of how much to order?, and when to order? How much to order is related with ordering the quantity but when to order is related with the frequency of ordering and reorder level.

Relevant Cost

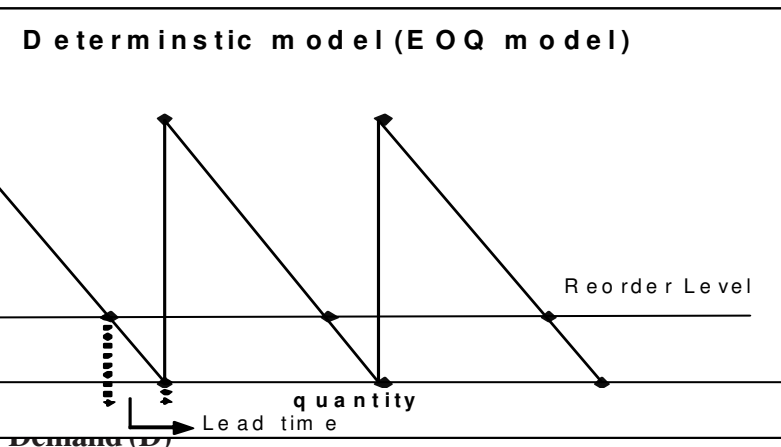
The relevant costs, namely, ordering cost, carrying cost, shortage costs are relevant cost. A cost is said to be relevant cost, provided the cost varies with the decision. If the ordering quantity (Q) is more that results in less shortage cost and ordering cost but the inventory carrying cost will be high. The purchase price is considered to be relevant only when the supplier offers discount.

The purchase cost becomes relevant because the decision, namely, the ordering quantity varies according to the offers provided by the supplier.

1.7.4 Deterministic Model

2.7.4.1 Figure below portrays EOQ model the deterministic inventory model. This is shown time vs. inventory Level.

Figure 2.12 - Deterministic Model



Demand rate is uniform and is known. D is the annual demand.

Lead time (L)

Lead time is known and constant.

Costs

Ordering cost, carrying cost are known. Purchase cost is irrelevant it means no price discount is offered. Shortage cost is not permitted.

NOTES

NOTES

Decision to be taken:

How much to order? - Ordering quantity (Q)

When to order? - Reorder Level

To answer for the questions related with the decisions, you have to proceed as follows:

- Any organization, it has to minimize the total inventory cost.
- Total annual inventory cost = ordering cost + carrying cost + purchase cost + short age cost
- With regard to this model, the shortage cost is not permitted.
- Total annual inventory cost = ordering cost + carrying cost + purchase cost

Since you should find the ordering quantity and re-order level, next you should consider relevant cost.

(i.e.) total annual relevant cost = ordering cost + carrying cost

= (no. of orders) (ordering cost per order)

+ (average inventory) (Carrying Cost)

$D/Q = \text{No. of Orders}$

Average inventory according to the figure = $(\text{min. inventory} + \text{max. inventory})/2$

$= (0+Q)/2$

$= Q/2$

Total annual relevant inventory cost = $(D/Q) \times C_o + (Q/2) \times C_c$

Since you have to establish 'Q'

Differentiating w.r.t. Q and equate it to zero.

$= - (D/Q) \times C_o + C_c/2 = 0$

Or

$$\frac{2DC_o}{C_c} = Q^2$$

Or $Q^2 = 2DC_o/C_c$

Or $Q = \sqrt{2DC_o/C_c}$ Answer to the question how much to order

NOTES

Total annual relevant inventory cost

$$= (D/Q)C_o + (Q/2)C_c$$

Substituting $q = \sqrt{2DC_o/C_c}$

$$= (D/\sqrt{2DC_oC_c/C_c})C_o + (\sqrt{2DC_oC_c/C_c}/2)C_c$$

=

$$= (\sqrt{2DC_oC_c})/\sqrt{2} + (\sqrt{2DC_oC_c})/\sqrt{2}$$

$$= (2/\sqrt{2}) \sqrt{2DC_oC_c}$$

$$= \sqrt{2DC_oC_c}$$

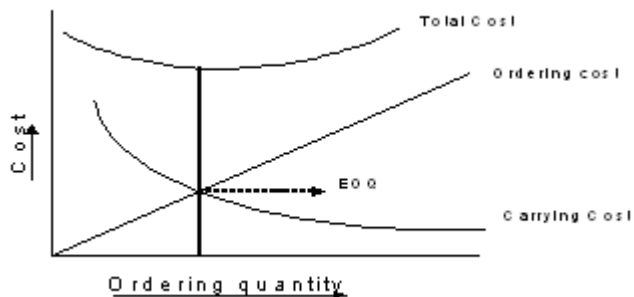
Total annual inventory cost

= Total annual ordering cost + Total annual carrying cost + Total annual purchase cost

$$TC = \frac{D}{Q} C_o + \frac{Q}{2} C_c + D.C$$

= Purchase cost + total annual relevant inventory cost

$$= DC_p + \sqrt{2DC_oC_p}$$



EOQ as follows.

Economic Order Quantity

Example 2.4

The demand for a certain item is 4800 unit per year. Each unit cost Rs.100. Inventory cost charges are estimated at 15%. No shortage cost is allowed. The ordering cost Rs. 400 per order. Lead time is one day. Assume 250 working days. Find the following:

1. EOQ
2. Time between the orders.

NOTES

3. Number of orders required each year.
4. Minimum relevant Inventory cost.
5. Minimum total inventory cost.
6. Reorder Level.
7. Plot a graph for inventory level fluctuation with time.

Solution

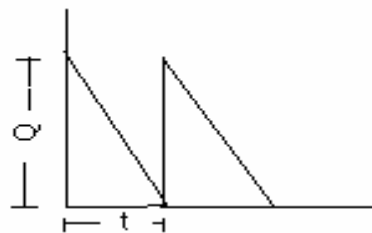
- (i) $EOQ = \sqrt{2DC_o/C_c}$
 $= \sqrt{2 \times 48000 \times 400 / (.15 \times 100)}$
 $C_c = (15/100) \times 100 = 1600$
- (ii) To determine reorder level
 $= L \times (D/12)$
 $= 2 \times (48000/12250) = 192 \text{ units}$

- (iii) Time between orders

$$Q/t = D$$

$$t = Q/D$$

Figure 2.14 – Inventory Level



$$= 1600/48000$$

$$= .033 \text{ years}$$

$$= .033 \times 250$$

$$= 8.33 \text{ days}$$

- (iv) Number of orders

$$= D/Q$$

$$= 48000/1600$$

$$= 30 \text{ orders}$$

- (v) Total minimum relevant cost

$$\text{Inventory cost} = \sqrt{2DC_oC_c}$$

$$= \sqrt{2 \times 48000 \times 400 \times .15 \times 100}$$

$$= \text{Rs. } 24,000$$

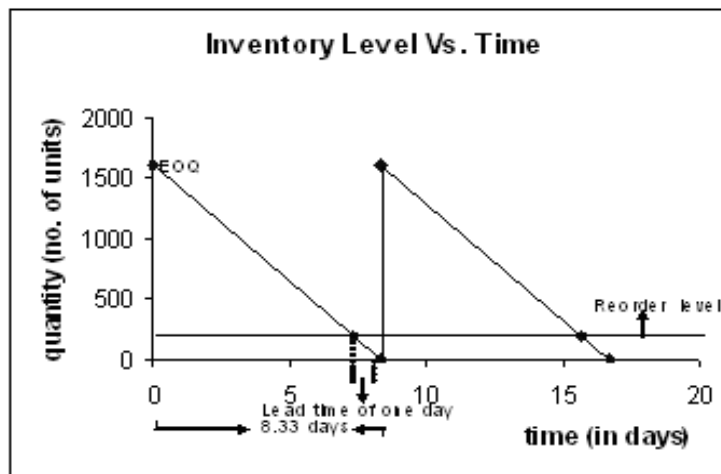
- (vi) Total minimum inventory cost

$$= DC_p + \sqrt{2DC_oC_c}$$

$$= 48000 \times 100 + 24000$$

$$= 4824000 \text{ Rs.}$$

Figure 2.15 – Inventory level vs. Time



Above problem is solved scientifically, but this problem can be also be solved graphically.

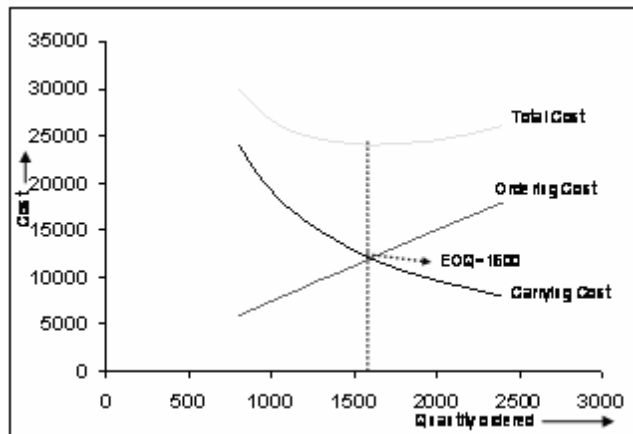
Table 2.2

Ordering quantity	No. of orders	Ordering Cost	Average Inventory	Carrying Cost	Total Cost	
600	80	32000	300	4500	36500	Decreases
800	60	24000	400	6000	30000	
1000	48	19200	500	7500	26000	
1200	40	16000	600	9000	25000	
1400	35	14000	700	10500	24500	
1600	30	12000	800	12000	24000	Increases
1800	27	10800	900	13500	24300	
2000	24	9600	1000	15000	26600	

NOTES

NOTES

Figure 2.16 – Graphical Calculation of EOQ



2.7.4.2 Economic Batch Quantity Model:

1. Demand:

- It is known and constant.
- It is nothing but the annual production requirement.

2. Production rate:

- It is known and is estimated based on the capacity of the plant.

3. Lead time:

It is known and constant.

4. Cost:

Setup/ordering cost: Since there is no purchase there is no ordering cost. Only setup cost comes into picture in the place of ordering cost .this is known.

Carrying cost: It is known and constant.

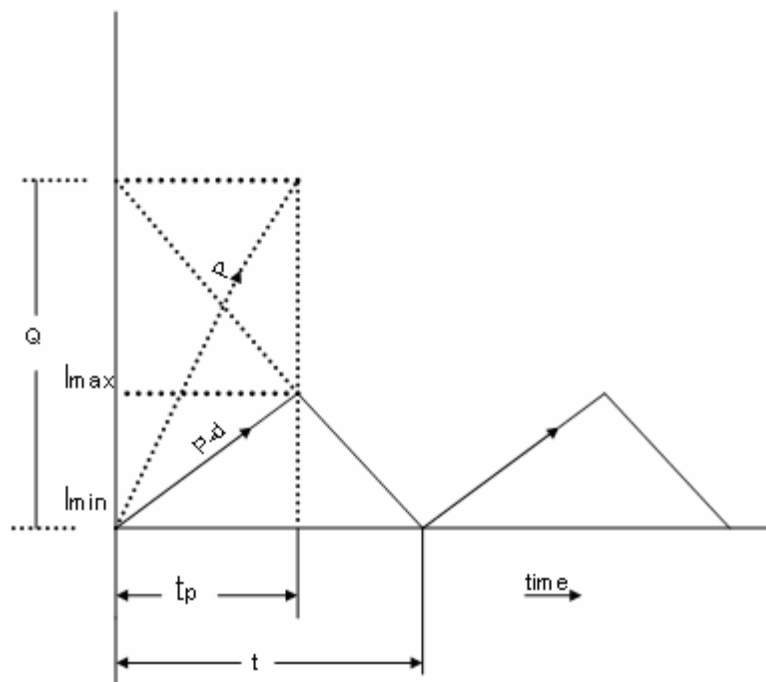
Product cost: assume that product cost per unit does not vary with the production i.e. unit is irrelevant of the quantity of production.

Decision

How much to produce?

When to produce?

The inventory model for this case will be as shown in the figure2.16.

Figure 2.17 – Inventory Model (Economic Batch Quantity)**NOTES**

t_p - It is the production period.

t - It is the time interval between the two productions.

From the fig. it is concluded that up to the period, both production and consumption take place and inventory is built up at the rate of $(p-d)$. Where 'd' is the demand rate.

Once the t_p period is reached there is no production, there is only consumption at the rate of 'd'. Next production starts after ' t ' period.

To find the quantity of production 'Q', production time period t_p and time interval between production ' t '. The following procedure is carried out.

Total inventory cost = setup cost + carrying cost + production cost + shortage cost.

Total relevant inventory cost = setup cost + carrying cost.

Shortage and production costs are zero because no shortage is allowed and the production cost becomes an irrelevant cost.

From the fig. the average inventory is calculated as follows:

$$\begin{aligned}\text{Avg. inventory} &= (I_{\max} + I_{\min})/2. \\ &= (I_{\max} + 0)/2 \\ &= I_{\max}/2.\end{aligned}$$

NOTES

To find I_{\max} , from the fig.

$$I_{\max}/t_p = (p-d).$$

$$\text{So, } I_{\max} = (p-d)t_p.$$

To find t_p ,

$$t_p \times p = Q$$

$$t_p = Q/p$$

$$I_{\max} = (p-d) Q/p$$

$$I_{\max} = (1-d/p) Q.$$

Total relevant inventory cost = setup cost + carrying cost

$$\begin{aligned} \text{Setup cost} &= (\text{number of setup}) \times \text{setup cost per setup} \\ &= (D/Q) C_o \end{aligned}$$

$$\begin{aligned} \text{Carrying cost} &= (\text{Average inventory}) \times \text{carrying cost per unit} \\ &= [(I_{\max} + I_{\min})/2] \times C_c \\ &= (1-d/p) \times (Q/2) C_c \end{aligned}$$

$$\text{Total relevant inventory cost} = (D/Q)C_o + (1-d/p)(Q/2)C_c$$

For cost minimization, differentiate w.r.t. Q and equate it to zero.

$$-DC_o/Q^2 = -(1-d/p)C_c$$

$$Q = \sqrt{2DC_o/C_c(1-d/p)}$$

$$\begin{aligned} \text{Total annual relevant inventory cost} &= D/v [2DC_o/(1-d/p) C_c] + \\ &\quad v [2DC_o/(1-d/p) C_c]/2 \end{aligned}$$

$$\begin{aligned} &= v [DC_o C_c(1-d/p)/v^2 + v[DC_o C_c(1-d/p)]/v^2] \\ &= (2/v^2) v [DC_o C_c(1-d/p)] \\ &= v [2DC_o C_c(1-d/p)] \end{aligned}$$

$$\text{Total annual inventory cost} = v 2DC_o C_c(1-d/p) + C_p D$$

Deducing EOQ from EBQ model

It is known that in case of EOQ model, the production rate is infinity i.e. there is an instantaneous replenishment.

Now

$$EBQ = v [(2DC_o)/(1-d/p) C_c]$$

$$\text{So when } p = \infty$$

$$EBQ = EOQ$$

Example 2.5

ABC Power Company has planned to cover the demand for electricity using coal. Annual demand for the coal input is estimated to be 8 lakh tones. It is used uniformly throughout the year. Coal can be strip mined at the rate of 5000 tonnes per day. The setup cost for mining is 200 rupees per run. The inventory holding cost is 5 rupees per tone per day. The total numbers of working days are given as 250. Determine.

1. EBQ.
2. Duration of mining run.
3. Time between runs.
4. Minimum relevant inventory cost.
5. Plot graph showing whole inventory fluctuation Vs time.

Solution:

To find EBQ,

$$EBQ = \sqrt{\frac{2DCo}{Cc(1-d/p)}}$$

Where

$$D = 8,00,000 \text{ tones per year}$$

$$D = 8,00,000/250$$

$$= 3200 \text{ tones per day}$$

$$p = 5000 \text{ tones/day}$$

$$Co = \text{Rs}2000 / \text{run}$$

$$Ch = \text{Rs}5 / \text{tones/day}$$

$$(i) EBQ = \sqrt{\frac{2 \times 8,00,000 \times 2500}{5 \times (1 - 3200/5000)}}$$

$$(ii) \text{Duration of each mining run } Q/p = t_p$$

$$t_p = 42164/5000$$

$$= 8.43$$

$$= 8.5 \text{ days (approx)}$$

$$(iii) \text{Time between runs}$$

$$Q = t * d$$

$$T = Q/d$$

$$= 42164/3200$$

$$= 13.17 \text{ days.}$$

$$(iv) \text{Minimum relevant inventory cost} = \sqrt{\frac{2DCoCc(1-d/p)}{}}$$

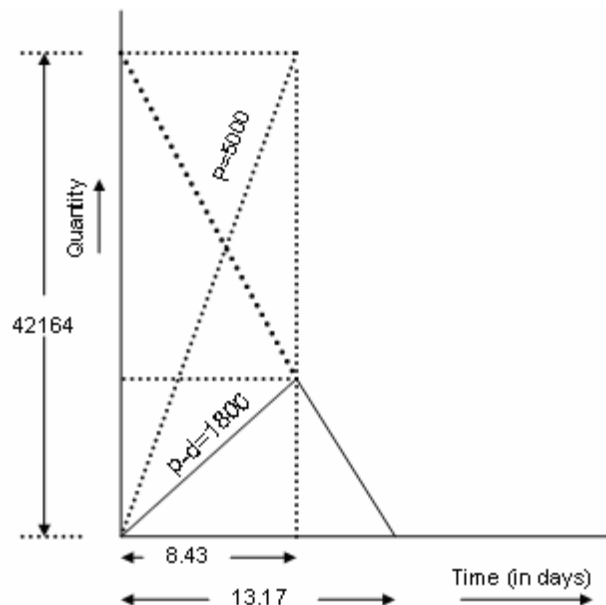
$$= \sqrt{2 \times 8,00,000 \times 2500 \times 5 \times (1 - 3200/5000)}$$

$$= \text{Rs. } 84853$$

NOTES

NOTES

Figure 2.18 – Graphical representation of above the example



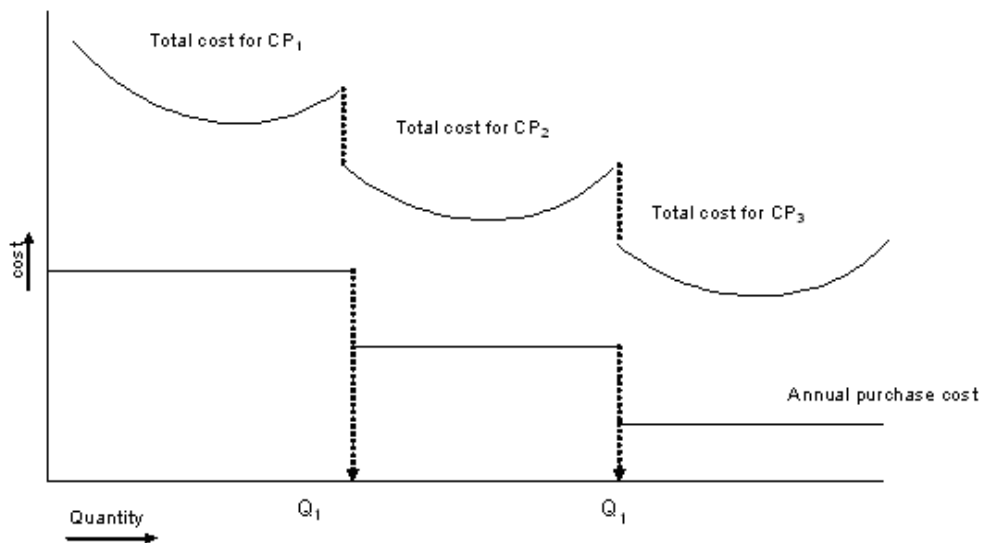
2.7.4.3 Quantity Discount Model

As it is mentioned already, the purchase cost becomes relevant with respect to the quantity of order only when the supplier offers discounts.

Discounts means if the ordering quantity exceeds particular limit supplier offers the quantity at lesser price per unit.

This is possible because the supplier produces more quantity. He could achieve the economy of scale, the benefit achieved through the economy of scale, he wants to pass it onto the customer. This results in lesser price per unit if the customer orders more quantity.

If you look at in terms of the customer's perspective, the customer should also see that whether it is advisable to avail the discount offered. This is done through a trade off between his carrying inventory by the result of acquiring more quantity and the benefit achieved through purchase price.

Figure 2.19 – Quantity Discount Model**NOTES****Solution:**

Start with the lowest price i.e. Rs 9 and to find whether Q is more than or equals to 5000.

$$\begin{aligned} \text{EOQ} &= \sqrt{2DC_o / C_c} \\ &= \sqrt{2 \times 25000 \times 60 / 2.7} \\ &= 1054.06 \text{ approx. } 1055 \text{ units} \end{aligned}$$

This is not a feasible solution because we expected that Q will be more than or equals to 5000 but the EOQ came as 1055.

By taking the next least value i.e. Rs 11 and to find whether Q is more than 1000 and less than 5000.

$$\begin{aligned} \text{EOQ} &= \sqrt{2 \times 25000 \times 60 / 3.3} \\ &= 956 \text{ units} \end{aligned}$$

This is also not a feasible solution because we expected Q will be more than 1000 and less than 5000 but the EOQ came as 956.

By taking the next least value i.e. Rs 12 and to find whether Q is equals to 1000.

NOTES

$$EOQ = \sqrt{(2 \times 25000 \times 60) / 3.6}$$

$$= 912.87 \text{ approx. is } 913 \text{ units}$$

This is a feasible solution

The total cost of inventory at EOQ is

$$\begin{aligned} TC &= \sqrt{(2 \times D \times C_c \times C_o)} + D \times P \\ &= \sqrt{(2 \times 25000 \times 60 \times 3.6)} + (25000 \times 12) \\ &= \text{Rs } 303286.33 \end{aligned}$$

Total inventory cost at other ordering quantities are -

Total inventory cost for Q equals to 5000

$$\begin{aligned} TC &= (D/Q) \times C_o + (Q/2) \times C_c + D \times P \\ &= (25000/5000) 60 + (5000/2) 2.7 + (25000 \times 9) \\ &= 232000 \end{aligned}$$

Total inventory cost for Q between = 1000 and 5000

$$\begin{aligned} TC &= (D/Q) \times C_o + (Q/2) \times C_c + D \times P \\ &= (25000/1000) 60 + (1000/2) 3.3 + (25000 \times 11) \\ &= 278150. \end{aligned}$$

The possible savings is equal to total inventory cost at feasible EOQ, total inventory cost at 5000 units.

$$\begin{aligned} \text{The possible savings are} &= 303286 - 232000 \\ &= 71,286 \end{aligned}$$

A ordinary quantity 5000, the total annual inventory cost is 2, 32,000

2.7.5 Probabilistic Models

In the previous section, it is assumed that the lead time and demand are constant. But in real life situations it is not so. The demand is always uncertain because it is difficult to exactly estimate the required quantity by the customer and the supplier is also usually not reliable. In the sense, he doesn't supply in the specified time period. Considering this kind of situation, the decision should be taken regarding the quantity of ordering, time at which the order to be placed, the time between the orders and how much inventory to be kept against the uncertainty of demand and the lead time become cumbersome.

To deal with the above scenarios, the inventory model to be adopted is known as **Probabilistic Inventory Model**.

NOTES

The inventory models called probabilistic inventory model because the demand or lead time or both are random variables. The probability distribution of demand and lead time should be estimated..

The inventory models answers for questions related to the decision raised above are called **Probabilistic Inventory Model**.

2.7.5.1 One such model is Fixed Order Quantity Model (FOQ).

In this model,

1. The demand (D) is uncertain, you can estimate the demand through any one of the forecasting techniques and the probability of demand distribution is known.
2. Lead time (L) is uncertain, probability of lead time distribution is known.
3. Cost(C) all the costs are known.

-Carrying costs C_c

-Ordering costs C_o

Stock out Cost

It is difficult to calculate stock out cost because it consists of components difficult to quantify so indirect way of handling stock out cost is through service levels. Service levels means ability of organization to meet the requirements of the customer as on when he demands for the product. It is measured in terms of percentage.

For example: if an organization maintains 90% service level, this means that 10% is “stock out” level. This way the stock out level is addressed.

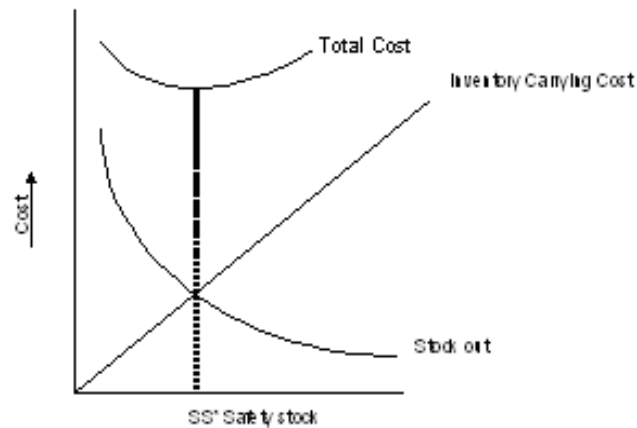
Safety stock

It is the extra stock or buffer stock or minimum stock. This is kept to take care of fluctuations in demand and lead time.

If you maintain more safety stock, this helps in reducing the chances of being “stock out”. But at the same time it increases the inventory carrying cost. Suppose the organization maintains less service level that results in more stock out cost but less inventory carrying cost. It requires a tradeoff between inventory carrying cost and stock out cost. This is explained through the following figure2.19

NOTES

Figure 2.20 – Safety Stock



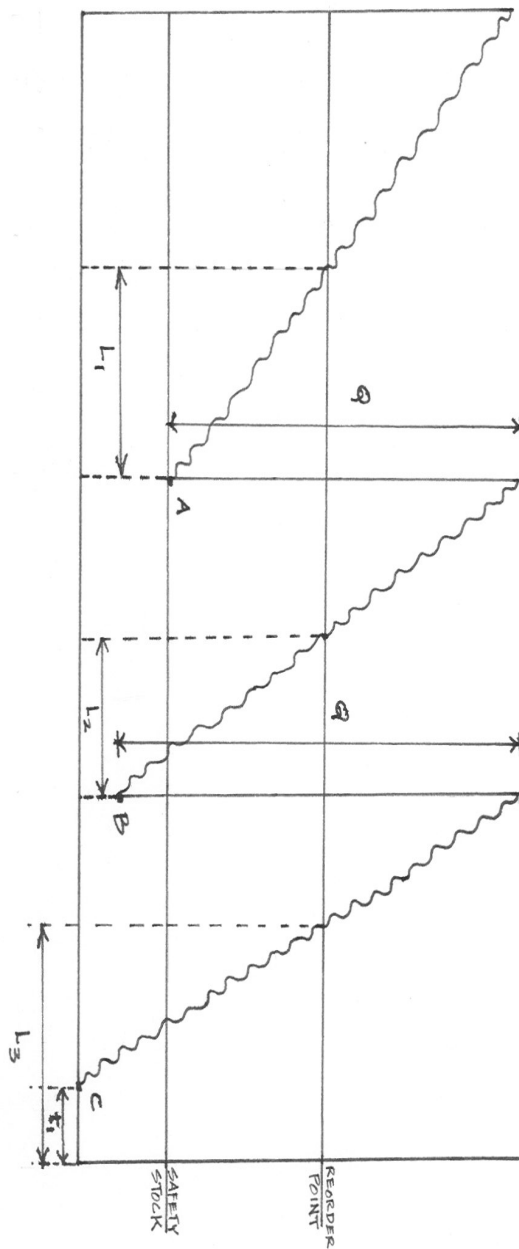
Safety stock ($S.S^*$) is to be stocked by the organization.

Working of fixed order quantity model

Fixed order quantity system is also known as **continuous review system** or perpetual inventory system or Q system. In this system, the ordering quantity is constant. Time interval between the orders is the variable.

The system is said to be defined only when if the ordering quantity and time interval between the orders are specified. EOQ provides answer for ordering quantity. Reorder level provides answers for time between orders. The working and the fixed order quantity model is shown in the figure 2.20 (next page).

Figure 2.21 – Fixed Order Quantity Model



Q - SYSTEM

- A. MATERIAL ARRIVED BEFORE MATERIAL CONSUMED FROM SAFETY STOCK.
 - B. MATERIAL ARRIVED AFTER MATERIAL CONSUMED FROM SAFETY STOCK.
 - C. MATERIAL ARRIVED AFTER CONSUMING ALL THE SAFETY STOCK.
- t_1 - STOCK OUT PERIOD.

NOTES

NOTES

Application of fixed order quantity system

1. It requires continuous monitoring of stock to know when the reorder point is reached.
2. This system could be recommended to "A" class because they are high consumption items. So we need to have fewer inventories. This system helps in keeping less inventory comparing to other inventory systems.

Advantages

1. Since the ordering quantity is EOQ, comparatively it is meaningful. You need to have less safety stock. This model is relatively insensitive to the forecast and the parameter changes.
2. Fast moving items get more attention because of more usage.

Weakness

1. We can't club the order for items which are to be procured from one supplier to reduce the ordering cost.
2. There is more chance for high ordering cost and high transaction cost for the items, which follow different reorder level.
3. You can not avail supplier discount. While the reorder level falls in different time periods.

Illustrative Example 2.7

1. ABC company requires components at an annual usage rate of 1200 units. The cost of placing an order is Rs 100 and has a five day lead time. Inventory holding cost is estimated as Rs 30 per unit per year. The plant operates 250 days per year. The daily demand is normally distributed with a standard deviation of 1.2 units. It has been decided to use fixed quantity inventory system based on a 95% service level. Specify the following
 1. Ordering quantity
 2. Reorder level

Solution:

Given data
Demand 1200 units
Ordering Cost Rs 100
Carrying cost Rs 30 per unit per year
Lead Time 5 days
Operating days 250 per year.
Standard deviation of demand per day is 1.2 units.

To determine the ordering quantity

$$EOQ = \sqrt{2DC_o / C_c}$$

$$= \sqrt{2 \times 1200 \times 100 / 30}$$

$$= 89.4 \text{ approx.} = 90 \text{ units}$$

To determine the reorder level

Reorder level = average demand during lead time + safety stock.

Safety stock calculations:

To find out the safety stock as it is mentioned already that you need to use the service level. As per this problem it is given 95% service level that means 5% stock out level. We need to have safety stock level against this 5% stock level. It is also given in the problem that consumption of items follows normal distribution.

The mean lead time demand distribution is $= (1200/250) \times 5 = 24 \text{ units} = X_L$

The mean of the distribution is $(1200/250) \times 5$
 $= 24 \text{ units}$

Variance of the distribution, since per day standard deviation is given. First it is to be converted into variance by taking the square

$$(1.2)^2 = 1.44 \text{ units}$$

From the per day variance, the five days variance determined as follows because leadtime equal to 5 days.

If V is the variance of one day then the five day variance is

$$V + V + V + V + V = 5 \times V$$

$$\text{Standard deviation} = \sqrt{5V} = \sqrt{5 \times 1.44} = \sqrt{7.2} = 2.68$$

$$\text{For 5 days} = \sqrt{5 \times 1.44} = 2.68$$

σ_L = standard deviation per day

In common, to convert the per unit standard deviation into lead time standard deviation, Based on above calculation it could be deduced that

$$\sigma_{L=VL} \times \sigma$$

Where σ_L is the standard deviation of demand during lead time.

σ is the standard deviation of demand per unit time

Since the demand during lead time follows the normal distribution.

It is given that 95% service level and 5% stock out level.

For 5% stock out level, the safety level is estimated as follows:

From the distribution you can calculate the safety stock using the formula

$$K \times \sigma_L$$

K is the safety factor for 5% stock out level; the K value is calculated using the standard distribution table.

NOTES

NOTES

To calculate K at 5% stock out level

$K=1.65$ from the table

Safety stock = $K \times \sigma_L$

$= 1.65 \times 2.68$

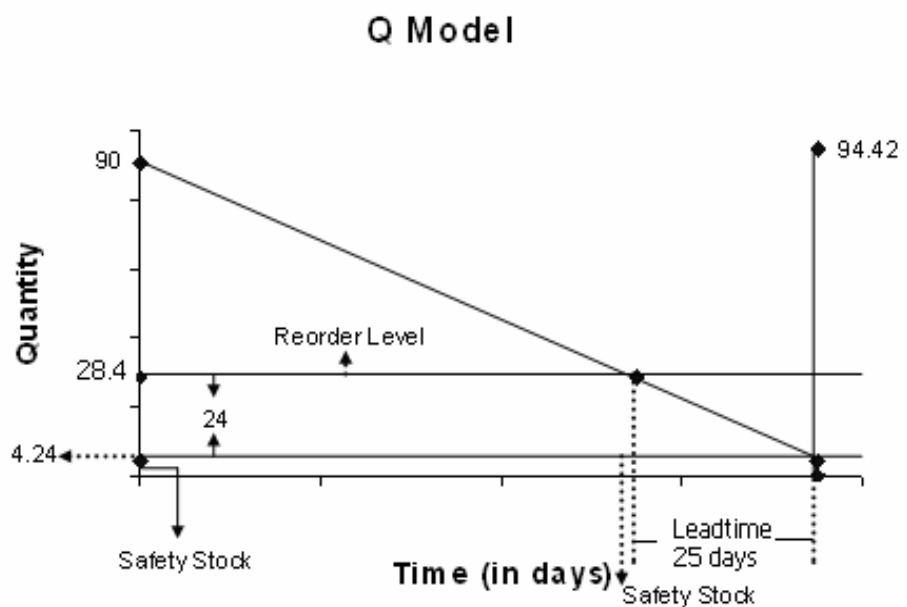
$= 4.42$

To find the re order level

$= 24 + 4.42$

$= 28.42$ units

Figure 2.22 – Graphical Presentation of Example 2.7



Review Questions:

1. Define Inventory
2. What is pipe line inventory?
3. Give formulae for EOQ?
4. Give formulae for EBQ
5. When purchase cost become relevant?
6. In which situations one has to adopt probabilistic model?

2.8 MATERIAL REQUIREMENT PLANNING

2.8.1 Introduction

Material Requirements Planning (MRP) is a computer-based production planning and inventory control system. MRP is concerned with both production scheduling and inventory control. It is a material control system that attempts to keep adequate inventory levels to assure that required materials are available when needed. MRP is applicable in situations of multiple items with complex bills of materials.

The major objectives of an MRP system are to simultaneously:-

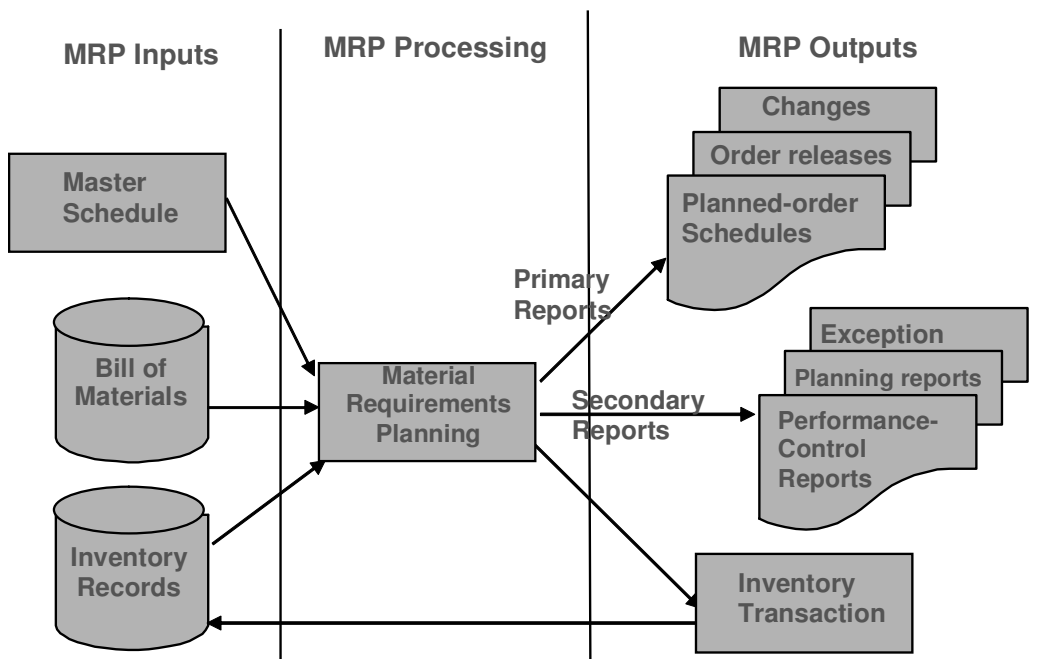
1. ensure the availability of materials, components and products for planned production and for customer delivery,
2. Maintain the lowest possible level of inventory,
3. Plan manufacturing activities, delivery schedules and purchasing activities.

MRP is especially suited to the manufacturing settings where the demand of many of the components and subassemblies depend on the demands of items that face external demands. Demand for end items is independent. In contrast, the demand for components used to manufacture end items depend the on the demands for the end items. This is known as Derived Demand. The distinctions between the independent and derived demands are important in classifying the inventory items and in developing systems to manage items within each demand classification. MRP systems were developed to cope better with derived demand items.

2.8.2 Overview of MRP system

The following figure shows the general overview of an MRP system.

Figure 2.23 – MRP system



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2.8.3 Inputs to MRP system

There are three major inputs for an MRP system. They are

1. Master production schedule,
2. Bill of Material
3. Inventory status records

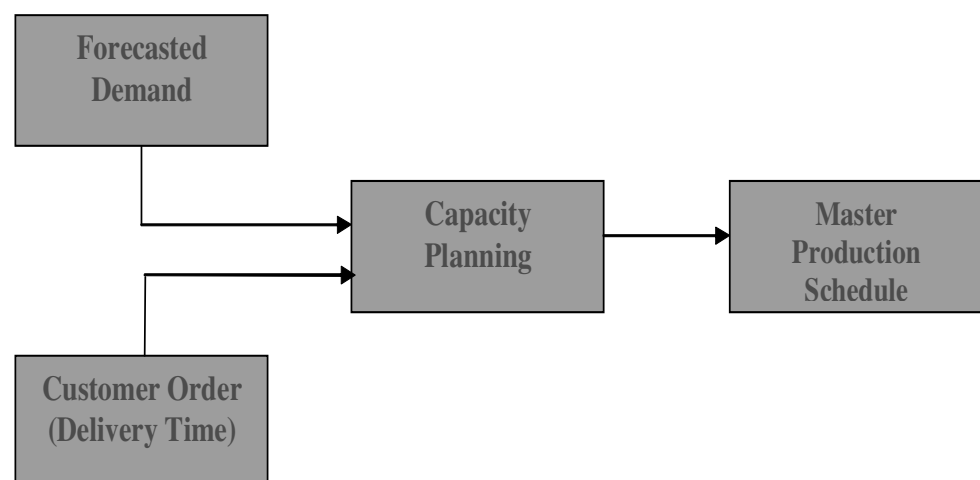
Without these basic inputs the MRP system cannot function.

1. Master production schedule

The demand for end items is scheduled over a number of time periods and recorded on a master production schedule (MPS). The master production schedule expresses how much of each item is wanted and when it is wanted. The MPS is developed from forecasts and firm, the customer orders for end items, safety stock requirements and internal orders. MRP takes the master schedule for end items and translates it into individual time-phased component requirements.

Overview of the Master Production Schedule

Figure 2.24 - Overview of Master Production Schedule



Master Production Schedule- Example

Table 2.7Aggregate Production
Plan for Mattresses

Month	1	2
Mattress production	900	950

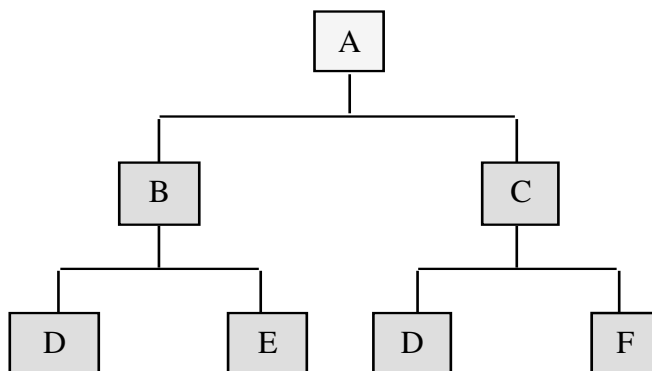
Master Production
Schedule for
Mattress Models

	1	2	3	4	5	6	7	8
Model 327	200			400		200	100	
Model 538		100	100		150		100	
Model 749			100			200		200

2. Bill of Materials

A bill of materials (BOM) file gives the complete product descriptions and documents quantities of each component, part, ingredient, or raw material needed to make that product or sub-assembly. It is also called as the product structure tree. A sample product structure tree is shown below.

For producing 1 unit of product A, 4 units of B and 2 units of C are required. For producing 1 unit of product B, 2 units of D and 1 unit of E are required. For producing 1 unit of product C, 3 units of D and 2 units of F are required Product Structure Tree.

Figure 2.25 - Product Structure Tree**NOTES**

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Explosion

If 20 nos. of product A is required then we require 80 nos. of B, 40 nos. of C, 280 nos. of D, 80 nos. of E and 80 nos. of F. This process of finding out the requirement of sub components based on the requirement of final product is known as Explosion.

3. Inventory status records

The following inventory status records goes as input to the MRP system

1. Item
2. Supplier
3. Lot size
4. Safety stock
5. Lead time
6. On hand inventory
7. Allotted
8. Level

i) **Item:** Name or number for the item being scheduled.

ii) **Supplier:** Name or number for the of the supplier for the scheduled item.

iii) **Lot size:** Several lot sizing techniques are available. Few of them are listed below.

a) Lot-For-Lot (LFL) ordering.

The lot-for-lot (LFL) is the simplest approach and it calls for producing in period t the net requirements for period t. The LFL approach minimizes the holding cost by producing just-in-time.

b) Economic Ordering Quantity (EOQ):

EOQ is a fixed quantity which is ordered whenever the inventory level reaches pre-determined level.

$$Q = \sqrt{\frac{2 \times D \times C_s}{C_c (1 - d/p)}}$$

Where,

Q – Economic ordering quantity

D – Annual demand

C_o – Ordering Cost (Rs. /Order)

Cc – Holding cost (Rs./Unit/Unit time)

Economic Production Quantity (EPQ)

EOQ is a fixed quantity which is produced whenever the inventory level reaches a predetermined level.

$$Q = \sqrt{\frac{2 \times D \times C_s}{C_c (1 - d/p)}}$$

Where,

Q – Economic Production quantity

D – Annual demand

Cs – Setup Cost (Rs. /Setup)

Cc – Holding cost (Rs./Unit/Unit time)

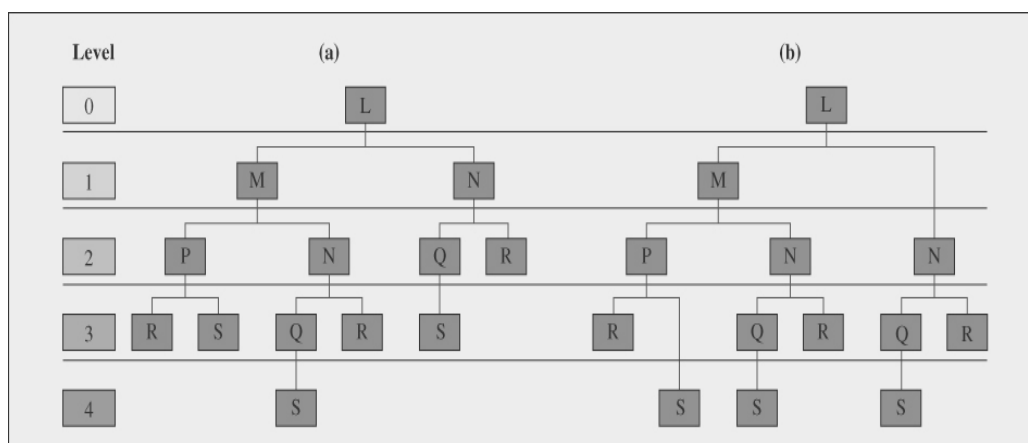
d – Demand rate

p – Production rate

There are also other algorithms available for lot sizing like Wagner-Whitin (WW) algorithm, Silver-Meal (SM) heuristic, part period balancing (PPB) heuristic etc. The lot sizing technique which incurs the lowest cost is chosen.

1. **Safety Stock:** It is the additional stock carried in order to protect against any uncertainty in demand.
2. **Lead time:** It is the time gap between placing an order and receiving the order.
3. **On hand inventory:** It is the actual quantity on hand during scheduling period.
4. **Allotted:** It the quantity of inventory allocated to other orders from the on hand inventory.
5. **Level:** It indicates the level occupied by the particular product/component in the product structure file.

Figure 2.26 – Levels in the product structure file



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If a component comes in more than one level then it should be assigned the lowest level code. For example, in the above figure R comes in both level 2 and level 3. But it should be assigned level code 3 as it is the lowest level.

MRP Process

The process of scheduling the Production of all items is done using an MRP Matrix. The MRP matrix is as shown below.

MRP Matrix

Table 2.8 – MRP matrix

Item: Lot Size:	Low-Level Code: Lead Time:	PD	1	2	3	4	5
Gross Requirements							
Scheduled Receipts							
Projected on Hand							
Net Requirements							
Planned Order Receipts							
Planned Order Releases							

Gross Requirements is the anticipated usage of demand for each period.

Scheduled Receipts is the existing replenishment orders at the beginning of period.

Projected on Hand is the projected inventory status at the end of period after taking into account the inventory to be provided for safety stock and already allotted for other orders.

Net Requirements is the actual number of items to be provided and when it is to be provided. This is calculated taking into account scheduled receipts and projected on hand inventory.

Planned Order Receipts shows when actually net requirements are expected to be received.

Planned Order Releases shows when the order has to be released if the order has to be received as per planned order receipt.

Process Flow

Calculate the exact requirements for each item managed by the MRP system by the explosion process explained previously, and proceed as follows:

1. Retrieve level 0 item requirements (gross requirements) from the master schedule.
2. Use projected on-hand balances and schedule receipts to calculate net requirements. This process is called **Netting**.
3. Calculate when orders should be received to meet net requirements, developing planned-order receipts schedule.
4. Planned-order *release* schedule is calculated by **offsetting** the planned-order receipts by the items' lead times.
5. Repeat steps 1-4 for level 1 items.
6. Repeat steps 1-4 for all items in each subsequent level of the bill of materials.

MRP Output

The primary outputs of MRP are the following:

1. Recommendations of planned order releases.
2. Rescheduling notices changing open-order due dates.
3. Notices to cancel or suspend open orders.
4. Item-status-analysis backup data.
5. Future planned order schedules.

A variety of secondary or byproduct outputs can be generated by MRP at the user's option. It is not practical to list and describe all possible outputs and formats generated by MRP found in industry; MRP lends itself to tailoring, individualization, and infinite modification of outputs. MRP files (database), particularly inventory status records, contain a wealth of data, providing almost unlimited opportunities for the supplying of these data to a whole spectrum of possible outputs. Here are some of the common secondary outputs:

1. Exception notices, reporting errors, incongruities, and out-of-limits situations.
2. Inventory-level projections (inventory forecasts).
3. Purchase commitment reports.
4. Tracers to demand sources (pegged requirements reports).
5. Performance reports for people and functional groups.

Six categories of outputs by functional use are:

1. Inventory order action.
2. Replanning order priority.

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3. Safeguarding priority integrity.
4. Capacity requirements planning.
5. Performance control.
6. Reporting errors, incongruities, and out-of-limits situations.

Inventory order action outputs occur when planned orders appear in current time-buckets. Other types of order action are increases, reductions, or cancellations of order quantities.

Re-planning order priority outputs alert inventory planners to cases of divergence between open-order due dates and dates of actual need, resulting from changed timing of net requirements.

Outputs to help **Safeguard priority integrity** aims at keeping order priorities honest, revealing inventory status problems caused by overstated MPS. Some companies use these reports to provide guidance for planners when accepting customer orders for guaranteed delivery. A “trialfit” of the order as an MPS item enables a net change MRP program to determine potential component shortages. If the order does not fit (too many shortages), the planner can recommend an alternative delivery date.

Capacity requirements planning outputs of MRP are open and planned shop orders in individual time periods, which are input into the load projection program. To keep load projections up-to-date and valid, they must be recomputed as MRP order schedules change.

Performance control outputs are comparisons of MRP plans with actual performance, enabling management to monitor the performance of inventory planners, buyers, the shop, suppliers, and cost accounting.

Outputs reporting errors, incongruities, and out-of-limits situations are called exception or action reports. Some examples:

1. Date of gross requirement is beyond the planning horizon.
2. Number of digits of quantity in gross requirement exceeds size of the field.
3. Planned order is offset into a past period but placed in current period.
4. Number of digits of quantity of open order exceeds size of the field.
5. Number of digits of quantity of net requirements exceeds size of the field.
6. Number of digits of quantity of receipt overflows size of quantity-on hand field.
7. Due date of open order is outside of planning horizon.
8. Allocated on-hand quantity exceeds current quantity on hand (potential shortage).
9. Past-due gross requirement has been included in the current period.

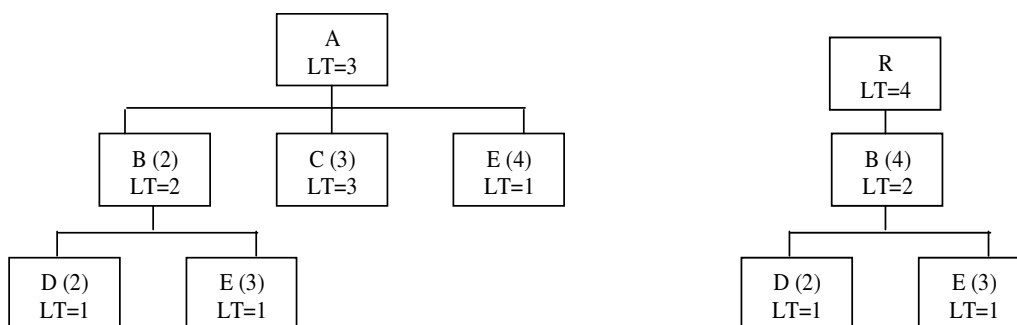
In addition to such exception reports, individual exception messages can be generated at the time inventory transaction are entered, listing reasons for transaction rejections. Some typical messages are

1. Part number is nonexistent.
2. Transaction code is nonexistent.
3. Part number is incorrect (using self checking digits).
4. Actual receipt exceeds quantity of scheduled receipt by x percent (test of reasonableness).
5. Quantity of reported scrap exceeds quantity on hand.
6. Quantity of disbursement exceeds quantity on hand.
7. Order being released exceeds planned quantity.

Sample MRP Problem:

Orders have been received for 20 units of product A and 50 units of product R with the product structures shown below for period 8. The on hand stock levels are A=1, R=4, B=74, C=19, D=190 and E=160. What is the low level code for each item? If the components are ordered as required (no fixed lot sizes), what should be the size of each order? When should the orders be released for each item?

Figure 2.27



**Solution
Table 2.8**

Item	Low Level Code
A	0
R	0
B	1
C	1
D	2
E	2

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Figure 2.28

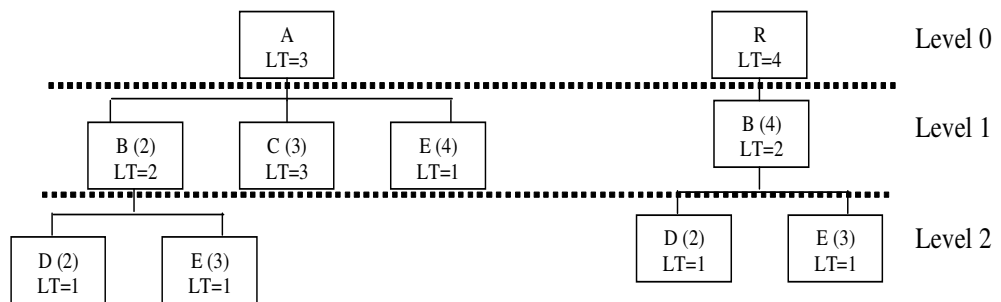


Table 2.9

Item	Lot Sizing	Lead time	Safety Stock	Allotted	Level	Period	PD	1	2	3	4	5	6	7	8
A	Lot for Lot	3	—	—	0	Gross Requirements									20
						Scheduled Receipts									
						Projected on Hand	1	1	1	1	1	1	1	1	1
						Net Requirements									19
						Planned Order Receipt									19
						Planned Order Release						91			

Table 2.10

Item	Lot Sizing	Lead time	Safety Stock	Allotted	Level	Period	PD	1	2	3	4	5	6	7	8
R	Lot for Lot	4	—	—	0	Gross Requirements									50
						Scheduled Receipts									
						Projected on Hand	4	4	4	4	4	4	4	4	4
						Net Requirements									46
						Planned Order Receipt									46
						Planned Order Release					46				

Table 2.11

Item	Lot Sizing	Lead time	Safety Stock	Allotted	Level	Period	PD	1	2	3	4	5	6	7	8
B	Lot for Lot	2	—	—	1	Gross Requirements					184	38			
						Scheduled Receipts									
						Projected on Hand	74	74	74	74	74	0			
						Net Requirements					110	38			
						Planned Order Receipt					110	38			
						Planned Order Release			110	38					

Table 2.12

Item	Lot Sizing	Lead time	Safety Stock	Allotted	Level	Period	PD	1	2	3	4	5	6	7	8
C	Lot for Lot	3	—	—	1	Gross Requirements						57			
						Scheduled Receipts									
						Projected on Hand	19	19	19	19	19	19			
						Net Requirements						38			
						Planned Order Receipt						38			
						Planned Order Release			38						

Table 2.13

Item	Lot Sizing	Lead time	Safety Stock	Allotted	Level	Period	PD	1	2	3	4	5	6	7	8
D	Lot for Lot	1	—	—	2	Gross Requirements			220	76					
						Scheduled Receipts									
						Projected on Hand	190	190	190	0					
						Net Requirements			30	76					
						Planned Order Receipt			30	76					
						Planned Order Release			30	76					

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Table 2.14

Item	Lot Sizing	Lead time	Safety Stock	Allotted	Level	Period	PD	1	2	3	4	5	6	7	8
E	Lot for Lot	1	—	—	2	Gross Requirements			330	114		76			
						Scheduled Receipts									
						Projected on Hand	160	160	160	0	0	0			
						Net Requirements			170	114		76			
						Planned Order Receipt			170	114		76			
						Planned Order Release		170	114		76				

Review Questions:

1. List input of MRP system.
2. List two MRP outputs.

2.9 MANUFACTURING RESOURCE PLANNING (MRPII)

2.9.1 Introduction

Till the early sixties, reorder point (ROP) systems was used by many manufacturing organizations. In this system the component stocks were reordered whenever stock fell to a pre-defined reorder level. Components were often ordered when not actually needed, and because of which ROP systems resulted in very high inventory levels.

In the sixties, customers became demanding, competition became tougher and the interest rates began to increase. This made organizations to realize the necessity to develop a much better response to the customer needs. At the same time the increase in interest rates made money tied up in inventory into a serious financial burden for manufacturing organizations.

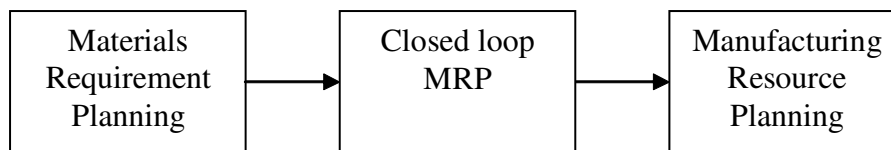
In this period, computers were brought into planning and production systems. As a result, several new manufacturing systems were developed. They were.

- Material requirements planning systems.
- Heavily reliant on computers and most frequently applied to batch or mass production. Comprising of:
 - Material requirements planning (MRP or MRP I).
 - Closed loop material requirements planning (Closed Loop MRP).
 - Manufacturing resource planning (MRP II).

- Just-in-time (JIT).
- Optimized Production Technology / Theory of Constraints (OPT/TOC)
- Project control
- Evolution of Manufacturing Resource Planning (MRP II)

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Figure 2.29- Evolution of Manufacturing Resource Planning (MRP II)



2.9.3 Closed Loop MRP System

In an open loop MRP system the plans are sent to buyers and production personnel but it is not possible to get feedback. As a result of which the adjustments could not be made to plans in order to keep schedules valid. For example, it assumed that infinite capacity was available, and that suppliers always delivered correctly and on time. And when there is a change in sales demand it will take excessive amount of re-planning.

Also, much of the demands from other sources are left out of the system and shortages become inevitable. Material requirements planning generates valid schedule that follow logically from the demand. But after planned orders are launched, some of the planning factors may begin to stray off course. Some of the examples that cause problem because of using MRP systems are shown below:

- ♦ Lead time estimates differ if: machine breaks down, deliveries are delayed, goods are damaged, power fails etc.
- ♦ If the system plans for 1000 of a component but 200 fail a quality inspection, this shows that the orders are arrived on time but there will be a shortage of material.
- ♦ The demand that drives material requirements planning consists of both forecast orders and actual customer orders. The forecasts may turn out to be wrong and customers may change their actual orders, for example, by asking for earlier or later delivery. This throws out all component orders.

In summary, 'open loop' material requirements planning could result in some or all of these problems:

- Uncontrollable costs.
- Late deliveries to customers.
- Late deliveries from suppliers.
- Unplanned overtime/offloading.

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- High work-in-progress levels.
- Mismatched inventories.
- Over- or under-utilized resources.
- Disruptions on the shop floor.
- Many full-time expeditors.
- Customer complaints.
- High 'past dues'.
- Long queues.

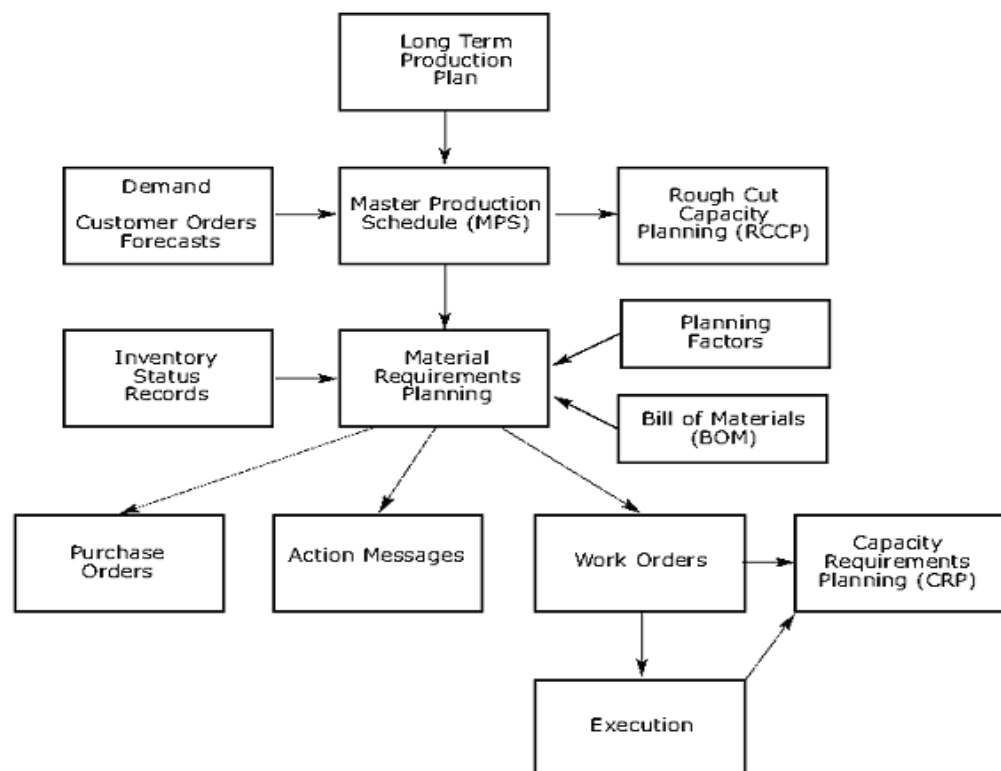
This is clearly not a list that any manufacturing organization could regard as acceptable. Something had to change, and so open loop MRP evolved into closed loop MRP.

Closed loop MRP

Material requirements planning is useful but due to the problems that are faced by the organization after implementation of MRP and lack of awareness of other related production and business functions, the organization started to shift towards closed loop MRP system. The diagram below shows the much wider data horizon that is now opened up for organizations which have started using better information technology to upgrade their MRP system.

Closed loop MRP

Figure 2.30 – Closed loop MRP



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Closed loop MRP has made feedback possible by including new functions such as file control, a master production schedule, rescheduling actions and shop floor control. It thus 'closed the loop', overcoming the fundamental weakness of 'open loop' material requirements planning.

The closed loop diagram shows several additions to the open loop diagram:

- The long-term production plan. This feeds information into the master production schedule about the organization's long-term manufacturing expectations.
- The master production schedule passes information to a separate rough cut capacity planning module, which estimates the amount of work achievable in a given time period.
- Orders generated by MRP are split into purchase orders and work orders.
- Manufacturing orders are passed to the capacity requirements planning module to see if there is sufficient labor and machine time available to carry them out in the time proposed by the master production schedule. This is a more detailed evaluation than rough cut capacity planning; it looks at individual work centers and their proposed workloads.
- The shop-floor execution phase is also shown; this is used to control the on-time completion of work orders.

2.9.4 Manufacturing Resources Planning (MRP II)

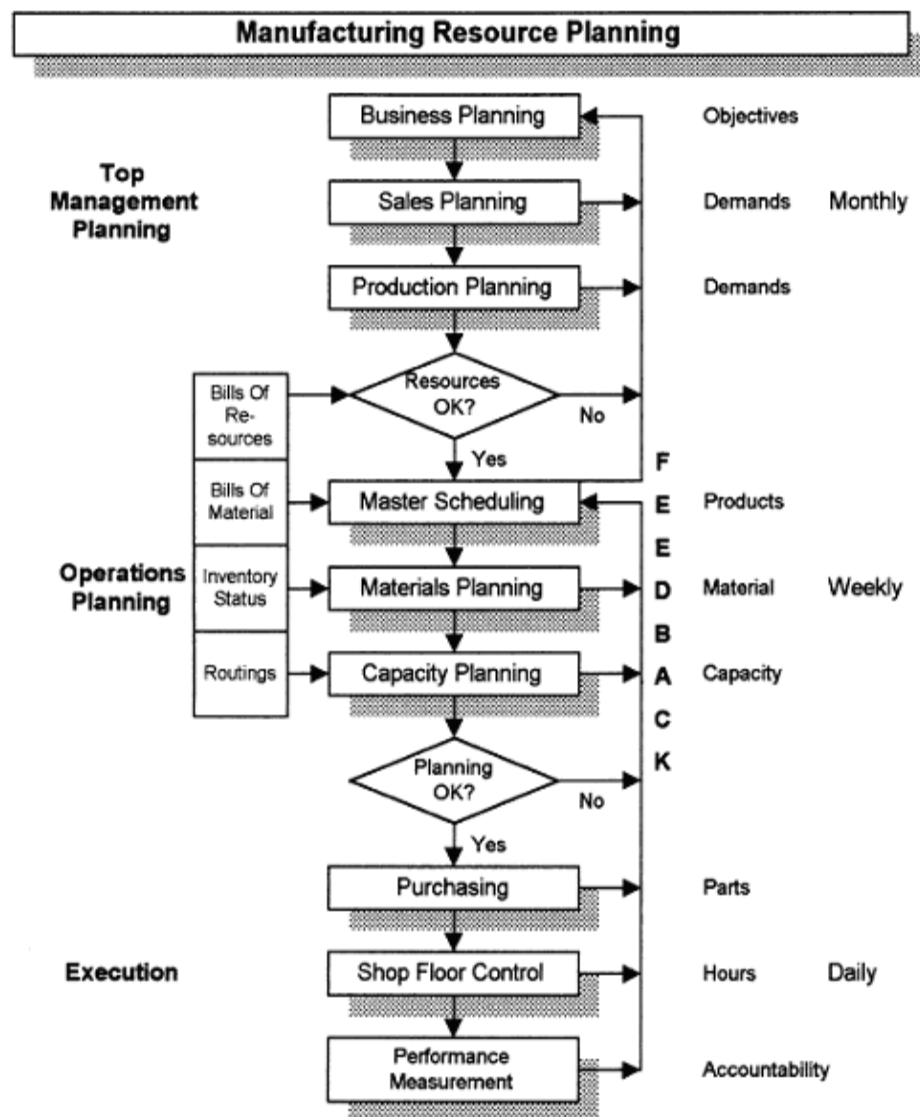
Manufacturing resources planning (MRP II) is an extended form of closed loop MRP that also incorporates strategic planning processes, business planning, and a number of other business functions such as human resources planning, profit calculation and cash flow analysis. MRP II uses the master production schedule as the basis for scheduling capacity, shipments, tool changes, some design work, and cash flow. Hence it requires several additions to the reference files. One is a bill of resources, which details key resources needed to produce one unit of product. These resources may include labour, machinery, tools, space and materials.

The MRP II system can use the bill of resources to project shortages at specific times, giving departments advance notice of required remedial action: for example, of the need to hire or train labour. MRP II can also project needs for support resources; for example, design engineering support if a customer order entails prior design work. This additional resource is added to the bill of resources. Given still more reference data, MRP II can keep track of tool wear and recommend when to replace or reshape tooling. It can also keep track of machine loads and project machine capacity shortages, which may signal a need for more machines or a subcontractor.

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For financial planning, MRP II treats cash flow almost like materials. The MPS is first exploded into component parts requirements; the system then calculates the cost and payment dates of all planned order releases, effectively creating a cash flow forecast. This includes not just payments to suppliers, but also wages, power and other consumables associated with production. Cash outflows may be projected for a year or more by expense category, work centre or department, making budgeting much simpler than it would be without an MRP II system.

Figure 2.31 - Framework of MRP II



2.9.3 Master Production Schedule

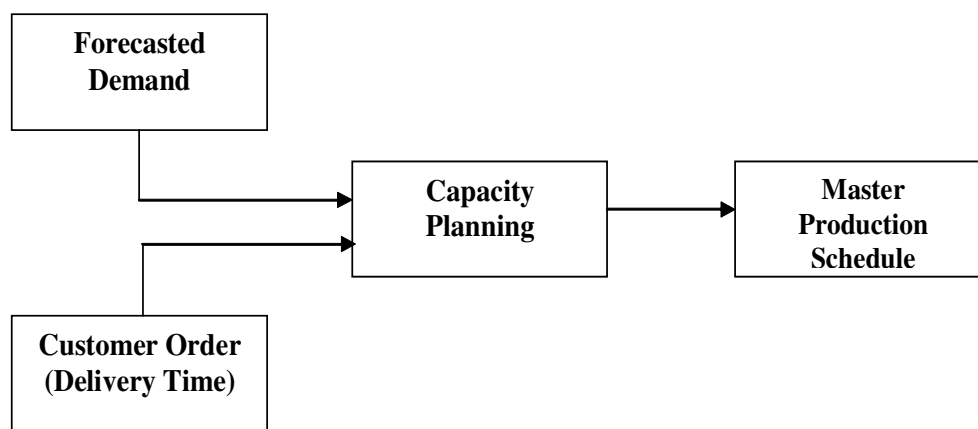
The MPS is a statement of the planned production of finished products that will meet the demand on time, within the organization's capacity. The master production

schedule expresses. What we intend to make, how much we intend to make and when we intend to make.

The demand for end items is scheduled over a number of time periods and recorded on a master production schedule (MPS). The MPS is developed from forecasts and firm customer orders for end items, safety stock requirements and internal orders. MRP takes the master schedule for end items and translates it into individual time-phased component requirements.

Overview of Master Production Schedule:

Figure 2.32 - Overview of Master Production Schedule



Capacity Planning:

Capacity planning essentially involves the following categories.

Resource Requirements Planning:

Resource requirements planning refers to the planning of the overall capacities of the firm. This planning is done to validate the aggregate production plans of the firm.

Rough Cut Capacity Planning (RCCP):

Rough cut capacity planning (RCCP) involves planning capacities at key / bottleneck work centers and broadly balancing workloads. It thus validates the MPS. Material requirements planning (MRP) uses a master production schedule (MPS) of end items to determine the quantity and timing of component part production. MRP is capacity insensitive; it implicitly assumes that sufficient capacity is available to produce components at the time they're needed.

A problem commonly encountered in operating MRP systems is the existence of an overstated MPS. An overstated master production schedule is one that orders

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more production to be released than production can complete. An overstated MPS causes raw materials and WIP inventories to increase because more materials are purchased and released to the shop than are completed and shipped. It also causes a buildup of queues on the shop floor. Since jobs have to wait to be processed, actual lead times increase, causing ship dates to be missed. As lead times increase, forecast accuracy over the lead-time gets affected because forecasts are more accurate for shorter periods than for longer ones. Thus, overstated master production schedules lead to missed due dates and other problems. Validating the MPS with respect to capacity is an extremely important step in MRP. This validation exercise has been termed **rough cut capacity planning (RCCP)**.

For example: consider the man hour requirement for three components over a three week period as follows:

Table 2.15

	Week 1	Week 2	Week 3
Component A	70	70	70
Component B	100	100	120
Component C	80	75	80

Let us now check the total man hours required to produce this master production schedule. From the above illustrated resource requirements, a rough cut analysis can be done as follows:

Table 2.16

	Week 1	Week 2	Week3
Required standard hours	250	245	270
Available standard hours	250	250	250
Negative deviation			-20
Positive deviation		+5	

RCCP DECISIONS

In this section, we discuss how to determine the amount of capacity that is available, how to compare the capacity available to the capacity required and the options that exist for adjusting the capacity available and/or the capacity required.

Determining the Capacity Available

The plastic molding department of Al's Lamps, presented in the previous section, has three plastic molding machines. Since Al's works one eight-hour shift each day and there are 21 working days in an average month, it might seem that the capacity available to the plastic molding department is 504 hours per month (3 machines times 8 hours/day/machine times 21 days/month).

However, two additional factors must be considered. First, the plastic molding machines may not be available all the time. The machines may break down, the worker may be absent, and the mold needed or the material needed may not immediately be available. Second, there must be an adjustment between the time standard average and the actual average production rate of the department. The first adjustment factor is known as utilization. Utilization is a number between 0 and 1 that is equal to 1 minus the proportion of time typically lost due to machine, worker, tool, or material unavailability. The second adjustment factor is known as efficiency. Efficiency is formally defined to be the average of standard hours of production per clock hour actually worked. If a time standard is exactly right, efficiency is 1. If the time actually required to perform the work is less than the standard, efficiency is more than 1. If the time actually required to perform the work is more than the standard, efficiency is less than 1. As mentioned previously, time standards tend to be slightly pessimistic due to continual improvement in production methods.

Capacity available is found by multiplying time available times utilization and times time efficiency:

$$\text{Capacity Available} = \text{Time Available} \times \text{Utilization} \times \text{Efficiency}$$

Assume that for the plastic molding department of Al's Lamps, utilization is 0.756 and efficiency is 1.05. The time available in a month having 168 working hours (21 eight-hour days) is 504 (3 machines times 168 hours/month/ machine). Thus,

$$\text{Capacity Available} = 504 \times 0.756 \times 1.05 = 400 \text{ hours (rounded to the nearest hour).}$$

When capacity is inadequate, four basic options are available to increase capacity: overtime, subcontracting, alternate routing, or adding personnel. If no combination of the four options can provide sufficient capacity, the MPS will have to be reduced. Options to adjust capacity required or available are discussed next.

• Increase Capacity

- Additional shifts
- Overtime
- Additional resources

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- **Reduce Load**

- Subcontract
- Reduce lot sizes if possible

- **Redistribute Load**

- Use alternate work centers or routings if possible
- Shift production to earlier periods that have additional capacity
- Temporarily use safety stocks and shift load to later period

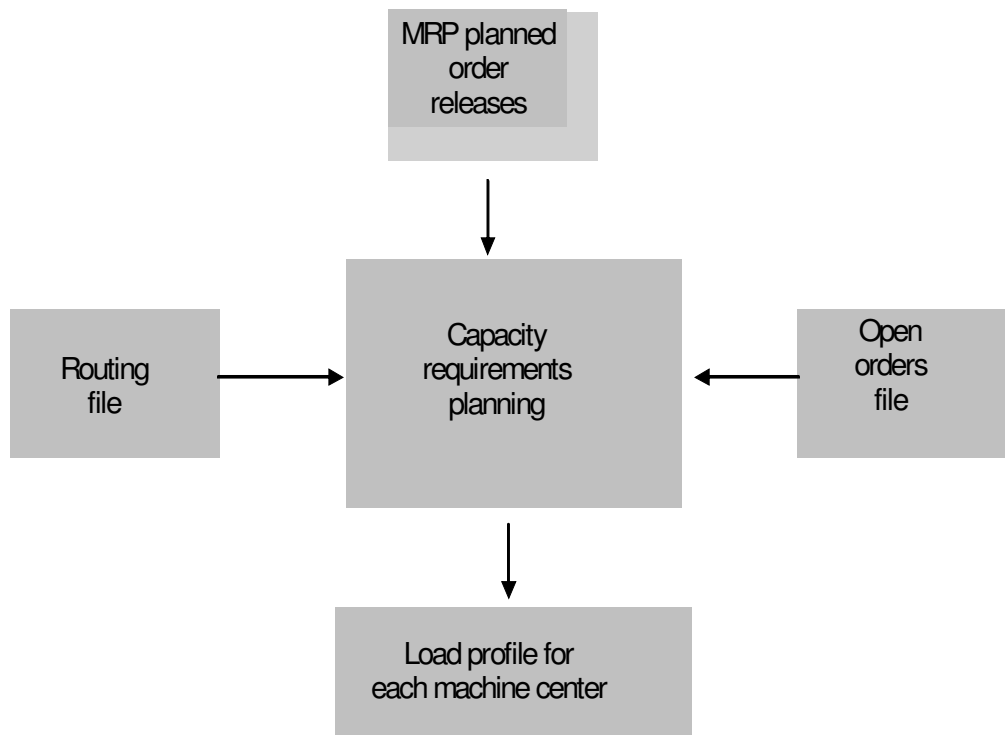
- **If all else fails, revise MPS**

2.9.4 Capacity Requirements Planning

Capacity requirements planning (CRP) is a computer-based extension of the MRP process that uses the results of MRP along with detailed production information and labor information to calculate planned workloads. It is a detailed capacity analysis that helps in validating the MRP schedule. CRP arises mainly due to batching of production work orders in the course of MRP. It is thus a computerized system that projects load from material requirements plan.

CRP Inputs & Outputs

Figure 2.33



Key Inputs

- Schedule of open orders and planned order releases (from MRP).

A typical example would be as follows:

Table 2.17

Release date	Due date	Planned orders	Number of batches of 20
week 5	week 7	40	2
week 8	week 10	80	4

- **BOM** with routing data:

A typical example would be as follows:

Table 2.18

<i>Part D routing (hours)</i>							
Operation	Work center	Run time	Setup time	Move time	Queue time	Total time	Rounded time
1	201	1.6	0.5	0.4	2.6	5.1	5.0
2	208	1.5	0.3	0.2	2.8	4.8	5.0
3	204	0.1	0.1	0.3	0.6	1.1	1.0
4	209	1.2	0.8	0.3	2.3	4.6	5.0
Total lead time 16 hr (2 days)							
<i>Part E routing (hours)</i>							
Operation	Work center	Run time	Setup time	Move time	Queue time	Total time	Rounded time
1	201	1.1	0.4	0.3	1.8	3.6	4.0
2	204	0.2	0.3	0.2	0.5	1.2	1.0
3	205	1.2	0.1	0.4	1.5	3.2	3.0
Total lead time 8 hr (1 day)							

- **Work center data**

A typical example would be as follows:

Table 2.19

Work centre	201
Queue time	2.5 hours
Available capacity	440.0 hours

- **Work order status**

Key Outputs

- Work center load report.
- Possible *revised* schedule of planned order releases.

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2.9.5 Forward Scheduling And Backward Scheduling

Forward scheduling:

In forward scheduling, we identify the earliest start date for the operation in question through consideration of the planned order release date generated by MRP. We then use the lead time to calculate the completion date. If the completion time is prior to the due date then we have slack time available. If completion date is after due date, we have a delay.

Backward scheduling:

In backward scheduling, we identify the due date for the operation in question and use the operation lead time to calculate the latest operation start date. If the latest start time is after the earliest start date then we have slack time available. If the operations start time is prior to the earliest start date then we have negative slack.

An Illustration of Capacity Requirements Planning:

Consider a component-A which has a planned order as follows:

Table 2.20

Release date	Due date	Planned orders	Number of batches of 20
week 5	week 7	60	3

This component has to undergo three process namely assembly, painting and inspection. the data for these work centers is as follows:

Table 2.21

Work center	Assembly
Queue time	10.0 hours
Available capacity	60.0 hours
Set up time	0.40 hours
Processing time	0.30 hours
Transport time	1.30 hours

Table 2.22

Work center	Painting
Queue time	18.0 hours
Available capacity	60.0 hours
Set up time	0.60 hours
Processing time	0.45 hours
Transport time	1.30 hours

Table 2.23

Work center	Inspection
Queue time	42.0 hours
Available capacity	60.0 hours
Set up time	0.04 hours
Processing time	0.30 hours
Transport time	1.30 hours

NOTES**Calculation of department loads:***Assembly department:*

Load from component-A

(Batch size X processing time) + Set-up

$$60 \times 0.30 + 0.4 = 18.4 \text{ Hours}$$

Painting department:

Load from component-A

(Batch size X processing time) + Set-up

$$60 \times 0.45 + 0.6 = 27.6 \text{ Hours}$$

Inspection department:

Load from component-A

(Batch size X processing time) + Set-up

$$60 \times 0.30 + 0.04 = 18.04 \text{ Hours}$$

Calculations of operation lead time:

Operation lead time is calculated as

Operation lead time = Load from component + Queue time + Transport time

For assembly,

$$\text{Operation lead time} = 18.4 + 10 + 1.3 = 29.7$$

For Painting,

$$\text{Operation lead time} = 27.6 + 18 + 1.3 = 46.9$$

For Inspection,

$$\text{Operation lead time} = 18.04 + 42 + 1.3 = 61.34$$

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Now we use backward scheduling .The inspection has a lead time of 61.34 hours and hence is loaded for the due date, which is week 7. Therefore the previous operation (painting) is scheduled for the previous week (week 6).Painting only has a lead time of 46.9 hours, which means the assembly operation can be scheduled for completion in week 6.

These load projections can be represented as follows:

Figure 2.34

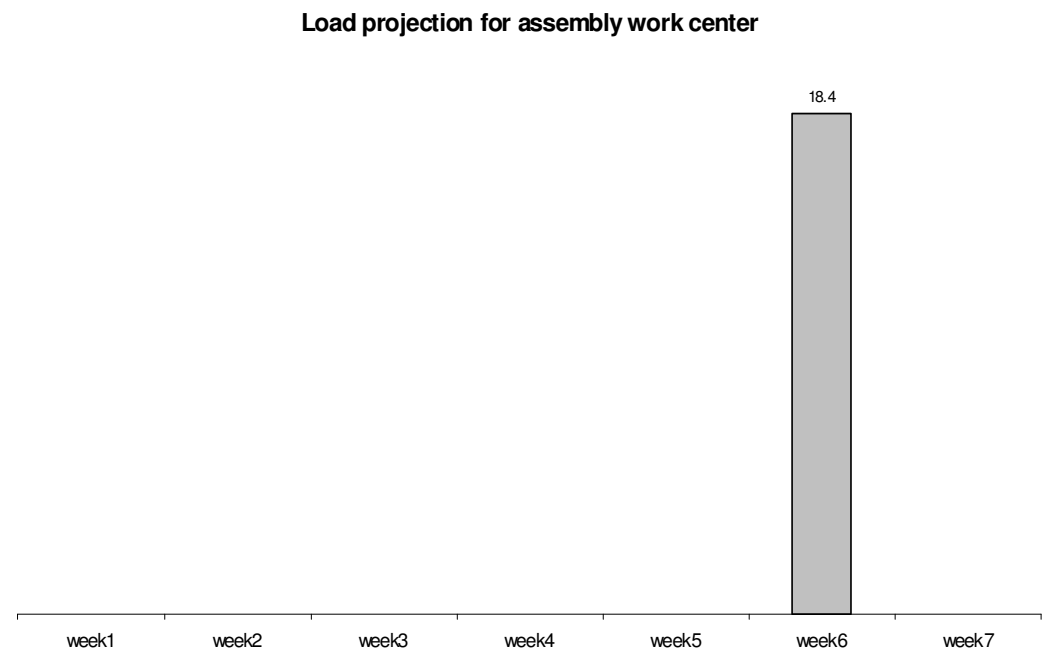


Figure 2.35 -

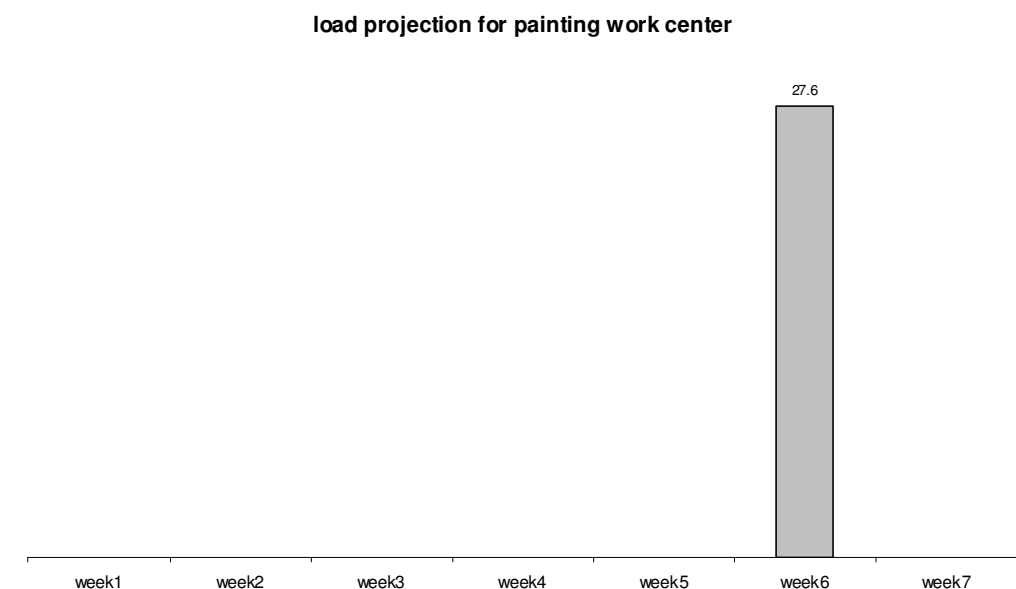
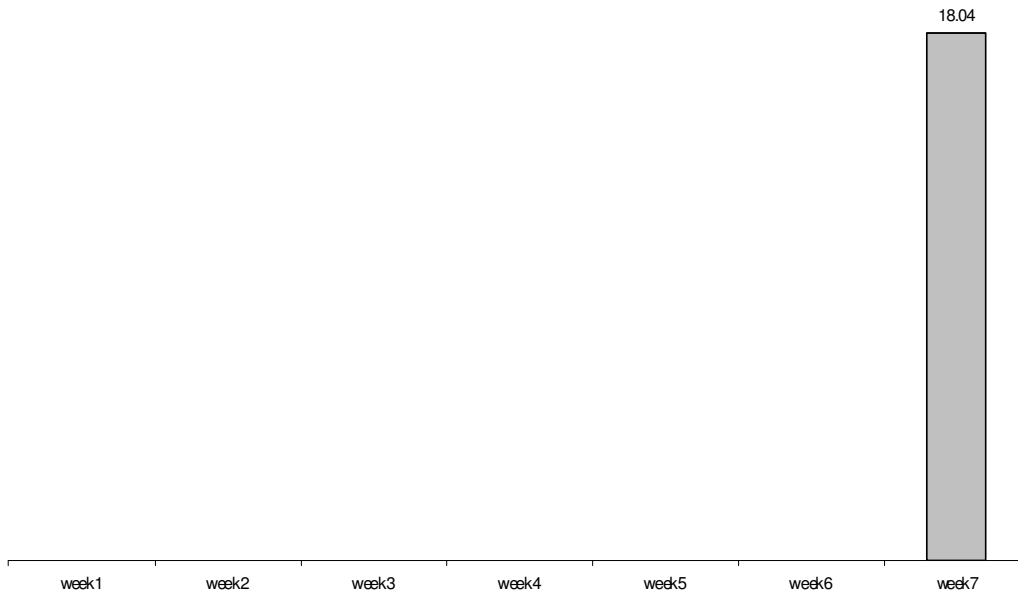


Figure2.36**Load projection for inspection work center****Shop floor control**

The system is provided with information on how many units were sent onwards and the date as each work centre completes a job. This information enables the MRP system to provide each work centre with daily notices of priority changes. After rescheduling, new due dates and quantities go out to the factory and supplier companies, who must act on them so that the previous schedule, with the jobs in progress, is updated. The shop floor control thus provides information on the reschedules with the help of which the existing schedules can be updated.

Production Activity Control (PAC)

PAC, Production Activity Control, is concerned with converting plans into action, reporting the results achieved and revising plans and actions as required achieving desired results. Thus, PAC converts plans into action by providing the required direction. This requires the appropriate prior master planning of orders, work force personnel, materials, and capacity requirements. They are useful in the management of lead-time, queue length, work center idle time, and scheduled order completion. The three primary functions of PAC

- Order release
- Dispatching
- Progress reporting

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Order Release

Order release initiates the execution phase of production; it authorizes production and/or purchasing. The planned order becomes a released (open) order. Placement of a purchase order or the initiation of manufacturing follows shortly. Order release planning may take place until the moment of order release.

Authorization of order release is based on the planned orders in the MRP output, the current priority, the availability of materials and tooling, and the loads specified by I/O planning. Release of an order triggers the release of the following:

1. Requisitions for material and components required by the order. If some of these items are not required immediately and have not been allocated previously, they are allocated now.
2. Production order documentation to the plant. This documentation may include a set of both engineering drawings and manufacturing specifications and a manufacturing routing sheet.
3. Requisitions for tools required in the first week or so of production. Tooling, including tapes for numerically controlled machines, required in later operations is reserved for the appropriate period. Tooling can be included in the master production schedule and the bill of material. Its availability is thus coordinated with material and equipment availability.

The time required to deliver production order documentation, tooling and materials to the first operation is included in the normal planned lead time for the order. An order is released by adding it to the dispatch list.

Dispatching

Dispatching informs first-line supervision of the released orders and their priority, that is, the sequence in which orders should be run. This information can be transmitted via a hard copy (handwritten, typed, or computer printout) or via video output on a cathode ray tube (CRT). In a job shop a dispatch list should be prepared for each work center with the frequency of updating depending on the typical order-processing time. If orders take a day or less to process, dispatch lists usually are prepared daily. If orders take a few days, lists may be prepared weekly with midweek revisions handled on an exception basis with on-line processing.

In a flow line process environment, a single list indicating the rate of flow (or in a batch flow line, the sequence in which orders are to be started) will control work on the entire line, which may be viewed as a single work center. An example of simple dispatch list information identifies the date, the plant, and the work center; it includes the work center capacity; and it lists the orders, their quantity, their capacity requirements, and their priority. Orders usually are listed in descending priority for a specified period.

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The list also may include jobs at upstream work centers to provide the supervisor with information concerning orders that will arrive shortly and an indication of their priority upon arrival. A computerized system may produce relative rankings on the basis of criteria such as critical ratio and earliest due date, as described earlier, but review by a planner is required to determine if other considerations are overriding.

The planner determines the final dispatch list ranking of orders on the basis of the multiple criteria including a formal priority index such as, the critical ratio or the due date, input control at downstream work centers, the availability of tooling, the status of other parts required in the same assembly, energy consumption patterns, and sequencing and assignment criteria.

Production Reporting

Reports describing the actual production status are necessary for control. Dynamic response to the changing conditions is possible only if timely, accurate, and adequate information is available. The information must enable management to take meaningful corrective action concerning production schedules.

The production environment influences the design of the production reporting system. Reporting in a line flow environment with long production runs, may take place on an exception basis with feedback occurring only when the output rate falls below an acceptable level. All reporting systems should have an exception reporting capability to inform management whenever machine failure, material shortages, or similar events threaten planned output.

2.9.6 Benefits of MRP II

In the narrow sense, the main benefit of MRP II is its ability to generate valid schedules and keep them valid. But valid schedules have broader benefits for the whole organization. These include, more or less in order of importance:

1. Improved on-time completion

A typical manufacturing organization using MRP II should be able to achieve on-time completion rates of 95 per cent or more, because completion of a parent item is less likely to be delayed for lack of a component. On-time completion helps improve customer service.

2. Reduced inventories

Inventory falls - typically by 20-35 per cent - because parts are not ordered until needed.

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3. Capacity requirements planning data

Work centre capacity requirements can be planned for many periods into the future.

4. Improved direct labour productivity

Fewer shortages mean significantly less lost time and overtime, and less disruption to accommodate shortage-list jobs.

5. Improved productivity of support staff

MRP II cuts expediting (or 'firefighting') and allows more time for planning. For example, purchasing can start looking for alternative or better suppliers; materials management can plan inventory needs better.

6. Total business planning

The ability to use one common set of data to help plan and control the whole business.

2.9.7 Drawbacks of MRPII

Though Manufacturing Resource Planning has a number of benefits, it has a few limitations too. They are:-

- MRP II system is complex.
- MRPII implementation programmer, takes a lot of time, effort and commitment at all levels of the organization to set up a successful MRP II system.

The benefits, however, should very quickly make the exertion worthwhile.

Review Questions:

1. MRPII stand for?
2. List the various phases of evaluation of MRPII
3. Discuss the input requirement of the capacity requirement planning.
4. What is dispatching?
5. List any two benefits of MRP

2.10 ENTERPRISES RESOURCE PLANNING

It is a system which integrates all the processes and data of an organization. It uses the hardware and software to integrate the activities of manufacturing, supply chain, Financials, Customer Relationship Management (CRM), Human Resources and Warehouse Management.

2.10.1 Need for ERP

In the past, then available software applications that don't talk to each other and do not effectively interfaces, so the organizations were in the pursuit of identifying a new software to eliminate the above limitation that result in the invention of ERP system.

ERP acts as a single database that includes all data for the software modules, which would include manufacturing, supply chain management, finance, projects, customer relationship management, data warehouse. This is shown in figure 2.36.

Manufacturing:

Engineering, Bills of Material, Scheduling, Capacity, Workflow Management, Quality Control, Cost Management, Manufacturing Process, Manufacturing Projects, Manufacturing Flow.

Supply Chain Management:

Inventory, Order Entry, Purchasing, Product Configurator, Supply Chain Planning, Supplier Scheduling, Inspection of goods, Claim Processing, Commission Calculation etc.

Finance:

General Ledger, Cash Management, Accounts Payable, Accounts Receivable, Fixed Assets.

Projects:

Costing, Billing, Time and Expense, Activity Management

Human Resources:

Human Resources, Payroll, Training, Time & Attendance, Benefits

Customer Relationship Management:

Sales and Marketing, Commissions, Service, Customer Contact and Call Center Support etc.

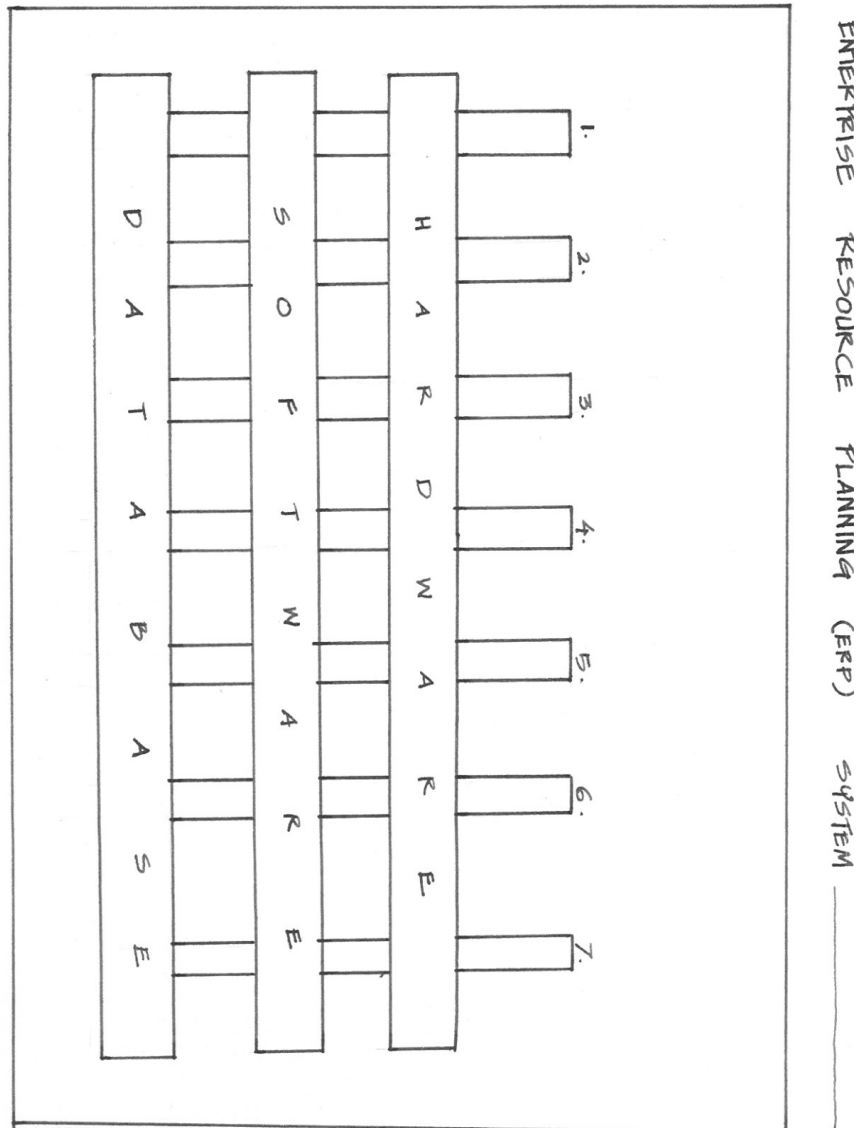
Data Warehouse:

Various Self-Service interfaces for Customers, Suppliers, and Employees.
The framework of ERP is shown in the figure 2.36

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Figure 2.36 - ERP System



1. MANUFACTURING
2. SUPPLY CHAIN MANAGEMENT
3. FINANCIALS
4. PROJECTS
5. HUMAN RESOURCES
6. CUSTOMER RELATIONSHIP MANAGEMENT
7. DATA WAREHOUSE

2.10.2 Evolution of ERP:

MRP – Material Requirement planning focused mostly in the plant production level, started, emphasizing the controlling of inventory for the dependent items. It acts as a production scheduling system also. Because of change in business scenario like more competition, more Global suppliers, warehousing, Global product demand, at different count, changing environment business currency complexities etc. Focus has been shifted from beyond the production level, to include all the activities that results in the development of manufacturing resource planning, MRP II includes the sub modules manufacturing, logistics, distribution, inventory, shipping, involving and accounting for a company. Then further, improvement in the MRP II leads to the birth of ERP.

2.10.3 Advantages of ERP system

1. ERP effectively interfaces all the activities of the organization.
2. Computer security is included within an ERP to protect against both outsider crime, such as industrial espionage and insider crime, such as embezzlement.

2.10.4 Disadvantages of ERP system

1. High investment required in buying and implementing the ERP system.
2. Problem due to a lack of corporate policy protecting the integrity of the data in the ERP system and how it is used.

2.10.5 Limitations of ERP include

1. There are compatibility problem with the various legacy system of the implementing organizations.
2. Hesitance in sharing sensitive internal information between departments can reduce the effectiveness of the software.
3. The blurring of company boundaries can cause problems in accountability, lines of responsibility, and employee morale.
4. ERP system can be difficult to use
5. ERP system is considered to be too rigid and too difficult to adapt to the specific work flow and business process of some companies.
6. Annual license renewal change is constant irrespective of the size of the company using the ERP.
7. Re-engineering of business processes to fit the “Industry Standard” prescribed by the ERP system may lead to lots of competitive advantages.
8. Customization of ERP software is limited.
9. The success of an ERP system depends on the skill and experience of the workforce.
10. Lack of training to the workforce result in failure of the ERP system.

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Review Questions:

1. What does ERP stands for?
2. List the Major phases in evaluation of ERP.

2.11 E-BUSINESS AND E-COMMERCE

Like any emerging field, e-business is changing fast and so is the thinking behind it. A firm's e-commerce strategy should aim to help organizations establish stronger ties with customers and business partners. These strategies should also focus on helping organizations acquire and retain customers efficiently. An electronic market not only offers a cheaper, more cost effective way to transact business but also brings about a more efficient market clearing mechanism, because it is not constrained by geographical distance or time.

The beginning of the second millennium will almost certainly be remembered as a time of unprecedented change in the business world. In the space of a few years entire industries have been radically transformed. New technologies such as Internet, digital televisions, intelligent home appliances have all reached critical mass at the same time and are poised to revolutionize business. To begin it's useful to describe what is meant by electronic business and electronic commerce. It is defined as 'the conduct of business on the Internet, not only buying and selling but also servicing customers and making strategic alliances with business partners.'

At this stage of development of e-commerce, everything that constitute a market products, industrial structure, trade is in the process of being redefined. This raises the issues of developing new strategies to answer questions like, how will the new networks affect industries and the economy at large, how should firms compete in the new market places that are developing, how can firm integrate the network into existing business operations and how they should manage the new organizations. This makes business strategy specialists to understand the networks and their business implications.

One of the advantages of using an electronic channel is the efficiency gain. E-business can generate tremendous efficiencies through reduced transaction costs, faster through out and better information to all members of the chain. Traditional strategy development process is difficult to be followed in the case of e-businesses, as it has to contend with additional issues of virtual transactions, unstable market, highly interconnected firm and high uncertainty in the markets. The most striking features of competitive strategies in e-business is that often new entrants have been able with limited resources to undermine existing competitions in the industry through the use of new business models. Strategy is driven by what is valued by the customer without being constrained by existing industry rules. E-business strategy makers build on the powerful commonalities in the features that customers value. This ensures these companies to capture the core of the market, even if it means that they lose some of the customers.

Apart from the instability of the market, one of the greatest challenges for e-business strategies is the sheer speed of change. Two processes are critical in time pacing. The first one is managing transitions or the shifts from one activity to the next. The second is managing rhythm, or the pace at which organizations change. Another

area where e-strategists should concentrate is the ability to connect individuals, groups and organizations worldwide. Complementary product providers and allies play a significant role in determining success in the industry.

Uncertainty is another characteristic which the e-business strategies maker has to cop up with. A firm's posture in state of uncertainty defines the intent of a strategy relative to the current and future state of an industry. Strategies are aimed at creating new opportunities in a market, either by shaking up relatively stable industries or by trying to control the direction of the market in industries with higher level of uncertainty. Many e-commerce firms adopt the strategic posture of reserving the right to play, which involves making incremental investments now that will put a company in a position of advantage in the future. This allows the company to wait until the environment becomes less uncertain before formulating a strategy.

As e-business technologies, coupled with continued advances in voice recognition and artificial intelligence, become more commonplace, even more radical changes in the use of information are expected. Just as there has been a paradigm shift in e-business strategy, this requires a shift from information management to knowledge management. This will require systems that move beyond simply capturing past experiences to using that information creatively. Another strategy that can be adopted to cop with the speed of change and uncertainty of e-business is to establish a separate e-business unit. Speed and flexibility are required to compete successfully in e-business, something that is difficult to achieve in large organizations. The strategies of dot.com business are best seen as a tradeoff between operational decisions and financial decisions.

We are on the verge of a revolution that is just as profound as the change in the economy that came with the industrial revolution named 'E-revolution'. So the e-strategies should be formulated such that it allows people to rise above the barriers of time and distance and take advantage of global markets and business opportunities.

SUMMARY

- This unit helped the reader to know the importance of one of the inputs of production system, namely, the material resource.
- The functions of materials management is dealt.
- Types of computer controlled material handling devices and their applications are discussed.
- The operation of Just in Time (JIT) system and the prerequisites to implement JIT in an organization are discussed.
- The deterministic inventory models and probabilistic inventory model and when do you adopt which model is elaborated.
- The working of MRP – I and MRP – II is illustrated with examples.
- Introduction of ERP, e-business and e-operation strategies are outlined.

Review Question:

What is e-business and e-commerce?

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NOTES**UNIT III
PLANNING AND FORECASTING****3.1 Introduction**

3.1.1 Learning Objectives

3.2 Forecasting

3.2.1 Importance of forecasting

3.2.2 Forecasting model:

3.2.3 Forecasting methods:

3.2.3.1 Quantitative methods:

3.2.3.1.1 Time Series Analysis

3.2.3.1.2 Econometric models

3.2.3.1.3 Economic Indicators

3.2.3.2 Qualitative Methods

3.2.3.2.1 Market Survey

3.2.3.2.2 Expert Opinion

3.2.3.2.3 Delphi Technique

3.2.4 Forecasting evaluation

3.3 Capacity Planning**3.4 Aggregate Production Planning**

3.4.1 Introduction

3.4.2 Objectives of Aggregate Planning

3.4.3 Strategies to Meet Demand Fluctuations

3.4.4 Aggregate Planning Methods

3.4.4.1 Error Method

3.4.4.2 Linear programming Model

3.4.4.3 Transportation Model

3.5 Product Design and Development

3.5.1 Product life cycle

3.5.2 New Product development process

3.5.2.1 Concept Generation

3.5.2.2 Concept testing

3.5.2.3 Technical Development

3.5.2.4 Standardization and Inter-changeability

3.5.2.5 Commercialization

3.6 Expert System in Product Development

3.6.1 Expert System Development

3.6.2 Putting System Together

3.7 Computer Aided Design and Drawing

3.7.1 Introduction

3.7.2 What to Expect from CADD?

3.7.3 A Look at the CADD Industry

UNIT - 3

NOTES

PLANNING AND FORECASTING

3.1 INTRODUCTION

In this unit the three levels of management are discussed. Product design and development activities are also discussed. The enablers of product design and development namely Expert system, Computer Aided Design (CAD) are also elaborated. Forecasting activity is dealt to provide the input for the capacity planning and aggregate planning activities. Capacity planning overview is done with the explanations of aggregate planning.

3.1.1 Learning Objectives

1. You should understand the three levels of the management and their characteristics.
2. Different forecasting methods and forecasting evaluation tools are to be understood.
3. To understand the capacity planning and the strategies for aggregate planning and then different methods of aggregate planning.
4. To comprehend the new product development process and the utility of computer aided design and the expert system in the new product development process.

3.1.2 Levels of Management

Generally, business activities can be classified into strategic, tactical and operational level activities. All the three levels are involved in all the subsystems, namely, production, finance, personnel and marketing. The characteristics of the decisions to be taken in all the three levels are shown in the table 3.1.2

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Table 3.1.2 - Characteristics of decision making at Strategic, Tactical and Operational Levels of Management

Characteristics	Level of Management		
	Strategic	Tactical	Operational
Time frame to which decisions apply	“future” – Extremely long time	“Current” – Year, quarter, or month	“Instant” – day to day, or real-time
Persons primarily involved	Executive management and staff	Middle management	First line management
Focus of decision	On one aspect of the organization/environment relationship at a time	On organization only, either in its entirety or a major portion of it	On small part of the organization
Complexity of decisions	Numerous variables, most of which cannot be quantified	Moderate number of variables; most of which can be quantified	Small number of variables, all of which can be quantified
Degree of structure in decision-making process	Occurs at irregular intervals, based almost exclusively on judgment; each problem differs.	Rhythmic; specifically prescribed procedures; repetitive problems	Rhythmic; specifically prescribed procedures; repetitive problems
Nature of information	External; predictive; qualitative; not particularly accurate precise	Internal; Historical or real-time; often non-financial; precise	Internal; historical or real-time; often non-financial;
Use of information	Prediction	Action	Action

You can see how the type of activities to be carried out in the strategic, tactical and operational levels of production system is shown below for your clarity.

Strategic level decisions in the production system are :

- Plant location decision
- New product introduction
- Technology Selection
- Supply chain network strategy

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Tactical level decisions in the production system are :

- Markets to be supplied
- Aggregate planning
 - overtime estimation
 - inventory decision
 - subcontracting decision
 - hiring and firing decision

Operational level decisions in the production system are :

- deciding about the individual customer order
- allocation of inventory or production to individuals order
- deciding a date that an order is to be filled
- allocated can order to a particular shipping mode
- set delivery schedule of trucks

Review Questions :

1. What are the three levels of management?
Give an example in each level of the management

3.2 FORECASTING

Forecasting activity is an important activity in the business. This is considered to be an important input for many activities in the organization. Forecasting is of two types, namely, long ranges forecasting and short range. The Long range forecast goes as input for long range decision making like technology selection, capacity planning. From the long range forecasts, the medium term forecasts are derived and used as input for the activity like aggregate planning. From the medium term forecasts the short range forecasts are outlined and go as input for activity like scheduling. Selection and usage of forecasting method differs according to whether the company needs forecast to the existing product or for a new product. When you forecast for the existing product, the past demand data is taken into consideration, the pattern for the demand is analyzed, then appropriate forecasting technique is chosen to predict the future. From the predicted demand the manager adds his own intuitions and experience based on the situation to change the estimated demand to suit the real life situation.

In the case of new product, since there is no past data available, the organization depends upon the qualitative methods of forecasting. Experts, customers, sales persons opinions are solicited.

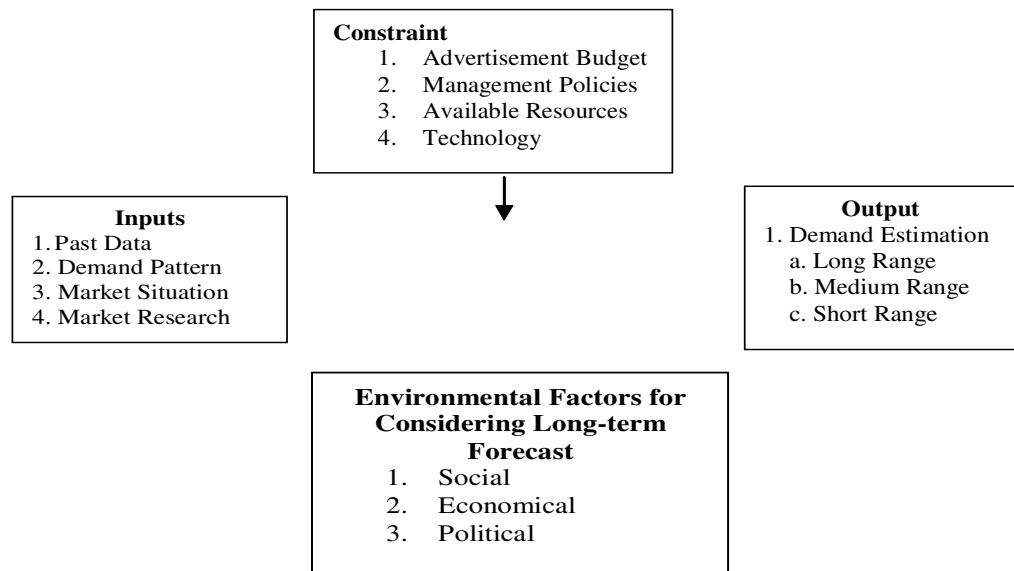
3.2.1 Importance of forecasting

Forecasting activity plays major role in activities like budget preparation, cash flow preparation, balance sheet and income statement. In marketing it does play a role in product life, pricing and promotional decisions. In production it provides information in capacity planning, aggregate planning and scheduling activities.

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3.2.2 Forecasting model

Figure 3.1 - Forecasting model



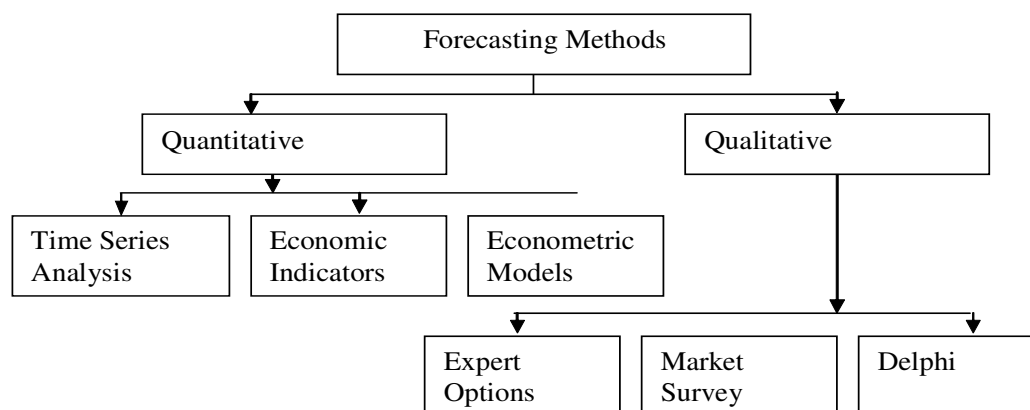
Before selecting any forecasting methods, you should see that whether you require forecasting for long range; then whole frame work given in the model is useful that is in addition to market and internal analysis you need to consider the environmental factors like social, economic and political factors for the long term forecasting.

3.2.3 Forecasting methods

In this material the forecasting methods are classified into quantitative and qualitative type. The past data and demand pattern play key role in selecting the best quantitative method and providing good forecasting results. Quantitative methods are very much used for forecasting the existing products. Qualitative method used for the new product forecast.

The classification of different methods is shown below figure 3.1

Figure 3.2 - Classification of forecasting method

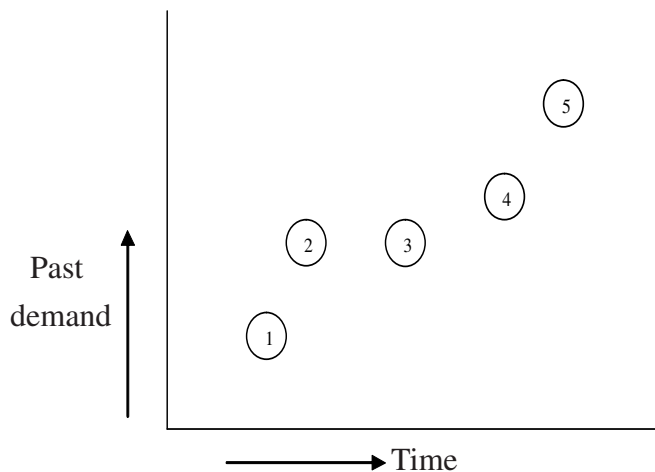


3.2.3.1 Quantitative methods:

The method is called quantitative methods because forecasting is done based on the data.

Time series analysis:

In this method, the past data is analyzed against time scale.

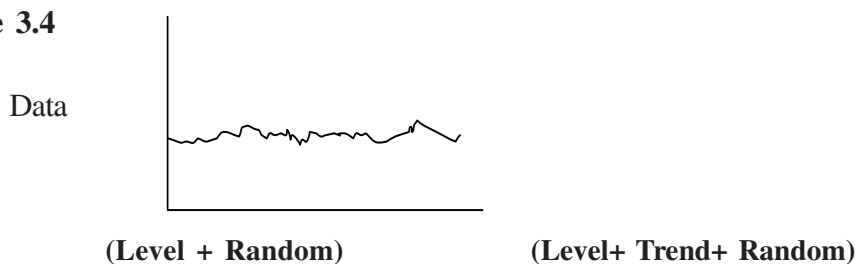
Figure 3.3 - Time series analysis

If you analyze the demand pattern against a time scale, usually it consists of the following components.

1. Level
2. Trend
3. Seasonal
4. Cyclic
5. Random

Before selecting a particular forecasting, the past data is plotted against their respective year or month or week the pattern analyzed in terms of what component the pattern possesses, then the appropriate forecasting technique is chosen.

The combination of components is shown in figure 3.4.

Figure 3.4**NOTES**

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(Level+Seasonal+Random)

(Level+Trend+Seasonal+Random)

Cycle component usually considered for the long term forecasting. The cycle means business cycle or economy cycle. The different phases of this cycle are growth, maturity and depression. Usually each phase may prevail for at least more than three years.

3.2.3.1.1 Time Series Analysis

For after analyzing the pattern of data, you can choose relevant method for forecasting. In this material important and complicated time series analysis methods are discussed.

Moving Average

The moving average technique generates the next period's forecast by averaging the actual demand for the last 'n' time periods.

$$\hat{Y}_t = \frac{Y_{t-1} + Y_{t-2} + \dots + Y_{t-n}}{n} = \frac{\sum_{i=1}^n Y_{t-i}}{n}$$

Where \hat{Y}_t = forecast for period 't'

Y_{t-i} = actual demand in period 't'

n = Number of periods included in each average

Moving average problem – 1

From the data below, determine the forecast for period 7 using two month moving average technique.

Table 3.2

Month	1	2	3	4	5	6
Demand	20	30	40	30	50	58

Solution:

Moving average period (n) = 2

Forecast for period 7 would be $= \frac{50 + 58}{2} = 54$

Moving Average – Problem 2

From the data below, determine MAD for the following forecasting techniques: (a) last period demand, (b) arithmetic average, and (c) three month moving average. What is the forecast for period 13?

Table 3.3

Period	Demand	Period	Demand
1.	93	7.	100
2.	105	8.	101
3.	114	9.	81
4.	111	10.	118
5.	106	11.	103
6.	116	12.	114

Month	Demand demand	Last Period Demand		Arithmetic Average		Three Month Moving Average	
		Forecast deviation	Absolute demand	Forecast deviation	Absolute demand	Forecast deviation	Absolute
1	93	-	-	105.16	12.16	-	-
2	105	93	12	105.16	0.16	-	-
3	114	105	9	105.16	8.84	-	-
4	111	114	3	105.16	5.84	104.00	7.00
5	106	111	5	105.16	0.84	110.00	4.00
6	116	106	10	105.16	10.84	110.33	5.67
7	100	116	16	105.16	5.16	111.00	11.00
8	101	100	1	105.16	4.16	107.33	6.33
9	81	101	20	105.16	24.16	105.67	24.67
10	118	81	37	105.16	12.84	94.00	24.00
11	103	118	15	105.16	2.16	100.00	3.00
12	114	103	11	105.16	8.84	111.67	13.30
13	114	Total 139	105.16	Total 96.00	111.67		Total 98.97

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$$= \frac{139}{11} = 12.63$$

$$MAD = \sum_{i=1}^n \frac{|Y_i - \hat{Y}_i|}{n} = \frac{96}{12} = 8$$

$$MAD = \sum_{i=1}^n \frac{|Y_i - \hat{Y}|}{n} = \frac{98.97}{9} = 10.99$$

Forecast for period 13 using last period demand = 114

Forecast for period 13 using arithmetic average = 105.16

Forecast for period 13 using three month moving average = 111.67

Exponentially weighted moving average

In the simple moving average technique, recent 'n' data have to be taken while calculating the forecast. 'n' represents, 'n' month moving average', exponentially weighted moving average gives more weightage to the recent data and less weightage to the old data moreover if you apply this technique to forecast the future, there is no need to store recent 'n' data as you did in the moving average method. Because all the data will be in one single value that is the previous forecast value.

Simple exponentially moving weightage average model

Forecast for period t = α (Actual demand of period t-1) + (1- α) (forecasted value of t-1)

This model is applicable only when the past data follows a horizontal pattern with error component.

Figure 3.5 - Simple exponentially moving weightage average model

Sales

Time \longrightarrow

Where ' α ' is the exponential smoothening constant, α varies between 0 to 1. let us analyze why this method is called exponential weighted moving average.

NOTES

Forecast for period t

$$= (\text{actual demand for period } t-1) + (1 - \alpha) (\text{forecasted value for } t-1)$$

\hat{X}_t = forecast for the level component for period t

$$\begin{aligned}\hat{X}_t &= Y_{t-1}\alpha + (1 - \alpha) [Y_{t-2}\alpha + (1 - \alpha) \hat{X}_{t-2}] \\ &= \alpha Y_{t-1} + \alpha (1 - \alpha) Y_{t-2} + (1 - \alpha)^2 \hat{X}_{t-2} \\ &= \alpha Y_{t-1} + \alpha (1 - \alpha) Y_{t-2} + (1 - \alpha)^2 [Y_{t-3}\alpha + (1 - \alpha) \hat{X}_{t-3}]\end{aligned}$$

From the above expressions, you can easily understand that the past data gets less weightage than the recent data as follows:

DATA	WEIGHTAGE	FOR $\alpha = 0.4$
Y_{t-1}	α	0.4
Y_{t-2}	$\alpha (1 - \alpha)$	0.24
Y_{t-3}	$\alpha (1 - \alpha)^2$	0.144

If you plot the weightage against the time data, it follows exponential pattern, so the method is called as exponentially weighted moving average.

Exponentially weighted moving average with trend correction (Level + Trend)

When you analyze the past data and if you have a feeling that the past data contains both the level(X) and trend component (T), then the model is used for adjusting trend and level component is

$$= \alpha Y_{t-1} + (1 - \alpha) (\hat{X}_{t-1} + T_{t-1})$$

$$T_t = \beta (\hat{X}_{t-1} - \hat{X}_{t-2}) + (1 - \beta) T_{t-1}$$

T_t = Trend adjustment for period 't'.

β is a smoothing constant for trend. This varies between 0 and 1.

Now the forecast for period t

$$+ T_t$$

If you want to forecast for 'n' period from the period 't' where in the forecast value available are \hat{X}_t and T_t , then the formula to be used

$$\hat{Y}_{t+n} = \hat{X}_t + (n + 1) T_t$$

Exponentially weighted moving average Problem - 3

Using exponential smoothing and the data in the previous problem, forecast monthly demand if $\alpha = 0.2$ and $\beta = 0.4$. Assume that the actual demand in the first

NOTES

month is the same as the forecasted demand and the initial level and the initial trend for month 1 both are 10. From these results forecast the demand for period 8.

Table 3.5

Month	Y_t Demand	Forecast Level	Tt Trend	Forecast
1	20	10	10	20
2	30	20	10	30
3	40	30	10	40
4	30	40	10	50
5	50	46	8.4	54.4
6	58	53.52	8.048	61.568
7	54	60.85	7.752	68.602
8		65.68	6.583	72.263

$$\alpha = 0.2, \quad \beta = 0.4$$

Table 3.6

Month	Y_t Demand	Forecast	Tt Trend Level	\hat{Y}_t Forecast
1	20	10	10	20
2	30			
3	40			
4	30			
5	50			
6	58			
7	54			
8				

$$\hat{X}_t = \alpha Y_{t-1} + (1 - \alpha) (\quad_{-1} + T_{t-1})$$

$$Tt = \beta (\quad - \hat{X}_{t-1}) + (1 - \beta) T_{t-1}$$

T_t = Trend adjustment for period 't'.

$$= \hat{X}_t + T_t$$

Forecast demand level for the 2nd month is obtained in the following manner

$$\hat{X}_2 = 0.2 * (20) + 0.8 * (10 + 10)$$

$$= 4 + 16$$

$$= 20$$

NOTES

Trend for the 2nd month is obtained in the following manner:

$$\begin{aligned}T_2 &= 0.4 * (20 - 10) + 0.6 * (10) \\&= 4 + 6 \\&= 10\end{aligned}$$

Forecast for month 2 is

$$\begin{aligned}Y_2 &= \hat{X}_2 + T_2 \\&= 20 + 10 \\&= 30\end{aligned}$$

Forecast demand level for the 3rd month is obtained in the following manner:

$$\begin{aligned}\hat{X}_3 &= 0.2 * (30) + 0.8 * (20 + 10) \\&= 6 + 24 \\&= 30\end{aligned}$$

Trend for the 3rd month is obtained in the following manner:

$$\begin{aligned}T_3 &= 0.4 * (30 - 20) + 0.6 * (10) \\&= 4 + 6 \\&= 10\end{aligned}$$

Forecast for month 3 is

$$\begin{aligned}\hat{Y}_3 &= \hat{X}_3 + T_3 \\&= 30 + 10 \\&= 40\end{aligned}$$

Forecast demand level for the 4th month is obtained in the following manner:

$$\begin{aligned}\hat{X}_4 &= 0.2 * (40) + 0.8 * (30 + 10) \\&= 8 + 32 \\&= 40\end{aligned}$$

Trend for the 4th month is obtained in the following manner:

$$\begin{aligned}T_4 &= 0.4 * (40 - 30) + 0.6 * (10) \\&= 4 + 6 \\&= 10\end{aligned}$$

Forecast for month 4 is

$$\begin{aligned}\hat{Y}_4 &= \hat{X}_4 + T_4 \\&= 40 + 10 \\&= 50\end{aligned}$$

Forecast demand level for the 5th month is obtained in the following manner:

$$\begin{aligned}\hat{X}_5 &= 0.2 * (30) + 0.8 * (40 + 10) \\&= 6 + 40 \\&= 46\end{aligned}$$

NOTES

Trend for the 5th month is obtained in the following manner:

$$\begin{aligned}T_5 &= 0.4 * (46 - 40) + 0.6 * (10) \\&= 2.4 + 6 \\&= 8.4\end{aligned}$$

Forecast for month 5 is

$$\begin{aligned}\hat{Y}_5 &= \hat{X}_5 + T_5 \\&= 46 + 8.4 \\&= 54.4\end{aligned}$$

Forecast demand level for the 6th month is obtained in the following manner:

$$\begin{aligned}\hat{X}_6 &= 0.2 * (50) + 0.8 * (46 + 8.4) \\&= 10 + 43.52 \\&= 53.52\end{aligned}$$

Trend for the 6th month is obtained in the following manner:

$$\begin{aligned}T_6 &= 0.4 * (53.52 - 46) + 0.6 * (8.4) \\&= 3.008 + 5.04 \\&= 8.048\end{aligned}$$

Forecast for month 6 is

$$\begin{aligned}\hat{Y}_6 &= \hat{X}_6 + T_6 \\&= 53.52 + 8.048 \\&= 61.568\end{aligned}$$

Forecast demand level for the 7th month is obtained in the following manner:

$$\begin{aligned}\hat{X}_7 &= 0.2 * (58) + 0.8 * (53.52 + 8.048) \\&= 11.6 + 49.25 \\&= 60.85\end{aligned}$$

Trend for the 7th month is obtained in the following manner:

$$\begin{aligned}T_7 &= 0.4 * (60.85 - 53.52) + 0.6 * (8.048) \\&= 2.932 + 4.82 \\&= 7.752\end{aligned}$$

Forecast for month 7 is

$$\begin{aligned}\hat{Y}_7 &= \hat{X}_7 + T_7 \\&= 60.85 + 7.752 \\&= 68.602\end{aligned}$$

Forecast demand level for the 8th month is obtained in the following manner:

$$\begin{aligned}\hat{X}_8 &= 0.2 * (54) + 0.8 * (60.85 + 7.752) \\&= 10.8 + 54.88 \\&= 65.68\end{aligned}$$

NOTES

Trend for the 8th month is obtained in the following manner:

$$\begin{aligned} T_8 &= 0.4 * (65.68 - 60.85) + 0.6 * (7.752) \\ &= 1.932 + 4.651 \\ &= 6.583 \end{aligned}$$

Forecast for month 8 is

$$\begin{aligned} \hat{Y}_8 &= \hat{X}_8 + T_8 \\ &= 65.68 + 6.583 \\ &= 72.263 \end{aligned}$$

Exponentially weighted moving average with seasonal correction (Level + Seasonal)

When you analyze the past data, if you identify that the past data contains level and seasonal pattern. The seasonal pattern means that you can find the similarity in the demand pattern with respect to each period. This similarity occurs within a year.

(e.g.). Demand of Air-conditioning equipment, Heating equipment, Ice Cream, Etc...

The last year demand in the month of January may have the similarity with the demand of January of this year. If you have monthly data, then the seasonal period = 12, if you have quarterly data, then the seasonal period = 4.

When there is no trend, the model used for forecasting

$$\hat{Y}_t = \hat{X}_t I_t$$

Where

\hat{Y}_t = forecast for the period 't'

\hat{X}_t = level forecast for the period 't'

I_t = seasonal index for the period 't'

The seasonal index also are updated by the following model:

$$I_{t+n} = \gamma + (1 - \gamma) I_t$$

Where γ is the seasonal smoothing constant, it varies between 0 and 1.

If you want to forecast for the 'n' period, where in you have then the forecast for the period 'n' after t

$$\hat{Y}_{t+n} = \hat{X}_t I_{t+n}$$

Exponentially weighted moving average Problem -4

Quarterly data for 12 periods is given below:

NOTES

Table 3.7

Quarter	Demand	Quarter	Demand
1.	497	7.	821
2.	454	8.	1017
3.	624	9.	709
4.	764	10.	715
5.	631	11.	1794
6.	624	12.	1242

Using the data from the first eight quarters, compute the quarterly seasonal indices.

Solutions -

Table 3.8

Period	Demand	Average of same quarter of each year	Seasonal Index
1	497	564	0.83
2	454	539	0.793
3	624	722.5	1.064
4	764	890.5	1.311
5	631	564	0.83
6	624	539	0.793
7	821	722.5	1.064
8	1017	890.5	1.311
Total	5432		7.996

$$\text{Overall quarterly average} = \frac{5432}{8} = 679$$

$$\text{Seasonal Index} = \frac{\text{Average of same quarter of each year}}{\text{Overall quarterly average}}$$

$$\text{Seasonal Index for Quarter 1} = \frac{564}{679} = 0.83$$

$$\text{Seasonal Index for Quarter 2} = \frac{539}{679} = 0.793$$

NOTES

$$\text{Seasonal Index for Quarter 3} = \frac{722.5}{679} = 1.064$$

$$\text{Seasonal Index for Quarter 4} = \frac{890.5}{679} = 1.311$$

Exponentially moving average with seasonal and trend corrections (Level + Trend + Seasonal)

If the past data consists of the level, seasonal and trend pattern, then you need three expressions to estimate the three components:-

$$\hat{X}_t = \alpha Y_t + (1 - \alpha) (\hat{X}_{t-1} + T_{t-1})$$

$$T_t = \beta (Y_t - \hat{X}_{t-1}) + (1 - \beta) T_{t-1}$$

$$I_{t+m} = \gamma Y_t + (1 - \gamma) I_t$$

The forecast model

$$= (\hat{X}_t + T_t) I_t$$

To forecast for the 'n' period

$$\hat{Y}_{t+n} = [\hat{X}_t + (n + 1) T_t] I_{t+n}$$

Exponentially moving average Problem – 5

Using the data from the last four quarters in the previous problem and the initial seasonal indices computed in the previous problem, determine MAD and bias of an Exponential weighted moving average with $\alpha = 0.2$, $\beta = 0.4$, $\gamma = 0.5$, an initial forecast of 720, an initial trend of 65, and an initial level of 801. What is the forecast for quarter 13? For quarter 15? (Assume period 9 as the initial period).

Given

Table 3.9

Quarter	Y _t Demand	Forecast Level	Tt Trend	Seasonal Index		Forecast
				I _t	I _{t+m}	
9	709	801	65	0.83		720
10	715			0.793		
11	1794			1.064		
12	1242			1.311		

NOTES

$$\alpha = 0.2, \quad \beta = 0.4, \quad \gamma = 0.5$$

New seasonal Index, I_{t+m} 9th quarter is obtained as follows:

$$\text{New seasonal Index, } I_{t+m} = \gamma + (1 - \gamma) I_t$$

$$= 0.5 + 0.5 * 0.83$$

$$= 0.4425 + 0.415$$

$$= 0.8575$$

Forecast demand level for the 10th quarter is obtained in the following manner:

$$\hat{X}_t = \alpha + (1 - \alpha) (\hat{X}_{t-1} + T_{t-1})$$

$$= \frac{0.2 * 709}{0.83} + 0.8 * (801 + 65)$$

$$= 170.84 + 692.8$$

$$X_{10} = 863.64$$

Trend for the 10th quarter is obtained as follows:

$$T_t = \beta (\hat{X}_t - \hat{X}_{t-1}) + (1 - \beta) T_{t-1}$$

$$= 0.4 * (863.64 - 801) + 0.6 * (65)$$

$$T_{10} = 64.056$$

Forecast for quarter 10 is

$$= (\hat{X}_t + T_t) I_t$$

$$= (863.64 + 64.056) * 0.793$$

$$\hat{Y}_{10} = 735.66$$

Forecast demand level for the 11th quarter is obtained in the following manner:

$$\hat{X}_t = \alpha + (1 - \alpha) (\hat{X}_{t-1} + T_{t-1})$$

$$= \frac{0.2 * 715}{0.793} + 0.8 * (863.64 + 64.056)$$

$$= 180.32 + 742.156$$

$$\hat{X}_{11} = 922.47$$

Trend for the 11th quarter is obtained as follows:

$$T_t = \beta (\hat{X}_t - \hat{X}_{t-1}) + (1 - \beta) T_{t-1}$$

$$= 0.4 * (922.47 - 863.64) + 0.6 * (64.056)$$

$$T_{11} = 61.96$$

NOTES

Forecast for quarter 11 is

$$= (\hat{X}_t + T_t) I_t$$

$$= (922.47 + 61.96) * 1.064$$

$$\hat{Y}_{11} = 1047.43$$

Forecast demand level for the 12th quarter is obtained in the following manner:

$$\hat{X}_t = \alpha + (1 - \alpha) (\hat{X}_{t-1} + T_{t-1})$$

$$= \frac{0.2 * 1794}{1.064} + 0.8 * (922.47 + 61.96)$$

$$= 337.21 + 787.54$$

$$X_{12} = 1124.75$$

Trend for the 12th quarter is obtained as follows:

$$T_t = \beta (\hat{X}_t - \hat{X}_{t-1}) + (1 - \beta) T_{t-1}$$

$$= 0.4 * (1124.75 - 922.47) + 0.6 * (61.96)$$

$$T_{12} = 118.08$$

Forecast for quarter 12 is

$$= (\hat{X}_t + T_t) I_t$$

$$= (1124.75 + 118.08) * 1.311$$

$$\hat{Y}_{12} = 1629.35$$

Forecast demand level for the 13th quarter is obtained in the following manner:

$$\hat{X}_t = \alpha + (1 - \alpha) (\hat{X}_{t-1} + T_{t-1})$$

$$= \frac{0.2 * 1242}{1.311} + 0.8 * (1124.75 + 118.08)$$

$$= 189.47 + 994.26$$

$$\hat{X}_{13} = 1183.73$$

Trend for the 13th quarter is obtained as follows:

$$T_t = \beta (\hat{X}_t - \hat{X}_{t-1}) + (1 - \beta) T_{t-1}$$

$$= 0.4 * (1183.73 - 1124.75) + 0.6 * (118.08)$$

$$T_{13} = 93.43$$

Forecast for quarter 13 is

$$= (\hat{X}_t + T_t) I_t$$

$$= (1183.73 + 93.43) * 0.8575$$

$$\hat{Y}_{13} = 1096.02$$

NOTES**Forecast for quarter 13 is 1096.02**

New seasonal Index, I_{t+m} for 10th quarter is obtained as follows:

$$\text{New seasonal Index, } I_{t+m} = \gamma + (1 - \gamma) I_t$$

$$= 0.413 + 0.5 * 0.793$$

$$= 0.413 + 0.396$$

$$= 0.809$$

I_{t+m} for 11th quarter,

$$I_{t+m} = \gamma + (1 - \gamma) I_t$$

$$= 0.972 + 0.5 * 1.064$$

$$= 0.972 + 0.532$$

$$= 1.504$$

I_{t+m} for 11th quarter,

$$I_{t+m} = \gamma + (1 - \gamma) I_t$$

$$= 0.552 + 0.5 * 1.311$$

$$= 0.552 + 0.655$$

$$= 1.207$$

Table 3.10

Quarter Demand	Y_t Forecast Level	\hat{X}_t	Tt Trend Index	Seasonal		Forecast
				I_t	I_{t+m}	
9	709	801	65	0.83	0.8575	720
10	715	863.64	64.056	0.793	0.809	735.66
11	1794	922.47	61.96	1.064	1.504	1047.43
12	1242	1124.75	118.08	1.311	1.207	1629.35
13		1183.73	94.43	0.8575		1096.02

Forecast for Quarter 15 is

$$_{t+2} = [1183.73 + 3 * (94.43)] * 1.504$$

$$= 1467.02 * (1.504)$$

$$\hat{Y}_{15} = 2206.39$$

Forecast for quarter 15 is 2206.39

Mean Absolute Deviation, $MAD = \sum_{i=1}^n \frac{Y_i - \hat{Y}_i}{n}$

$$MAD = \frac{|11 + 20.66 + 746.57 + 387.35|}{4}$$

$$= \frac{1165.58}{4}$$

MAD = 291.39

$$\text{Bias} = \frac{\sum_{i=1}^n (Y_i - \hat{Y}_i)}{n}$$

$$= \frac{(-11 - 20.66 + 746.57 - 387.35)}{4}$$

=

Bias = 81.89

NOTES

$$\frac{327.56}{4}$$

3.2.3.1.2 Econometric models

Econometric models may be designed as social science in which the tools of economic theory, mathematics, and statistical inference are applied to the analysis of economic phenomena.

The traditional econometric methodology proceeds along the following steps:

1. Statement of theory.
2. Development of model.
3. Specification of econometric model.
4. Obtaining the data.
5. Estimation of the parameters of the econometric model.
6. Hypothesis testing.
7. Forecasting.
8. Using the model for central or policy purpose.

The above steps can be explained by an example:-

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1. Economic theory says, other things remaining the same, a reduction of price of a commodity results in increase of quantity demanded for that commodity.
2. You can find an inverse relationship and a mathematical model can be developed.
3. Use of mathematical model which enables you to develop an economical equation.
4. Get the past data for the price and quantity.
5. Estimate the parameters for the economic model.
6. Use the model as well as parameters.
7. The predicted data further used for decision making purpose.

Thus econometric models are developed and used for decision making purpose.

3.2.3.1.3 *Economic Indicators*

In this kind of model the independent and dependent variables are economic indicators. The variables may be GNP, Personal income, Bank deposits, Inflation, Pre-capita income, Purchasing Power Parity, Wholesale price index, Consumer price index, etc. You should develop a relationship .

$$Y = f(x_1, x_2, \dots, x_p)$$

Then develop a model using the variable and treat the problem as simple linear regression or multiple regression model. Then use the model to forecast for the future and test the model and parameters using ANOVA and 't' test. The difference between econometric models and economic indicators are, in econometric model you may have more than one equation which you may get to show the relationship between the economic variables and the parameters estimated and it is used for forecasting, but in the case of economic indicator model you will be having single regression model to predict the future.

3.2.3.2 *Qualitative Methods*

Qualitative methods of forecasting are adopted where you don't have past data for projections. But, these techniques are adopted to forecast for new products. These techniques also adopted to validate the forecast which is derived from the quantitative methods mentioned in the early sections.

3.2.3.2.1 Market Survey is a technique, where the market / consumer are surveyed to estimate the potential market through various techniques like direct survey, questionnaire, interview methods etc.

3.2.3.2.2 Expert Opinion has a method in which the experts are called and they are allowed to discuss to arrive at the decisions related to market potential. This method has a disadvantage of the dominating expert – who may sway away the whole discussion in his way. The docile expert view may not find a remarkable place in the discussion.

3.2.3.2.3 Delphi Technique - the short coming of the expert opinion method is eliminated in the Delphi technique method. In this method, the experts are not invited for the discussion, instead the questions is prepared for which is indented and circulated to all experts. The responses of experts are collected and then the reasoning for their response will also be collected and then same such process is continued until the consensus is arrived at. The whole task is carried out by a person called Facilitator.

Review Questions:

1. List the techniques under qualitative methods.
2. List the different techniques used in the quantitative methods.

3.2.4 Forecasting evaluation

Forecasting evaluation tools are many. But each tool is the function of forecast error that is the difference between the actual sales and the forecasted value. The forecasting methods are evaluated based on the forecasting evaluation tool.

The best method is chosen where the forecast error is minimum. Different forecasting evaluation tools are:

1. Sum of squared error
2. Mean squared error
3. Mean absolute deviation
4. Tracking signal

Let us assume that

$F_t \rightarrow$ Forecast for the period 't'

$A_t \rightarrow$ Actual for the period 't'

$n \rightarrow$ number of observation

1. Sum of Squared Error (SSE)

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

2. Mean Squared Error (MSE)

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

3. Mean Absolute Deviation (MAD)

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

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$|F_t - A_t|$ is the absolute value
Tracking Signal (TS)

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

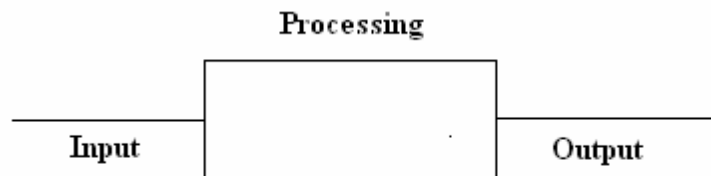
3.3 CAPACITY PLANNING

Capacity planning is a process, which is to be carried out after deciding the product and the long range demand for the product. Suppose if you produce custom made product, the demand is not estimated through the product but in terms of hours. Once if you know the long range demand, the effort needed to determine the amount of resources needed to meet the demand requirement is all about capacity planning.

Capacity Measure

In this section, you can learn a method of measuring a capacity of system. Consider anything for which you need to measure the capacity, as a system.

Figure 3.6 – Capacity Measures



Analyze the system into input, processing and output. When you analyze, see to that, where there is a less variability, choose that side and identify the product, process-resources, the input resources and attach time frame to provide the capacity measure.

Measure of Capacity through output

Consider an automobile mass production industry. You can't find much variation in the output side compared to the input resources and processing parts. So the number of cars/time is considered as the measure. Mostly in the case of mass production industry, the output side is considered to measure the capacity.

Measure of the capacity through Input

Consider an educational institution; here the output side is not taken into consideration because the number of outgoing students per time may vary depending upon the pass result. But the intake is always constant because the intake depends upon the government approved. So, the capacity of educational institution is measured through the input, namely, the number of students intake.

Measure of the capacity through processing

Consider a sugarcane industry, the capacity of that industry is not measured in terms of the output and input. There is a variability in terms of yield rate that means some times “y” tons of sugarcane may give “x” tons of sugar or some times same “y” may give more than or less than the “x” tons of sugar. Since variability is existing in both the input side and output side. Inputs and outputs are not considered for measuring the capacity. But in the processing side there is a less variability namely the crushing capacity or the number of tons of sugarcane could be crushed by the crushing machine is considered to be a best measure to measure the capacity of the sugarcane industry from the processing point of view.

In summary, if you want to fix the measure for the capacity, then see the system as input, processing and output. Find where there is a less variability choose that side and correspondingly choose the product or the resources to estimate the measure. The table- 3.11 provides some of the systems and their corresponding measure to measure the capacity.

Table 3.11 - Capacity planning involves three stages of planning.

System	Components of System considered for capacity measure	Unit of Measure
Automobile Industry	Output	Number of Automobiles
Bottling Plant	Output	Gallons / Day
University	Input per year	Number of students intake
Auto repair shop	Processing day	Number of machines hour per day
Restaurant	Processing	Seating Capacity

Stage 1 involves ***resource planning*** this is considered to be long range planning. In the long range planning, mostly the type and amount of man power requirement, the capital equipment requirements are to be decided.

Stage 2 is by considering the resource planning; the ***rough cut capacity planning*** is carried out. Here it is not discussed in detail because it has been discussed in unit II.

Stage 3 is ***capacity requirement planning*** this is lower level planning. This is carried out with the input of rough cut capacity planning. This is also discussed in the unit II.

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Review Questions:

1. How do you measure the capacity planning?
2. Give an example for the capacity measure based on output?

3.4 AGGREGATE PRODUCTION PLANNING

3.4.1 Introduction

In the operational planning, the long range planning involves capacity planning which involves the determination of long range capacity needs of an organization. Next to the capacity planning is the process of **aggregate planning** which comes under intermediate range planning. Aggregate planning is done considering capacity planning as a framework.

Aggregate Planning

Aggregate Planning includes identifying different feasible production alternatives and selecting the best one in order to reduce the production cost to minimum. First let us analyze what is meant by aggregate planning? And why this is called aggregate planning? There are organizations which involve the production of various products and each product has its own measurable dimension. For e.g. Assume that an organization produces three products – Product A, Product B and Product C. Product A is measured in terms of tons, product B is measured in terms of length and Product C in terms of number of units. As you know aggregate planning is a medium range planning, you need not plan the capacity of individual products. Instead you should plan the capacity for aggregate demand by converting the different product demand into an aggregate demand. For doing so, you need to find out a common unit, for the above mentioned three products. If possible you can convert into total hours of production. Here the dimension becomes time. Hence time becomes the aggregate unit. After finding the aggregate requirement then you should plan the capacity for the aggregate requirement. This is a planning done at a broader level and does not include details of individual product.

Aggregate planning includes:

Staffing plan – related to staff and labor related factors.

Production plan – related to production level and inventory.

3.4.2 Objectives of Aggregate Planning

The main objective is to minimize the cost. The others include:

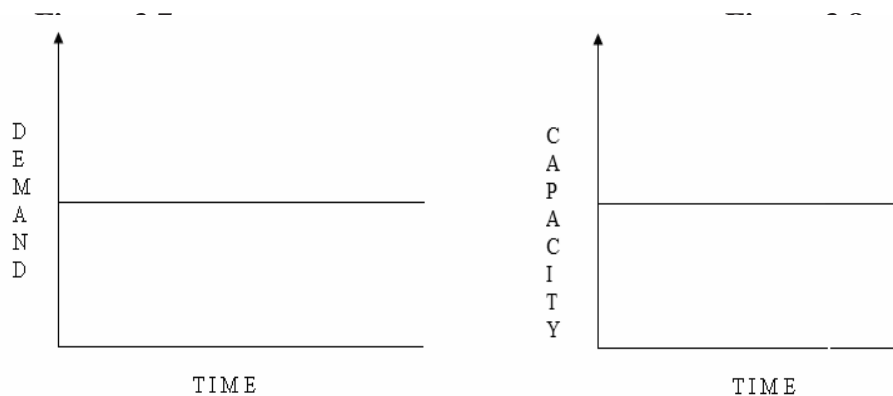
- To maximize
 1. customer service and.
 2. utilization of resources.

- To minimize
 1. changes in workforce and.
 2. changes in production.

NOTES

3.4.3 Strategies to Meet the Demand Fluctuations

Suppose the annual requirement is 1200 units, then you can establish a constant capacity for production as $1200/12 = 100$ units per month.



In reality, the demand fluctuates. It could follow seasonal, trend pattern. To meet these demand fluctuations there are certain strategies to be adopted with regard to capacity to meet the demand. They are:

- Inventory carrying through constant workforce.
- Subcontracting.
- Variable workforce.
- Variable Working hours.
- Promotional Activities.
- Backordering.

a. Inventory Carrying Through the Constant Workforce

In this strategy a constant workforce is maintained throughout the planning period, because of which there is a constant output. But the demand may vary. So during certain periods there will be excess output and at certain times decreased output. The excess demand is met through excess output produced through constant workforce in the previous demands by carrying the inventory.

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Figure 3.9 - Inventory Carrying Through Constant Workforce

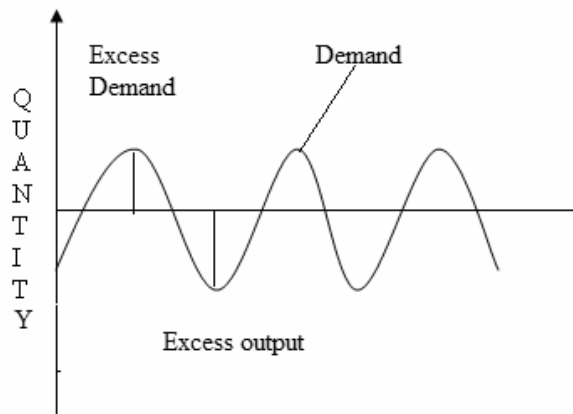
Inventory carrying through constant workforce

- Subcontracting
- Variable workforce
- Variable Working hours
- Promotional Activities
- Backordering

a. Inventory Carrying Through Constant Workforce

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Figure 3.9 - Inventory Carrying Through Constant Workforce



Advantages:

- This method provides a stable workforce who can give better quality products because of their experience.
- The employees feel secured about their job and hence high productivity level is maintained.
- It avoids hiring and firing cost.

Disadvantages

- There will be inventory carrying cost when there is excess output during a period.

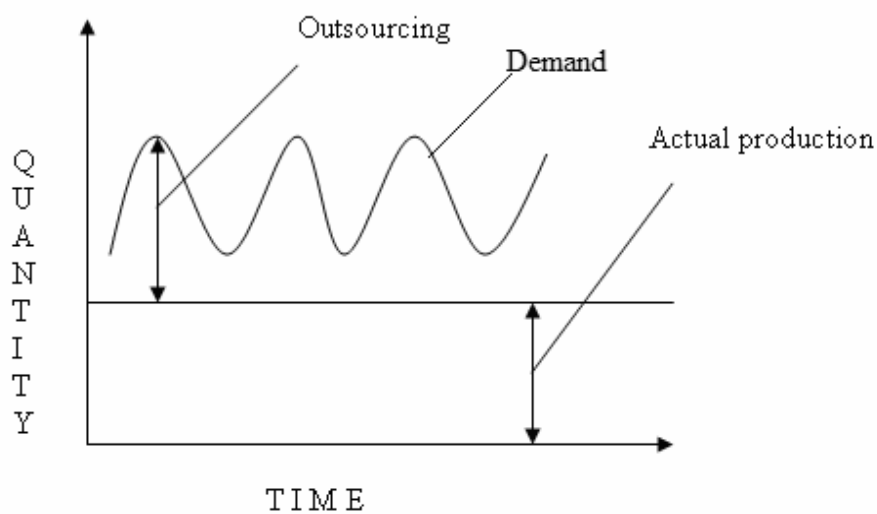
- There is a difficulty in finding a stable workforce that will keep the inventory cost at its minimum.
- This strategy cannot be followed for perishable goods.

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b. Subcontracting

This is one of the strategies to meet demand fluctuation in which a portion of the production is placed with a subcontractor or subcontractors.

Figure 3.10 - Subcontracting



Advantages

- During the period of the peak demand this is a good alternative if the company is unable to produce the demand needs in a given time period.

Disadvantages

- Unless the company has good relations with the suppliers it cannot have much a control on the product quality and delivery time.
- If practiced extensively it will result in increased competition among subcontractors which in turn leads to subcontractors becoming competitors for the firm.

c. Variable Workforce

This strategy involves hiring and firing of employees based on demand fluctuations. When the demand increases workforce is hired and when the demand decreases some amount of workforce is fired.

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Figure 3.11

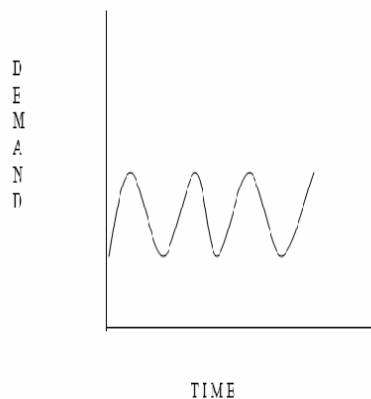
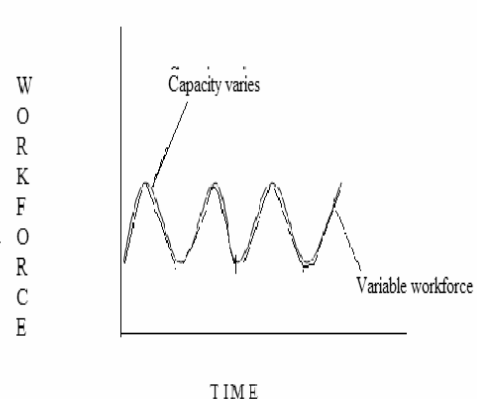


Figure 3.12



- Variable workforce enables to match between production quantity and demand because of which inventory cost can be kept at minimum.

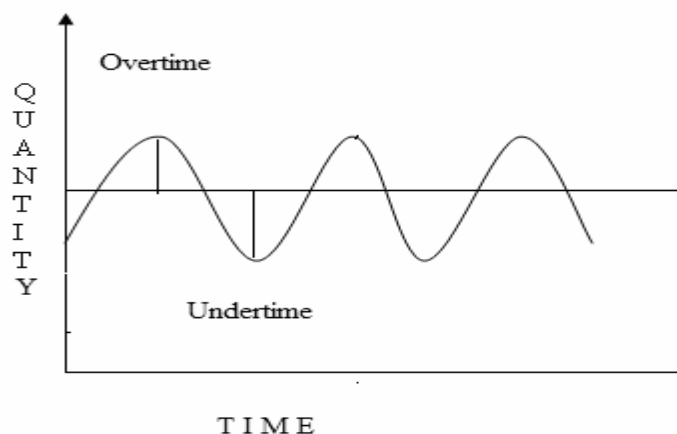
Disadvantages

- There is a cost involves in hiring and firing the employees.
- Newly hired employees need training and hence initially productivity might be lowered.
- Workers might feel unsecured about their job which may in turn affect productivity.

d. Variable Working Hours

Under this strategy, workforce remains constant but working hours would vary as per the demand. During periods of increased demand employees are made to work overtime. If the demand is low workers are idle but the firm would be paying them full salary. This is a loss to the company.

Figure 3.13 - Variable Working Hours



Advantages

- It helps to maintain a stable workforce.
- The company can save the cost on inventory.

Disadvantages

- In case of very large demand it is difficult to follow this strategy.
- Overtime wages are higher than regular time wages.
- Employees are idle during periods of low demand.
- During overtime, if the employees are very much stressed, it will lead to a decrease in their efficiency of working.

e. Promotional Activities

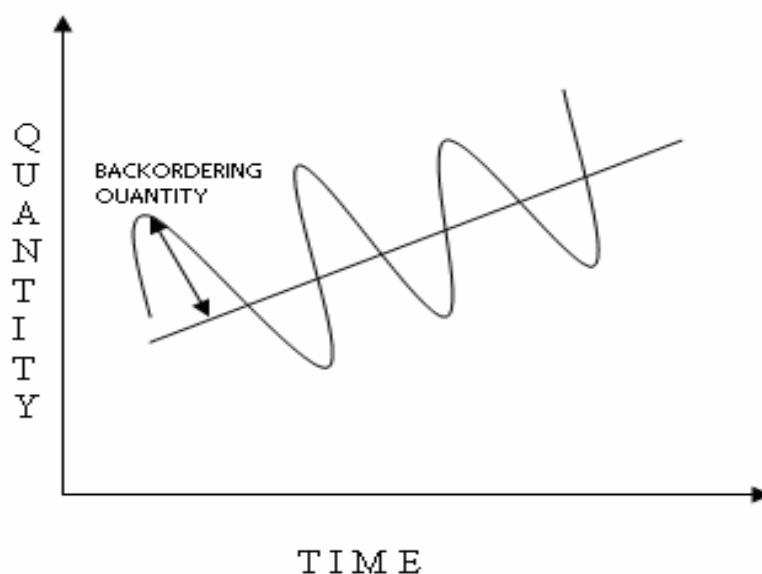
During off seasons, there is a decrease in demand. At such times firms can promote the sales by offering discounts, selling at a lower price, “buy one get one free” sales, etc. This can be adopted to sell the excess inventory.

Example: Giving off-season discounts for soft drinks during winter season.

f. Backordering

Here products are supplied to the customers only after a period of waiting time. i.e., customers are made to wait for the product. As soon as the goods are produced they are first supplied to back orders. It is the same as shortage of a product.

Figure 3.14 - Backordering

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If any one of the above strategies is used it is called pure strategy. If a combination of the above strategies are used it is then called mixed strategy.

The Cost Aspects

Various costs are associated with aggregate planning strategies. They are explained as follows:

Production cost

This includes the fixed cost and variable cost associated with production activities

- Fixed cost – Cost such as rent for the building, salaries, property tax, insurance etc. These cost that does not vary with the volume of production.
- Variable cost – The cost of labor, material or overhead and this changes according to the change in volumes of unit produced.

Hiring and Firing cost

The cost associated with variable workforce size. Costs involved with termination of employee will come under firing cost. Similarly if an employee is recruited temporarily during increased demand there will be costs of training, wages to the new employees. These come under the hiring cost. Hiring cost would include employer expenses on job advertising, screening cost and training of newly hired employees.

For employee lay-off, the firm incurs certain cost such as compensation, expenses on legal advice for settlement, counseling of fired employees, etc.

Back-order cost

This is nothing but the shortage cost, when the demand for a product is met later. In other words, customer is made to wait for the product. This may result in any one of the following

- The customer may wait for the product, but there is a cost associated with this which is proportional to the waiting time of the customer.
- The customer may be dissatisfied, and the cost associated with this is independent of waiting time. This is called fixed shortage cost.
- The customer may also switch to competitor's products and hence the sale is lost. This may result in losing the goodwill of the customer also.

Overtime Cost

In case of variable work hours, the employees may be asked to work overtime during periods of peak demand. This results in paying the employee for the overtime. This cost is usually much more than the regular time cost.

3.4.4 Aggregate Planning Methods

In this section you can see about the different methods used for aggregate planning. The methods are classified based on the above discussed cost varying linearly

or non- linearly against the activities to be measured. It is also based on whether you need optimal solution or non-optimal solution.

The aggregate planning methods can be represented as follows:

Table 3.12 - Aggregate Planning Methods

Solution Requirement	Cost Behavior	
	Linear	Non-Linear
Optimal	Linear Programming - Transportation model - Simplex method	Linear Decision rule Dynamic Programming
Non-Optimal	Trial and Error method	Heuristic method Computer research

Real life aggregate planning problem consist of more complex interacting variable and constraints. So it is difficult to formulate the optimal model. Here, planner resorts to non-optimal solution. In this section you can understand the Trial and Error method, Simplex method and Transportation model. Other methods are out of scope and thus not included.

3.4.4.1 Error Method

The following example is solved through the Trial and error method. This method is called as the Trial and Error method because you are following a particular logic to solve the problem, but there is no guarantee that whether the solution that you got is optimal or not.

Example 3.1

A company has estimated the demand for each product for 12 months as follows:

Table 3.13

Month	Demand
1	1200
2	2400
3	3000
4	3200
5	3500
6	4000
7	4500
8	4700
9	3200
10	2900
11	4800
12	5000

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These demands can be met through Regular Time, Overtime and Subcontracting.

Regular Time capacity – 200 units

Overtime capacity – 1500 units

Subcontracting capacity – infinity

Regular Time cost, r_t = Rs.30 per unit per period

Overtime cost, o_t = Rs.50 per unit per period

Subcontracting cost, u_t = Rs.100 per unit per period

It is possible to carry inventory from one period to another and carrying cost C_c = Rs. 10 per unit. Provide feasible production alternatives.

Solution:

Table 3.14

Month	Demand	R_T (2000)	O_T (1500)	S_T (infinity)
1	1200	1200, 500 (6), 300 (7) - 500 units required in 6 th month is produced in 1 st month and carried as inventory. 300 (7) - 300 units required in 7 th month is produced in 1 st month.	700 (7), 800 (8) 700 units required in 7 th month is produced in 1 st month and carried as inventory. 800 (8) - 800 units required in 8 th month is	
2	2400	2000	1400, 400 (8), 700 (11) 400 units required in 8 th month is produced in 2 nd month and carried as inventory. 700 (11) - 700 units required in 11 th month is produced in 2 nd month.	
3	3000	2000	1000, 500(11) 500 units required in 11 th month is produced in 3 rd month and carried as inventory.	
4	3200	2000	1200, 100(11), 200(12) 100 units required in 11 th month is produced in 4 th month and carried as inventory. 200 (12) - 200 units required in 12 th month is produced in 4 th month.	
5	3500	2000	1500	
6	4000	2000	1500	
7	4500	2000	1500	
8	4700	2000	1500	

9	3200	2000	1200, 300 (12) 300 units required in 12 th month is produced in 9 th month and carried as inventory.	
10	2900	2000	900, 600 (12) 600 units required in 12 th month is produced in 10 th month and carried as inventory.	
11	4800	2000	1500	
12	5000	2000	1500	400

NOTES

Total production cost = $\sum_{t=1}^{12} C_t$, where C_t is the cost incurred for the month 't'.

$$C_1 = (2000 \times 30) + (1500 \times 50) = \text{Rs. } 135000$$

$$C_2 = (2000 \times 30) + (1500 \times 50) = \text{Rs. } 135000$$

$$C_3 = (2000 \times 30) + (1500 \times 50) = \text{Rs. } 135000$$

$$C_4 = (2000 \times 30) + (1500 \times 50) = \text{Rs. } 135000$$

$$C_5 = (2000 \times 30) + (1500 \times 50) = \text{Rs. } 135000$$

$$C_6 = (2000 \times 30) + (1500 \times 50) + (500 \times 50) = \text{Rs. } 160000$$

$$C_7 = (2000 \times 30) + (1500 \times 50) + (300 \times 60) + (700 \times 60) = \text{Rs. } 195000$$

$$C_8 = (2000 \times 30) + (1500 \times 50) + (800 \times 70) + (400 \times 60) = \text{Rs. } 215000$$

$$C_9 = (2000 \times 30) + (1500 \times 50) = \text{Rs. } 135000$$

$$C_{10} = (2000 \times 30) + (1500 \times 50) = \text{Rs. } 135000$$

$$C_{11} = (2000 \times 30) + (1500 \times 50) + (700 \times 90) + (500 \times 80) + (100 \times 70) = \text{Rs. } 245000$$

$$C_{12} = (2000 \times 30) + (1500 \times 50) + (200 \times 80) + (300 \times 30) + (600 \times 20) + (400 \times 100) \\ = \text{Rs. } 212000$$

Total Production cost = Rs. 19,721,000

3.4.4.2 Linear programming Model

The aggregate planning problem can be formulated as a Linear Programming Model when cost behavior is linear and the optimal solution is required you can have two kinds of linear programming model. One is for constant workforce and the other for variable workforce as shown below.

Fixed Work Force Model

The following notation is used to describe the above model.

- v_{it} = unit production cost for product I in period t (exclusive of labor cost)
- c_{it} = inventory carrying cost per unit of product I held in stock from period

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t to t+1

r_t = cost per man hour of regular labor in period t

o_t = cost per man hour of overtime labor in period t

d_{it} = forecast demand for product i in period t

k_i = man hours required to produce one unit of product i

$(r m)_t$ = total man hours of regular labor available i period t

$(o m)_t$ = total man hours of overtime labor available i period t

I_{io} = initial inventory level for product i

W_o = initial regular work force level

T = time horizon, in periods

N = total number of products

Decision variables

X_{it} = units of product i to be produced in period t

I_{it} = units of product to be left over as inventory in period t

W_{it} = man hours of regular labor used during period t

O_t = man hours of overtime labor used during period t

Fixed work force cost model is:

$$\text{Minimize } Z = \sum_{i=1}^N \sum_{t=1}^T (v_{it} X_{it} + c_{it} I_{it}) + \sum_{t=1}^T (r_t W_t + o_t O_t)$$

Subject to:

$$X_{it} + I_{i,t-1} - I_{it} = d_{it}$$

$$\sum_{i=1}^N k_i X_{it} - W_t - O_t = 0$$

$$0 \leq W_t \leq (rm)_t$$

$$0 \leq O_t \leq (om)_t$$

$$X_{it}, I_{it} \geq 0$$

The objective function expresses minimization of variable production, inventory, regular and overtime labor costs.

Constraint one represent production – inventory balance. Second constraint defines total manpower to be used in every period. Last two constraints impose lower and upper bounds on the use of regular and overtime man hours in every time period.

Variable workforce models

When there is a change the workforce level to meet demand fluctuations, the workforce becomes a decision variable and hiring and firing cost will be part of objective

function. The model below also includes backordering cost.

H_t = man hours of regular work force hired in period t

F_t = man hours of regular work force laid off in period t

I_t^+ = units ending inventory of product I in period t

I_t^- = units of product I backordered at the end of period t

b_t = cost per unit of backorder of product i carried from period t to $t+1$

h_t = cost of hiring one man hour in period t

f_t = cost of laying off one man hour in period t

p = overtime allowed as a fraction of the regular hours

Variable workforce model can be formulated as follows:

$$\text{Minimize } Z = \sum_{i=1}^N \sum_{t=1}^T (v_{it} X_{it} + c_{it} I_{it}^+ + b_{it} I_{it}^-) + \sum_{t=1}^T (r_t W_t + o_t O_t + h_t H_t + f_t F_t)$$

Subject to

$$X_{it} + I_{i,t-1}^+ - I_{i,t-1}^- + I_{it}^+ - I_{it}^- = d_{it}$$

$$\sum_{i=1}^N K_i X_{it} - W_t - O_t \leq 0$$

$$W_t - W_{t-1} - H_t + F_t = 0$$

$$-pW_t + O_t \leq 0$$

$$X_{it}, I_{it}^+, I_{it}^- \geq 0$$

$$W_t, O_t, P_t, H_t, F_t \geq 0$$

$$i = 1, \dots, N$$

$$t = 1, \dots, N$$

The first constraint represents the production inventory balance equation.

The Second constraint limits the production to variable man power. It is possible at some point regular work force W_t will be partially idle therefore is justified.

The Third constraint define the change in workforce during period t i.e. $W_t - W_{t-1} = H_t - F_t$. Labor is added when $H_t > 0$ or subtracted whenever $F_t > 0$.

The Fourth constraint imposes an upper bound on the total overtime available in period t as a function of regular work force size.

Example 3.2

The following data pertain to demand forecast, production alternatives, and costs for the XYZ Company which manufactures a cleaning fluid used in hospitals.

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NOTES**Table 3.15**

Capacity Limit, tons				
Quarter Demand	Estimated Production	Regular production	Overtime per ton	Unit cost
1	210	210	15	$r_t = \text{Rs.}2000$
2	200	210	15	$o_t = \text{Rs.}3000$
3	170	180	10	$C_c = \text{Rs.}200$ per period
4	230	210	15	

Furthermore, the cost of hiring is Rs.4800 per unit increase in output ($h_t = \text{Rs.}4800$ per unit) while the cost of firing is Rs.72000 per unit decrease in output ($f_t = \text{Rs.}72000$ per unit). The starting regular production rate is $P_0 = 220$ tons from the work-force level of the previous period.

Formulate the aggregate planning problem as a linear programming problem using simplex method and solve it if computer program is available.

Solution:

Demand data	Regular Time Capacity	Overtime Capacity
$D_1 = 210$	$X_1 = 210$	$O_1 = 15$
$D_2 = 200$	$X_2 = 250$	$O_2 = 15$
$D_3 = 170$	$X_3 = 180$	$O_3 = 10$
$D_4 = 230$	$X_4 = 210$	$O_4 = 15$

Regular time cost per unit, $r_t = \text{Rs.} 2000$

Over Time cost per unit, $o_t = \text{Rs.} 3000$

Carrying cost per unit per period, $C_c = \text{Rs.}200$

Hiring cost per unit, $h_t = \text{Rs.} 4800$

Firing cost per unit, $f_t = \text{Rs.} 72000$

Starting regular production rate $P_0 = 220$ tons

Initial inventory $I_0 = 0$ (assume)

A linear programming problem for the above aggregate planning problem is presented below.

X_t, O_t = Units produced during regular time and overtime respectively.

A_t, R_t = Number of units increased or decreased respectively during consecutive periods.

D_t = Sales forecast

Minimize $z = 2000 (X_1 + X_2 + X_3) + 4800 (A_1 + A_2 + A_3 + A_4) + 7200 (R_1 + R_2 + R_3 + R_4) + 3000 (O_1 + O_2 + O_3 + O_4) + 200 (I_1 + I_2 + I_3 + I_4)$

Subject to constraints:

$$X_1 \leq 210$$

$$X_2 \leq 250$$

$$X_3 \leq 180$$

$$X_4 \leq 210$$

$$O_1 \leq 15$$

$$O_2 \leq 15$$

$$O_3 \leq 10$$

$$O_4 \leq 15$$

$$R_1 + O_1 - I_1 = 210$$

$$X_2 + O_2 + I_1 - I_2 = 200$$

$$X_3 + O_3 + I_2 - I_3 = 170$$

$$X_4 + O_4 + I_3 - I_4 = 230$$

$$X_1 - A_1 \leq 220$$

$$-X_1 + X_2 - A_2 \leq 0$$

$$-X_2 + X_3 - A_3 \leq 0$$

$$-X_3 + X_4 - A_4 \leq 0$$

$$X_1 + R_1 \leq 220$$

$$-X_1 + X_2 + R_2 \leq 0$$

$$-X_2 + X_3 + R_3 \leq 0$$

$$-X_3 + X_4 + R_4 \leq 0 \quad X_t, R_t, A_t, O_t, I_t \geq 0 \text{ where } t = 1, 2, 3, 4$$

The results are given below :

Table 3.16

Quarter I	Quarter II	Quarter III	Quarter IV
$P_1 = 210$	$P_2 = 210$	$P_3 = 180$	$P_4 = 180$
$O_1 = 0$	$O_2 = 5$	$O_3 = 10$	$O_4 = 15$
$I_1 = 0$	$I_2 = 15$	$I_3 = 35$	$I_4 = 0$
$A_1 = 0$	$A_2 = 0$	$A_3 = 0$	$A_4 = 0$
$R_1 = 10$	$R_2 = 0$	$R_3 = 30$	$R_4 = 0$

Minimum Cost is = Rs. 19,48,000

The above results are shown diagrammatically as follows:

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Figure 3.14

3.4.4.3 Transportation Model

A generalized transportation model for more than one alternative (for production) can be represented as follows:

Table 3.17 - Aggregate Planning Methods

	I	II	III	IV	Cost	Supply
I	r	$r_t + C_c$	$r_t + 2 C_c$	$r_t + 3 C_c$	r_t	S1
	o	$o_t + C_c$	$o_t + 2 C_c$	$o_t + 3 C_c$	o_t	
	u	$u_t + C_c$	$u_t + 2 C_c$	$u_t + 3 C_c$	u_t	
II	$r_t + Cs$	r_t	$r_t + C_c$	$o_t + 2 C_c$	r_t	S2
	$o_t + Cs$	o_t	$o_t + C_c$	$v_t + 2 C_c$	o_t	
	$u_t + Cs$	u_t	$u_t + C_c$	$u_t + 2 C_c$	u_t	
III	$r_t + 2Cs$	$r_t + Cs$	r_t	$o_t + C_c$	r_t	S3
	$o_t + 2Cs$	$o_t + Cs$	o_t	$v_t + C_c$	o_t	
	$u_t + 2Cs$	$u_t + Cs$	u_t	$u_t + C_c$	u_t	
IV	$r_t + 3Cs$	$r_t + 2Cs$	$R_t + Cs$	r_t	r_t	S4
	$o_t + 3Cs$	$o_t + 2Cs$	$o_t + Cs$	o_t	o_t	
	$u_t + 3Cs$	$u_t + 2Cs$	$u_t + Cs$	u_t	u_t	
Demand	D1	D2	D3	D4		

Where

r_t = regular time cost

o_t = over time cost

u_t = subcontracting cost

C_s = shortage cost

C_c = carrying cost

In case of back ordering, for three periods in advance the shortage cost will be three times. i.e. $3C_s$ will be added to the existing labor cost. Similarly for two periods backordering $2C_s$ will be added to the existing labor cost.

C_c represents carrying cost. Products produced during a period for usage in subsequent periods will have a carrying cost. For e.g. $3C_c$ indicates that product had been carried over three months.

Example 3.3

A producer is considering either producing or procuring a certain part. The relevant data are as follows:

Table 3.18

	PERIOD			
	I	II	III	IV
Production capacity				
In house	20	20	20	20
Outside Vendor	40	40	40	40
Unit cost				
In House	12	13	15	16
Outside vendor	15	15	18	20
Demand	70	40	60	90

Initial inventory is 20 units and the holding cost is Rs.8 per unit per period. What is the optimal aggregate plan?

Solution:

Table 3.19

	I	II	III	IV	Supply
Initial Inventory	8	16	24	32	20
I	12	20	28	36	20
	15	23	31	39	40
II	∞	13	21	29	20
		15	23	31	40
III			15	23	20
			18	26	40
IV				16	20
				20	40
Demand	70	40	60	90	

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The holding cost is Rs. 8 per period. Therefore for the second, period it will be Rs. 16 (8+8), for third period it will be Rs. 24 (8+8+8) and for the fourth period it will be Rs 32.

In a similar manner it is calculate for subsequent periods.

Infinity symbol indicates that product produced during a period is sold during that period or subsequent periods and not in previous periods. i.e. there is no back order.

Solving the above, using Vogel's approximation method

Table 3.20

Initial feasible solution:

$$\begin{aligned} \text{Transportation cost} &= (20 \times 8) + (12 \times 20) + (30 \times 15) + (23 \times 10) + (13 \times 20) + (10 \times 15) + \\ & (23 \times 30) + (15 \times 20) + (18 \times 10) + (26 \times 30) + (16 \times 20) + (40 \times 20) \\ &= \text{Rs. 4560} \end{aligned}$$

Optimality Test – Modi Method

Conditions:

- Individual allocated cells should be equal to $m+n-1$
 - m – number of rows
 - n – number of columns

- Test for optimality on initial feasible solutions
- Write the matrix of the cost of allotted cells
- Determine a set of $m+n$ numbers

$$U_i = 1, 2, \dots, m$$

$$V_j = 1, 2, \dots, n$$

$$C_{rs} = u_r + v_s, \text{ r- supply, s- demand}$$

Table 3.21

	I	II	III	IV	U_i
Initial Inventory	8				$U_1 = 0$
I	12				$U_2 = 4$
	15	23			$U_3 = 7$
II		13			$U_4 = -3$
		15			$U_5 = -1$
III			15		$U_6 = -9$
			18	26	$U_7 = -6$
IV				16	$U_8 = -16$
			20	$U_9 = -12$	
V_j	$V_1 = 8$	$V_2 = 16$	$V_3 = 24$	$V_4 = 32$	

Cost (C_{ij}) of un-allotted cells

Table 3.22

	I	II	III	IV
Initial Inventory		16	24	32
I		20	28	36
			31	39
II	∞		21	29
				31
III				23
IV				

$U_i + V_j$ for un-allotted cells

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Table 3.23

	I	II	III	IV
Initial Inventory		16	24	32
I		20	28	36
			31	39
II	5		21	29
	7			31
III	-1	7		23
	-2	10		
IV	-8	0	8	
	-4	4	12	

$C_{ij} - (U_i + V_j)$ for un-allotted cells

Table 3.24

	I	II	III	IV
Initial Inventory		0	0	0
I		0	0	0
			0	0
II			0	0
				0
III				0
IV				

Since there are no negative values in the above table the initial feasible solution is the optimal solution i.e. The optimal transportation cost = $(20 \times 8) + (12 \times 20) + (30 \times 15) + (23 \times 10) + (13 \times 20) + (10 \times 15) + (23 \times 30) + (15 \times 20) + (18 \times 10) + (26 \times 30) + (16 \times 20) + (40 \times 20) = \text{Rs. } 4560$.

Review Questions:

1. When do you go for the aggregate planning?
2. Discuss the optimal method when the cost behaves linearly?
3. Discuss the optimal methods when the cost behaves non linearly?

3.5 PRODUCT DESIGN AND DEVELOPMENT

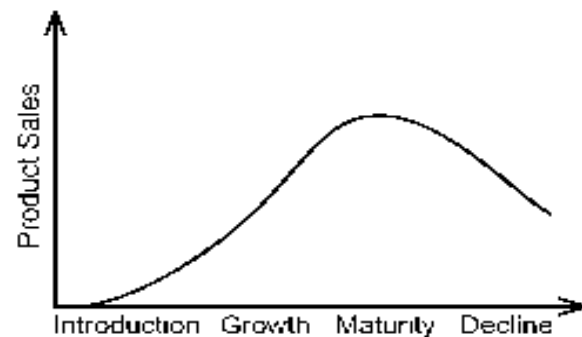
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The Activity namely the new product design or development in the existing product arises because of an opportunity available to tap the untapped market or a thing required to solve the problem. Like medicine to cure the AIDS or Cancer, these are opportunities to solve the problem. These kind of opportunity problem leads the organization to manufacture new product. Sometimes the demand for the existing product declining. The organization thinks of reviving the product by adding some improvement or the features in the existing product. Both the functions come under the process of product design and development.

3.5.1 Product life cycle

Understanding in which phase of the product life cycle, the product is there is the basis for the any product design and development activity. As you know any product has many brands, example, if you consider refer generator. You have Samsung, brands. Each brand has the demand pattern the summation of the entire brand's demand pattern provides information in which phase the product is,

Figure 3.15 - The Pattern of PLC



Introduction

In this phase there is a more risk involved there is possibility that the product is not accepted by the customers. This results in early exit of the product. This is all about the acceptability of the product.

In this phase the competition will be less if the product in the introduction phase, you should not think about going for heavy investment because of more chance for infant mortality of the product.

Growth

In this phase the people know more about the product that increases the potentiality of the demand. The competition gradually picks up here you should

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concentrate more on the attributes like quality, performance, delivery time, serviceability that helps the organization to establish the product as a leader among the players. At present in Indian cell phone is in the growth stage of PLC. Comparatively the profit the maturity stage will be high.

Maturity Stage

In this phase more competitors will be there and here all well established facilities were available and everyone is enjoy is the economy scale. But profit margins of the competitor are less. Because the facilities may be in reality at the end of their life cycle. Because markets are matured, organization finds it difficult to capture a small increase in market share. Packed mass consumption goods, soap are for examples which are in the maturity state of the PLC.

Decline

After maturity phase, the product enters into the declining phase. The reasons may be attributed to people would have found another alternative for the product, usually for the most of the time the business cycle and product cycle go together. In this case, if the economy is in the declining stage then there is a chance that product may enter into the declining stage. In such a case the organization has to make all effort to revive the product by adding some features in the product or family declining stage early then this becomes big problem for the organization because you can not utilize facility available. This problem is made in the case of mass production industry. This problem is severe if the industry is of the mass production type because the less demand the investment made in technology becomes turtle. At present the black and white TV is in the declining phase of PLC.

Because of Organization and lot of development in the field of electronic goods the product life cycle is so short may be three or four gems. The organization should be more vigilant in introducing more number of products within short span of time.

With this understanding of product life cycle curve, another activity inter turned with the use product life cycle namely the new product development process in this next section.

3.5.2 New Product development process

In the last section you have studied about the product life cycle. Suppose the produce is in the declining stage of life cycle course, if you allow the situation to continue the demand for the product decline and the organizational resources are under utilized. The cost of the product increases and your market share declines at faster rate and you may have to close down the plant soon.

But as soon as the demand for the product starts declining, the organization has to face different problems like-

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1. Under utilization of resources.
2. Cost of the product increase.
3. Price of your product increases.
4. More inventory.
5. Overhead burden etc.

These problems are converted into an opportunity in terms of developing an existing product by adding some features according to the requirement of the customers or you can go for introducing a new product which could use the available facilities. So the starting point for the new product development process is the concept generation.

3.5.2.1 Concept Generation

To solve the problem or utilize the opportunity available the idea may come from different sources, the sources may be-

1. The basic research in the field of physics, chemistry and biology etc.
2. Technology innovations.
3. Ideas from the staff in R & D Production, quality control etc.
4. Ideas from competitors consumers.

The above ideas should be in line with the first organization's mission statement, or it should not disturb much the on going marketing or the idea should utilize the existing state of inventory.

3.5.2.2 Concept testing

A preliminary analysis different project ideas are screened using scoring models ATR techniques etc.

In the preliminary analysis different product ideas are screened using the techniques

Table 3.25

FACTORS	SCORE				
	1	2	3	4	5
Product superiority, quality, uniqueness					
Overall project firm / resource compatibility					
Market need growth and size					
Newness to the firm					
Technology resource compatibility					
Market competitiveness					
Product score					

Product concepts

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ATR MODEL (Awareness – Trial – Repeat) model:

The basic formula is given below:

Profits = Buying units x percent aware x percent trial x percent availability x percent repeat x annual units bought (revenue per unit – costs per unit).

For e.g: Assume that an organization is developing a new cleaning powder for washing sports can

1. Number of owners: 1,00,000
2. Percentage who will become aware of the power: 30 percent
3. Percentage of those aware who will buy it: 10 percent
4. Percentage of the retail outlet store the powder : 30 percent
5. Percentage of the triers who like the product and but more : 40 percent

Number of pockets a typical user will but in a year: 10 pocket

Revenue the unit Rs.1000

Cost Per unit Rs.700

Profit according to ATR model

$$= 1,00,000 \times .3 \times .10 \times .3 \times .4 \times 10m (1000 - 700)$$

$$= 10,800$$

like ATR, scoring model and the best ideas are chosen for

The outcome of the screening is the product definition or the benefits the new item is to yield.

3.5.2.3 Technical Development

After concept testing is over, 'you should see that whether you have technical capacity and resources appropriate to produce or provide the product / service.

In technical development, the output is the prototype of the product. In general, in any product design & development activity the product specifications for the product are to be arrived through market survey, for example, the product specification for a car represent the color, the size of the car, fuel efficiency power of the engine. Product specification usually collected from the customer. The customer may not be knowing the technical details about the product, so his/her requirement is obtained through the word of the mouth.

Then the product specifications are converted into engineering specification. To start with, first what kind of material is to be purchased when you purchase the material, it should be economical and the purchased material do not hamper the performance, reliability of the final product were lot of value analysis and value engineering application helps to choose the right material without affecting the function for which it is indented for economically. Here you should see the product where it is

positioned. For example: if you are manufacturing car for luxury purpose then you may prefer the leather seat rather than vinyl seat. So, when you design a product. To whom the product is targeted for according the material selection and supplier selection take place. When you select the material you should see the process or the resources available because selecting the high quality material may demand high processing requirement that results in high production cost which allows your product to become less competitive.

It is mentioned in the process paragraph now we can develop some time on the product specification, tolerance and allowances.

Allowable deviation from the targeted value is the tolerance, example, shaft diameter designed by the designer to satisfy the final requirement of product aims a target value of 2 cm but you can not produce 2 cm diameter consistently. So because of in built nature of the processing system, there exists variety in the processing. For that you need data like process capability input to fix the tolerance limit etc. for example: the existing process capability of a productive system is to produce 2 ± 0.05 cm, then it is the design demands for more than 2.05 and less 1.95 cms (10) 2 ± 0.10 . This is the specification required then there is no problem but if you design a shaft of 2 ± 0.03 cm, then the productive system may produce more back quality product. So in the engineering design one should have the input like process capability to fix tolerance engineering specification.

3.5.2.4 Standardization and Inter-changeability

When you design a product you should not design in such a manner that all the parts sustainability are of your own design because after your product has been purchased by the customer put into use, if there is a problem in the product, it is difficult to service the product because of the components are of you own design and availability of the components become problem. Even there is an availability you need to have more components that result in more inventory cost at the same time the customers also put into lot of trouble in terms of idle time of the product. The problem is a complex one if your product is a capital equipment product. In this case your product design consists of components subassembly of standard product available.

In your product suppose if you have came to use standard components like tin and steel sheets, nuts, bolts, washers transistors, capacitors etc. You try to use the same. Instead you need not design on your own for those components you design should be in such manner that the above mentioned standard products could be transit may use. Usage of the standardized components or products lower the cost of production reduces the inventory cost. It case the maintenance and repair that result in less cost. It also helps in more easier and effective quality control.

The concept of standardization spread to the service industry also, because nowadays for fast food restaurant the standard mix is always speedy according to the

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type of order they mix. Different mix and service requires food at lesser time. Even in the house you need not prepare all the cooking ingredients as it was done in the olden day. Nowadays standard ingredients are available and only mix with less time you can get what you want.

Here we are not saying that all the time you should use the standard components if your product requires. If possible any new design of the components reduces the cost of the product, and then instead of going for standard component you can use your newly designed components. This serves the purpose of continuing innovation and design of the organization.

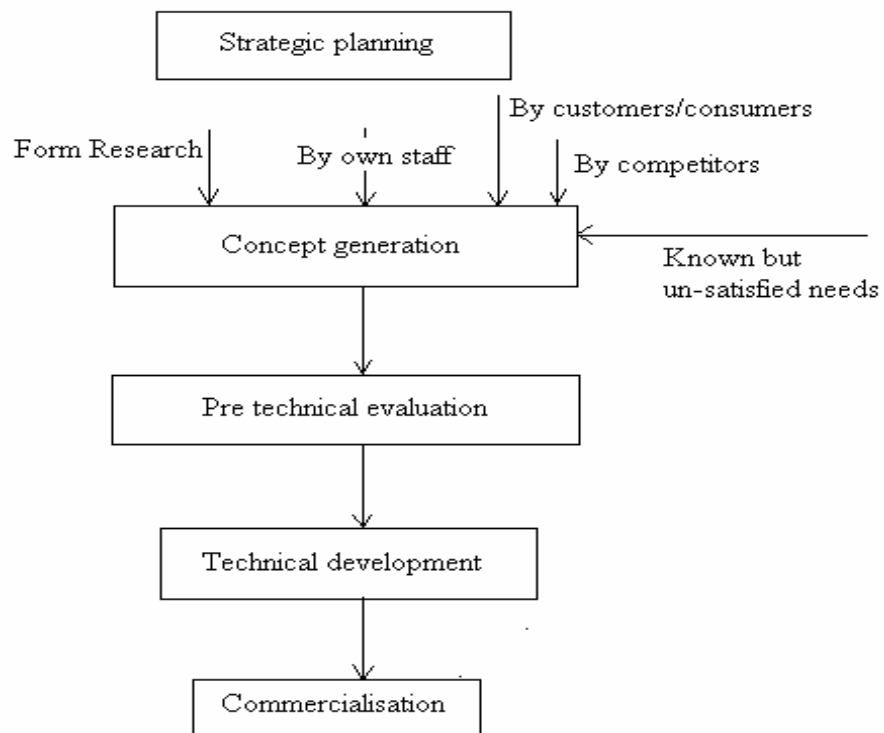
3.5.2.5 Commercialization

In commercialization you must decide to whom this item will be targeted, what will be the value of the product and how do we get the value into it, how it will be positioned relative will be the product's brand, building support around the organization for the marketing actions to follow and overcoming problems that arise in the field and which might cause the firm to fail to achieve the necessary awareness, that and repeat use which are discussed in the concept testing phase.

Once market trial is over, then the products are produced according to the plan. This involves detailed production plan, quality plan, and story and distribution strategy. All the actions are carried out by keeping in the company's strategy objectives and goals.

The above explained new product development process is shown in a flow chart.

Figure 3.16 : Commercialization



Review Question:

1. Highlight the stages of Product Life Cycle.
2. Why products fall into maturity stage?
3. How would you expand the life time of saturated product?

3.6 EXPERT SYSTEM IN PRODUCT DEVELOPMENT

Strategy planning plays a vital role in defining where a corporation wants to be in the near and long terms, how they will get there, and how they will monitor their progress in getting there. These are derivations of the Total Manufacturing Assurance three **C's: Create, Control, and Critique**.

The same applies to the product development test program. The test program strategy must reflect the overall corporate business strategy.

Combining strategic planning with expert system technology enables the engineer or manager to quickly define the “best” or “optimal” test program for a given product development effort. The expert system makes this happen by using “expert” knowledge derived from its knowledge base of engineering, marketing, and customer requirements.

To make money and enjoy long term survival, a company must be productive and efficient. That statement is very simple and acceptable in light of the evermore competitive business environments being experienced. It thus is imperative to eliminate, or minimize, company bureaucracy. Bureaucracy causes aggravation. It directly correlates to unnecessary company overhead. It is impractical to think that overhead can ever be completely eliminated. It can be optimized and in this case that means minimized. There is still overhead, but it is value-added overhead. To make this happen three things must be readily available in the planning process:

1. Expert knowledge about testing,
2. Expert knowledge about customer market requirements and
3. A mechanism to get all this expert knowledge into one room to quickly make good decision(s).

The expert system facilitates “Optimized strategic test program planning”. An engineer or manager defines the “best” or “optimal” test program for a given product development effort. The expert system forces this by using “expert” knowledge derived from its knowledge base of engineering, marketing, and customer requirements.

3.6.1 Expert System Development

Product reliability, safety, and quality requirements are a key element of a strategic business plan since they reflect what the customer needs. These product design performance parameters in turn provide a basis for defining the test program necessary as part of the overall product assurance strategy. The product assurance strategic plan balances many interrelated variables and factors.

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These include:

1. Establishing quantitative performance goals (LWBF, MTTR, service-life, defect level, etc.).
2. Implementing a product development management control and tracking activity to ensure timely outputs consistent with major design and program milestones.
3. Performing and implementing analyses and quality checks, audits, and controls to ensure that all test, inspection, and screen data are complete.
4. Performing a fully coordinated product development program, which emphasizes failure analysis and corrective action, and provides growth/verification of specified design requirements.
5. Exposing design deficiencies and initiating corrective action in a timely manner.
6. Maximizing achieved availability to minimize overall life cycle costs and enhance the probability of commercial success.
7. Identifying, evaluating and eliminating design hazards and risks.
8. Applying historical data and lessons learned into the design process.
9. Minimizing unforeseen impacts on overall project cost and schedule.

It is desirable to assure that the above factors (and others) are adequately considered during a product development test program. It is through the strategic planning that it is possible to initiate the “best” program. That is, one that ensures critical project decisions involving significant investment of resources are keyed to the achievement of specific reliability, safety, and quality requirements, as well as other performance requirements. Obviously, specific test program objectives are dependent on the technology under consideration, the nature of the product, the customer, and other factors as appropriate. But merely defining a test program strategy orients product development, and ultimately manufacture, toward a practical, serviceable, and affordable commercial product.

The expert system output is a baseline test program structure which includes characteristic parameter values and ranges for each of the basic test categories. This strategically defined test program is then tailored, as necessary, to meet the specific product development project’s needs while adhering to cost and time constraints. Regardless of which baseline structure is selected, the basic concept of a strategically well-planned, logically structured and phased test program, where each subsequent test is designed to reflect the knowledge gained during the proceeding test and design effort, applies. The expert system provides assurance that the cornerstone (i.e., test program) of a successful product development project is put in place.

3.6.2 Putting System Together

The very first task in the expert system development process is to identify the domain, the domain expert and the knowledge expert. The domain of the system must

be properly scoped out, well defined, sufficiently focused, and capable of solution by the use of expertise. A domain expert, or experts, must be found; either a person who can solve the task, a collection of well documented case studies, or perhaps a good textbook. A knowledge engineer, or someone willing to learn to become one, must be appointed to the task. Finally, the appropriate development platform must be acquired which can be an expert system shell with some sort of development environment. The physical expert system is then developed via the following steps.

Step 1—Structural Design

Step 2—Knowledge Acquisition

Step 3—Coding

Step 4—Validation

Step 5—Growth

The result is a working expert system

Review Questions:

1. Expand 3C's.
2. Discuss the steps through which the Physical Expert System is developed.

3.7 COMPUTER AIDED DESIGN AND DRAWING

3.7.1 Introduction

When we think of Computer Aided Design and Drafting (CADD), certain questions arise that we never think of while working on the drawing board. We do not use the essential drawing board tools: paper, pencil, T-square, compass, eraser or scale, yet still have to design or make a drawing. When even one of these tools is missing we know how aggravating it can be. With CADD we don't need even one of them!

CADD is an electronic tool that enables you to make quick and accurate drawings with the use of a computer. Unlike the traditional methods of making drawings on a drawing board, with CADD you can sit back in an easy chair and create wonderful drawings just by clicking the buttons of a keyboard. Moreover, drawings created with CADD have a number of advantages over drawings created on a drawing board. CADD drawings are neat, clean and highly presentable. Electronic drawings can be modified quite easily and can be presented in a variety of formats.

A decade ago, CADD was used only for specific engineering applications that required high precision. Due to CADD's high price, only a few professionals could afford it. In recent years, however, computer prices have decreased significantly and more and more professionals are taking advantage of CADD.

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There are hundreds of CADD programs available in the CADD industry today. Some are intended for general drawing work while others are focused on specific engineering applications. There are programs that enable you to do 2D drawings, 3D drawings, renderings, shadings, engineering calculations, space planning, structural design, piping layouts, plant design, project management, etc. There is a CADD program for virtually every engineering discipline you can think of.

CADD is primarily intended for single-line drafting. It has very limited capabilities to create artistic impressions. However, CADD's 3D and rendering features are fascinating. You can create a 3D model of an object and view it from any angle. With proper shading and rendering, it can be made to look picture perfect!

3.7.2 What to Expect from CADD?

You can do amazing things with CADD that you never thought possible while creating drawings with a pen or pencil. The following are some of the important capabilities that make CADD a powerful tool:

- o Presentations
- o Flexibility in editing
- o Units & accuracy levels
- o Storage and access for drawings
- o Sharing CADD drawings
- o Project reporting
- o Engineering analysis
- o Computer Aided Manufacturing (CAM)
- o Design
- o Add-on programs

Presentations

You can create fine drawings with hundreds of colors, line types, hatch patterns, presentation symbols, text styles, etc. Even if you don't like something about your presentation after you have finished it, you can instantly change it. It takes only a few simple steps to change the text style, color or line type and you can print a fresh copy of the drawing every time. This kind of luxury is available only when working with CADD.

There are a number of ready-made presentation symbols and hatch patterns available in CADD that can be used to enhance the look of drawings. For example, a site planner can instantly add tree symbols, shrubs, pathways, human figures, and other landscape elements to create a site plan. Similarly, an architect can use ready-made symbols of doors, windows, furniture, etc., to make a presentation.

In addition to preparing impressive presentations on paper, you can use CADD to make on-screen presentations. You can plug your computer into a projector and present your ideas on-screen. Advanced CADD programs allow you to create animated

images as well. You can illustrate how a building would appear while walking through it, or how a machine assembly will operate when different machine parts move.

Flexibility in Editing

CADD provides the flexibility to make quick alterations to drawings. You can erase any portion of a drawing with pinpoint accuracy. It takes only seconds to do a job that could take hours on a drawing board. In many cases, you do not even have to erase to make the change. You can rearrange the existing components of the drawing to fit the new shape. This enables you to analyze design options with minimal effort.

The following are some of the editing capabilities of CADD:

- o Move or copy drawing elements.
- o Enlarge or reduce parts of a drawing.
- o Add one drawing to another.
- o Stretch a drawing to fit new dimensions.
- o Make multiple copies of a drawing element.
- o Change the size, style and fonts of text.
- o Change units of measure of dimensions.

Units & Accuracy Levels

CADD allows you work with great accuracy. If you need to create highly accurate geometrical shapes, CADD is the answer. It can help avoid time-consuming mathematical calculations.

You can work with different units of measure, such as architectural units, engineering units, scientific units and surveyor's units. These units can be represented in various formats commonly used by professionals.

Example 3.4: When working with engineering units, you can specify whether all the dimensions should be represented in inches, feet-inches, centimeters, or meters. Similarly, you can choose angular units of measurement such as decimal degrees, minutes, seconds or radians.

You can set an extremely high accuracy for the units of measurement. You can work with as high precision as $1/1000^{\text{th}}$ of an inch! However, such accuracy is seldom required; you will often need to set it to a lesser accuracy to avoid unnecessary fractions.

In general, when you need to work on a large scale drawing such as a plan of a township, you may want to set a lesser degree of accuracy, say 1'-0". The computer will round off all the measurements to the next foot and you won't see any fractions less than a foot. When you need to work on a minute detail, you can set a higher degree of accuracy such as $1/8^{\text{th}}$ or $1/64^{\text{th}}$ of an inch.

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Storage and Access of Drawings

It is quick and convenient to organize for a CADD drawing in the computer. You can have thousands of drawings on a computer's hard disk and can open any one of them within seconds.

A computer's electronic filing system has the following advantages over the traditional filing system:

- o It enables you to create a highly organized environment
- o It contributes to large savings in working space
- o An electronic drawing never gets old and faded. Any time you need a drawing, you can print a new copy from disks.

Sharing CADD Drawings

The electronic drawings can be shared by a number of users, allowing them to coordinate their tasks and work as a team. This is accomplished by connecting different computers via a network.

Example 3.5: In a building project, different professionals such as architects, engineers and construction managers can use the same electronic drawings to coordinate building services. If a change is made to the drawings, this information becomes available to all the team members instantly.

With the use of modems and the Internet, it has become far easier to share information. Professionals located in different cities can instantly send electronic drawings via telephone lines.

You can publish your drawings on the Internet for anyone to see. Most CADD programs include special functions that allow you to export drawings in a format that can be viewed on the Internet.

Project Reporting

The computer can be used to prepare project reports such as records of areas, quantities and cost estimates. Using the database capabilities of CADD, you can link specific non-graphic information (such as text or value) with the graphic elements of the drawing. The non-graphic information is stored in a database and can be used to prepare reports.

Example 3.6: An architect can attach text attributes associated with the symbols of doors and windows in a drawing. The attributes can describe the size of the door, material, hardware, cost, etc. Later on the computer can automatically prepare a door schedule listing all the doors and windows in the drawing!

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The non-graphic information is directly linked with the graphics on the screen. When a change is made to the drawing, the values in the reports are updated automatically. This provides a useful means to manage large projects from design through project completion.

There is a special category of software called Computer Aided Facility Management (CAFM) designed for project management. These programs can import information from CADD drawings and allow you to add attributes to drawing elements to build a database. The database can be used to prepare project reports in a number of formats.

Engineering Analysis

CADD drawings can be used to perform specific engineering analysis. There is a separate category of programs called Computer Aided Engineering (CAE) that can use CADD drawings for engineering analysis.

Example 3.7: A structural engineer can use a CAE program to test the design of structural components in different conditions. The engineer can instantly analyze the impact on structural members when a different load is applied to the structure or the spacing between the members is changed. Similarly, there are programs for mechanical engineers to test machine assemblies. The mechanical engineer can create a prototype electronic model and test it without building a physical model.

The advanced engineering programs even provide the ability to link calculations with the geometry on the screen. This capability is known as “parametric design” that allows the computer to automatically update the graphics when the associated calculations are changed and vice versa.

Computer Aided Manufacturing (CAM)

CADD extends its power to yet another branch of engineering called Computer Aided Manufacturing (CAM). CAM is a common method of manufacturing used by large corporations. CADD and manufacturing programs are often integrated into one system called CAD-CAM. These systems import CADD drawings into CAM programs to automate the manufacturing process.

Example 3.8: An engineer can draw a machine part using CADD. The CADD drawing is brought into a computer aided engineering (CAE) program for engineering analysis. When the design is finalized, the drawing is brought into a CAD-CAM system that uses numerical data from the CADD drawing for actual manufacturing.

Design

CADD provides a convenient means to create designs for almost every engineering discipline. It can be used for architectural design, landscape design, interior design, civil and surveying, mechanical design, electrical engineering, plant design,

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industrial design, duct design, electronic circuit design, plumbing design, textile design and product design.

CADD's drafting capabilities provide ample means to create a design scheme. You can create designs with great accuracy and have the flexibility to easily edit them. This allows you to quickly prepare design alternatives.

In addition to the drafting capabilities of CADD, there are special programs that can analyze designs or even create new ones. These programs use artificial intelligence to "think" and make design decisions.

The design capabilities of CADD are available only in advanced CADD programs. There are only a few such programs available. Design programs are usually not generic. They often need to be custom-written to accomplish a specific task. See Chapter 9 "Maximizing CADD" for discussion on design programs.

Add-on Programs

There are a number of separate programs available that can enhance the power of CADD. The add-on programs work as an extension of CADD to accomplish specific tasks. Today, there are hundreds of add-on programs available for popular CADD programs.

An architectural add-on program can allow you to instantly draw symbols of doors, windows, kitchens, bathrooms, staircases, etc. Shading and rendering program can be used to enhance the look of 3D images. A plumbing design program includes special functions to draw pipes, drains and plumbing joints. A civil engineering program includes special features to work with contours and land development; the list goes on and on.

Most manufacturers market CADD programs in separate modules. They sell a basic drafting module for a certain price with the options to add on other modules. There are a number of add-on programs available from independent vendors as well.

3.7.3 A Look at the CADD Industry

There are hundreds of CADD programs available in the CADD industry today. Most of them are simply drafting programs, while some offer certain engineering analysis, design or database capabilities. Some programs are more elaborate than others. You can purchase a CADD program with just the basic drawing capabilities for as little as \$200. These are called low-end programs and are commonly used for general drawing work.

Another category of software is mid-range. This category offers advanced drafting techniques such as layers, 3D, basic database capabilities, advanced dimensioning and many automated drawing features. Architecture and engineering design

firms commonly use mid-range software. About 80% of all the CADD programs fall into this category and there is immense competition in this market. Their prices vary significantly.

There are a few advanced CADD programs available, which are commonly used by large corporations for manufacturing. These programs include integrated features such as solid modeling, engineering analysis, design, database and project management. These are called high-end programs. Most of the time they are customized to meet the specific requirements of the corporation. These programs are priced quite high.

Summary

You would have now understood the differences between the 3 levels of management and usage of CAD and Expert System in the strategic level activity, namely product design and development. In this unit the exponential weighted average method, for all the components of Time series analysis are discussed. In addition you are exposed to qualitative technique like Market survey, Expert opinion, Delphi technique. In this section, the different methods of aggregate planning are elucidated for your understanding.

Review Questions:

1. What is CADD?
2. List the major capabilities of CADD.

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NOTES**UNIT IV
SCHEDULING AND
PROJECT MANAGEMENT METHODS****4.1 Introduction****4.2 Learning Objective****4.3 Scheduling**

4.3.1 Resources Allocation

4.4 Sequencing4.4.1 Sequencing “ n ” jobs / single machine problem4.4.2 Sequencing “ n ” jobs / two machines problem - Johnson’s Algorithm

4.4.3 Extension of Johnson’s Rule

4.4.4 M machines and N jobs:**4.5 Project Scheduling**

4.5.1 Planning

4.5.2 Project network scheduling

4.6 Resource scheduling

UNIT - 4

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SCHEDULING AND PROJECT MANAGEMENT METHODS

4.1 INTRODUCTION

This unit deals with the operations levels of management namely scheduling activity. The job shop scheduling and project scheduling are also discussed in detail.

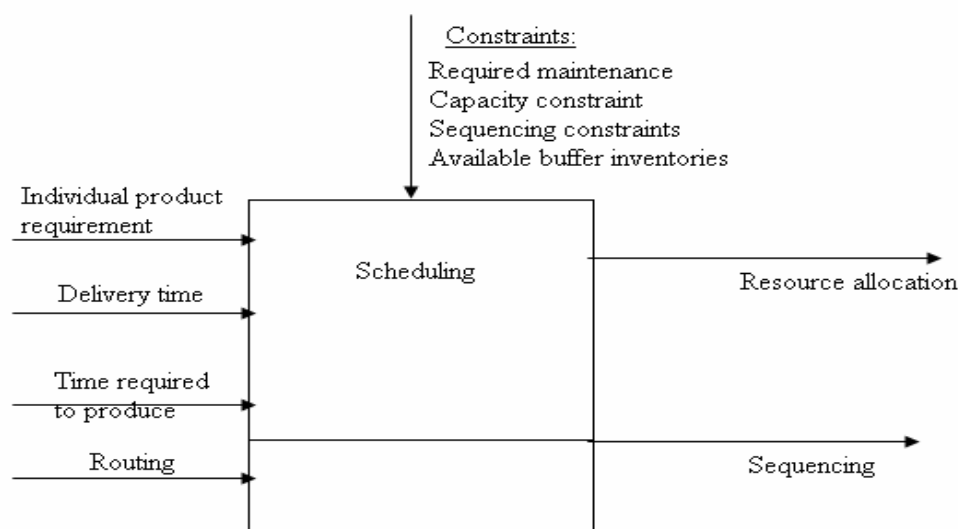
4.2 LEARNING OBEJECTIVE

1. To understand the phases of scheduling namely resource allocation and scheduling.
2. To comprehend the resources allocation techniques.
3. To know the various sequencing technique to different job shop types.
4. To understand the project management techniques and their application.

4.3 SCHEDULING

This is the lower level activity in the operation planning and control. The output of aggregate planning goes as input to the scheduling activity. The aggregate demand is broken down into individual product requirement.

Figure 4.1 - Scheduling



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Based on the information mentioned in the figure, resource allocation and sequencing activities are carried out.

Scheduling is considered to be an important activity because if this activity is not carried out properly, there is more waiting time that results in delayed delivery time which in turn affects the customer satisfaction. The through put time increases because of the more waiting time. Thus the longest through put time may be due to the more waiting time of the product for the operation because the workcenter where the process is demanded is engaged by the other product. The above situation paves the way for more work in progress (WIP) inventory. Thus the scheduling activities determine many important objectives of the organization. So, this is the activity which is getting lot of importance nowadays.

4.3.1 Resources Allocation

Based on the process requirement and the available resources, in the first phase of scheduling, resources are allocated for different jobs based on the availability and time requirement when there is no splitting of the orders. This process may be carried out using the Assignment method.

Assignment Model

Assignment model is considered to be one of the resource allocation techniques. If you want to apply assignment model for resource allocation, the number of process centers should be equal to the number of jobs to be assigned. This problem could be treated as a maximization or minimization problem, based on the type of entry in the cell. If the entry in the cell is profit etc., then it should be considered as a maximization problem. If the entry is processing time etc., then the problem is considered as a minimization problem. In this model, once a job is assigned to a work center, then the job and the assigned work center should not be considered for further assignment. This kind of problem can be solved by a well known method called Hungarian method. You would have studied Hungarian model in Operation research. Consider the following resource allocation problem.

4.4 SEQUENCING

4.4.4.1 Sequencing “n” jobs / single machine problem

Normally, the total number of jobs exceeds the number of work centers. Therefore, **Priority Rules** should be developing to determine the sequencing of machining operations. The Priority Rules come into picture when many jobs or operations are chasing for the same capacity.

Factors to be considered in setting priorities for jobs include:

- a. Customer satisfaction.
- b. Order urgency
- c. Order profitability

d. Impact on capacity utilization

e. Shop performance

The most popular priority rules are

- First come first served (FCFS)
- Shortest processing time (SPT)
- Earliest due date (EDD)
- Least slack (LS)

An example for working of these rules.

Example 4.1

The following table is the required time and due time in days attached to Five jobs waiting in queue to share a same work center.

Table 4.1

Job	Required Time (Days)	Due Date (Days hence)
A	2	4
B	5	5
C	1	3
D	4	6
E	6	7

Solution

- **First come first served rule (FCFS)**

According to this principle, the job which comes first to the workcenter will occupy the machine first.

Table 4.2

Job Time	Required (Days)	Due Date (Days hence)	Processing Period (Start+Req.)	Completion date	Days Late
A	2	4	0+2	2	0
B	5	5	2+5	7	2
C	1	3	7+1	8	5
D	4	6	8+4	12	6
E	6	7	12+6	18	11
Sum	18			47	24

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Average throughput time = $47/5 = 9.4$ days

Average number jobs in the work center = $47/18 = 2.611$ jobs

Average number of days late = $24/5 = 4.8$ days

- **Shortest processing time (SPT)**

According to this principle, the job which is having shortest processing time will occupy the machine first.

Table 4.3

Job	Required Time (Days)	Due Date (Days hence)	Processing Period (Start+Req.)	Completion date	Days Late
C	1	3	0+1	1	0
A	2	4	1+2	3	0
D	4	6	3+4	7	1
B	5	5	7+5	12	7
E	6	7	12+6	18	11
Sum	18			41	19

Average throughput time = $41/5 = 8.2$ days

Average number jobs in the work center = $41/18 = 2.277$ jobs

Average number of days late = $19/5 = 3.8$ days

- **Earliest due date (EDD)**

According to this principle the job with earliest due date will occupy the machine first regardless of job arrival or processing time.

Table 4.4

Job	Required Time (Days)	Due Date (Days hence)	Processing Period (Start+Req.)	Completion date	Days Late
C	1	3	0+1	1	0
A	2	4	1+2	3	0
B	5	5	3+5	8	3
D	4	6	8+4	12	6
E	6	7	12+6	18	11
Sum	18			42	20

Average throughput time = $42/5 = 8.4$ days

Average number jobs in the work center = $42/18 = 2.333$ jobs

Average number of days late = $20/5 = 4$ days

- **Least slack (LS)**

Least slack is the time difference between time remaining and work time required. According to this principle, the job with least slack time will occupy the machine first.

Slack = time remaining until due date - process time remaining

Table 4.5

Job	Required Time (Days)	Due Date (Days hence)	Slack Time (Days)	Processing Period (Start+Req.)	Completion date	Days Late
B	5	5	0	0+5	5	0
E	6	7	1	5+6	11	4
C	1	3	2	11+1	12	9
A	2	4	2	12+2	14	10
D	4	6	2	14+4	18	12
Sum	18				60	35

Average throughput time = $60/5 = 12$ days

Average number jobs in the work center = $60/18 = 3.333$ jobs

Average number of days late = $35/5 = 7$ days

Summary Table:

Scheduling with Priority Rules

Table 4.6

Performance Dimension	FCFS	SPT	EDD	LS
Average throughput time	9.4	8.2	8.4	12
Average number jobs in the work center	2.611	2.277	2.333	3.333
Average number of days late	4.8	3.8	4	7

Research has shown that Shortest processing time (SPT) has the good priority rule to follow for job scheduling. This rule results in the shortest manufacturing lead time, therefore, lowest work-in process inventory. It will often minimize the average throughput time so minimum number jobs in the system. The queue position changes with the arrival of new jobs, this makes to follow the Shortest processing time (SPT) in real time scenario. First come first served (FCFS) becomes the only practical solution to the scheduling. Earliest due date (EDD) might prefer when jobs must meet up with other outputs later in an assembly.

Critical ratio

Critical ratio is one of the priority rule which helps the scheduler to know about which job should be given priority for the production in a job shop. The informations required for using the technique are:

1. The number of jobs to be processed.

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2. The production calendar.
3. The requirement date for the jobs.
4. The processing time remaining.

From the above information, you can calculate the critical ratio-

Critical ratio = (date required – today's date) / days needed to complete the job.

This ratio tells you about the urgency attached with the each job. If the critical ratio is a dimensionless index. If the index = 1, that means the job is on schedule, if the index is less than 1 that means that the job is behind the schedule. It needs much attention and priority should be given for the job. If the index is greater than 1 then the job is ahead of the schedule.

Problem

1. Suppose there are 6 jobs. Today is the 40th day on production calendar other information are given in the table. Provide the sequence in which the jobs are to be processed using critical ratio technique.

Table 4.7

Job	Days required	Processing time remaining (days)
1	50	3
2	48	4
3	45	3
4	43	2
5	42	4
6	41	3

Solution

Table 4.8

Job	Critical ratio
1	$(50-40)/3 = 3.3$
2	$(48-40)/3 = 2.0$
3	$(45-40)/3 = 1.6$
4	$(43-40)/3 = 1.0$
5	$(42-40)/3 = 0.5$
6	$(41-40)/3 = 0.3$

From the above problem, you can conclude that jobs 1,2 and 3 are ahead of schedules. Job 4 is on schedule. But job 5 and 6 are behind the schedules. So job 6 should be given first priority than job 5 should be given next priority.

4.4.2 Sequencing “n” jobs / two machines problem - Johnson’s Algorithm

The two machine flow shop problem with the objective of minimizing makespan is also known as Johnson’s problem. The results originally obtained by Johnson are now standard fundamentals in the theory of scheduling. In the formulation of this problem, job j is characterized by processing time t_{j1} , required on machine 1, and t_{j2} , required on machine 2 after the operation on machine 1 is complete. An optimal sequence can be characterized by the following rule for ordering pairs of jobs.

Johnson’s Rule:

Job i proceeds job j in an optimal sequence if

$$\min(t_{i1}, t_{j2}) \leq \min(t_{j1}, t_{i2})$$

In practice, an optimal sequence is directly constructed with an adaptation of this result. The positions in sequence are filled by a one-pass mechanism that identifies, at each stage, a job that should fill either the first or last available position.

Algorithm:

- STEP 1 : Find $\min(t_{i1}, t_{i2})$.
- STEP 2a: If the minimum processing time requires machine 1, place the associated job in the first available position in sequence. Go to step 3.
- STEP 2b : If the minimum processing time requires machine 2, place the associated job in the last available position in sequence. Go to step 3.
- STEP 3 : Remove the assigned job from consideration and return to step 1 until all positions in sequence are filled. (Ties may be broken arbitrarily.)

To illustrate the algorithm, consider the five – job problem shown in table as follows. The accompanying work-sheet shows how an optimal sequence is constructed in five stages using the Algorithm. At each stage, the minimum processing time among unscheduled jobs must be identified. Then step 2 assigns one or more positions in the sequence, and the process is repeated.

Problem statement:

The following table shows the five jobs to be allocated in two machines and their respective processing time in the two machines.

Table 4.9

Job j	1	2	3	4	5
$T_{j1}(\text{min})$	3	5	1	6	7
$T_{j2}(\text{min})$	6	2	2	6	5

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Solution:

Table 4.10

Stages	Unscheduled jobs	Minimum t_{jk}	Assignment	Partial schedule
1	1,2,3,4,5	T_{31}	3=[1]	3 x x x x
2	1,2,4,5	T_{22}	2=[5]	3 x x x 2
3	1,4,5	T_{11}	1=[2]	3-1 x x 2
4	4,5	T_{52}	5=[4]	3-1 x 5-2
5	4	$T_{41} = T_{42}$	4=[3]	3-1-4-5-2

The sequence that emerges is 3-1-4-5-2.

4.4.3 Extension of Johnson's Rule

Johnson's Rule to Three machines:

Consider a three machines and n jobs problem.

Table 4.11

Job	1	2	3	.	.	i	.	n
Machine1	t11	t21	t31	.	.	ti1	.	tn1
Machine2	t12	t22	t32	.	.	ti2	.	tn2
Machine3	t13	t23	t33	.	.	ti3	.	tn3

Johnson rule can be applied to three machines when the problem exhibits 'Dominance'.

Dominance can be understood when a situation of n jobs with three machines and a processing order requirement of M1, M2, M3 follows for all the jobs, with the following condition holds good

Minimum of $ti1 \geq \text{Maximum of } ti2$

or

Minimum of $ti3 \geq \text{Maximum of } ti2$

Where tij is the operation time for job i in machine j .

If any one of the above conditions satisfied then we say the problem exhibited Dominance.

We will combine the operating times of machines as follows

$$t1 = ti1 + ti2$$

$$t2 = ti2 + ti3$$

t_1, t_2 are the new operating time of machine1 and machine2.

The optimal solution for the above problem is obtained through Johnson's rule.

Converting the three machine problem into a two machine problem.

Table 4.12

Job	1	2	3	.	.	i	.	n
Machine1	$t_{11}+t_{12}$	$t_{21}+t_{22}$	$t_{31}+t_{32}$	.	.	$t_{i1}+t_{i2}$	.	$t_{n1}+t_{n2}$
Machine2	$t_{12}+t_{13}$	$t_{22}+t_{23}$	$t_{32}+t_{33}$	.	.	$t_{i2}+t_{i3}$	.	$t_{n2}+t_{n3}$

Now apply Johnson's rule to machine-1 and machine-2 to obtain optimal sequence.

Practice problem:

Table 4.13

1. A company is faced with five tasks that have to be processed through three work centers. Assume work centers works continuously and that they are using Johnson's rule. Data appear below in minutes:

Task	A	B	C	D	E
Workstation 1	10	8	15	7	12
Workstation 2	6	4	3	2	5
Workstation 3	8	11	6	10	9

Johnson rule can be applied to three machines when the problem exhibits 'Dominance'.

So check for Dominance.

Minimum of $t_{i1} \geq \text{Maximum of } t_{i2}$

or

Minimum of $t_{i3} \geq \text{Maximum of } t_{i2}$

Minimum of $t_{i1} = 7$

Minimum of $t_{i3} = 6$

Maximum of $t_{i2} = 6$

The above conditions satisfied and the problem exhibited Dominance.

We will combine the operating times of machines as follows:

$$t_1 = t_{i1} + t_{i2}$$

$$t_2 = t_{i2} + t_{i3}$$

Converting a three machine problem into a two machine problem.

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Table 4.14

Task	A	B	C	D	E
Workstation 1	16	12	18	9	17
Workstation 2	14	15	9	12	14

By applying Johnson's rule the optimal sequence is as follows:

D - B - A - E - C (or) D - B - E - A - C

Finding of Make span is as follows :

Table 4.15

Task	Time	D	B	A	E	C
Workstation1	In	0	7	15	25	37
	Out	7	15	25	37	52
Workstation2	In	7	15	25	37	52
	Out	9	19	31	42	55
Workstation3	In	9	19	31	42	55
	Out	19	30	39	51	61
Idle Time of						
W/S 2		7	6	6	6	10
W/S 3		9	0	1	3	4
Total Idle time						35
						17

The Make span of the above optimal sequence is 61 minutes.

4.4.4 M machines and N jobs:

Johnson's algorithm and Multiple Machines

Johnson's method only works optimally for two machines. However, since it is optimal, and easy to compute. Johnson's rule can be tried to adopt it for M machines, ($M > 2$). All the methods developed for the m machines and n jobs are heuristic in nature. The heuristics methods are based on a logic based and thumb rules.

Which may not be an optimal solution, but a better solution will be provide.

For jobs scheduled in flow shop of more than three machines, no optimal solution except exhaust search has ever been proposed. **Campbell, Dudek and Smith** proposed a heuristic method named CDS algorithm to achieve a nearly minimum make span in the CDS method.

Assumptions:

1. Jobs are not preemptive.
2. Each job has **m tasks** to be executed in sequence on **m** .
3. Given a set of n independent jobs, each having m executed in the same sequence on m machines
(P_1, P_2, \dots, P_n), scheduling seeks the minimum completion time of the last job.

Algorithm:

1. Create $(m-1)$ stages.
2. Each stage should have 2 workstations.
3. Apply Johnson's rule for each pair of workstations created by certain conditions.
4. From all the $(m-1)$ sequences find out the make span of each sequence.
5. Choose the best among the $(m-1)$ sequences which yields low make span or flow time.

NOTE: We should be careful in determining the make span. The original processing time required by the job on m machines are to be taken into consideration in evaluating the make span but not the converted time for the workstations.

Let us consider a four machines and n jobs problem.

Table 4.16

Job	1	2	3	.	.	i	.	n
Machine1	t11	t21	t31	.	.	ti1	.	tn1
Machine2	t12	t22	t32	.	.	ti2	.	tn2
Machine3	t13	t23	t33	.	.	ti3	.	tn3
Machine4	t14	t24	t34	.	.	ti4	.	tn4

Follow the CDS algorithm step by step.

In this problem the numbers of machines are 4.

We should generate $(4-1) = 3$ sequences.

The first sequence will come from workstation-1 and workstation2. Here workstation-1 is equals to machine-1 and workstation-2 equals to machine-4 in operating time.

Table 4.17

Job	1	2	3	.	.	i	.	n
Workstation1	t11	t21	t31	.	.	ti1	.	tn1
Workstation2	t14	t24	t34	.	.	ti4	.	tn4

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The second sequence will come from workstation-1 and workstation2. Here workstation-1 is equals to machine-1&2 and workstation-2 equals to machine-4&3 in operating time.

Table 4.18

Job	1	2	3	.	.	i	.	n
Workstation 1	$t_{11}+t_{12}$	$t_{21}+t_{22}$	$t_{31}+t_{32}$	.	.	$t_{i1}+t_{i2}$	.	$t_{n1}+t_{n2}$
Workstation 2	$t_{14}+t_{13}$	$t_{24}+t_{23}$	$t_{34}+t_{33}$	.	.	$t_{i4}+t_{i3}$	.	$t_{n4}+t_{n3}$

The third sequence will come from workstation-1 and workstation2. Here workstation-1 is equals to machine-1+2+3 and workstation-2 equals to machine-4+3+2 in operating time.

Table 4.19

Job	1	2	3	.	.	i	.	n
Workstation1	$t_{11}+t_{12}+t_{13}$	$t_{21}+t_{22}+t_{23}$	$t_{31}+t_{32}+t_{33}$	.	.	$t_{i1}+t_{i2}+t_{i3}$	.	$t_{n1}+t_{n2}+t_{n3}$
Workstation2	$t_{14}+t_{13}+t_{12}$	$t_{24}+t_{23}+t_{22}$	$t_{34}+t_{33}+t_{32}$	.	.	$t_{i4}+t_{i3}+t_{i2}$	.	$t_{n4}+t_{n3}+t_{n2}$

Apply Johnson's rule to the above feasible sequences. Choose the least make span among the above sequences.

Practice problem:

1. A company is faced with four jobs that have to be processed through four machines. Assume machines works continuously. Data appear below in minutes

Table 4.20

Job	A	B	C	D
Machine1	3	2	1	4
Machine2	3	2	4	3
Machine3	3	1	4	3
Machine4	3	2	2	2

Follow the CDS algorithm step by step.

This problem is a 4 of machines. So we should generate $(4-1) = 3$ sequences.

The first sequence will come from workstation-1 and workstation2. Here workstation-1 is equals to machine-1 and workstation-2 equals to machine-4 in operating time.

Table 4.21

Job	A	B	C	D
Workstation1	3	2	1	4
Workstation2	3	2	2	2

By applying Johnson's rule the optimal sequence for the above setup is

C - B - A - D

The second sequence will come from workstation-1 and workstation2. Here workstation-1 is equals to machine-1&2 and workstation-2 equals to machine-4&3 in operating time.

Table 4.22

Job	A	B	C	D
Workstation1	6	4	5	7
Workstation2	6	3	6	5

By applying Johnson's rule the optimal sequence for the above setup is

C - A - D - B

The third sequence will come from workstation-1 and workstation2. Here workstation-1 is equals to machine-1+2+3 and workstation-2 equals to machine-4+3+2 in operating time.

Table 4.23

Job	A	B	C	D
Workstation1	9	5	9	10
Workstation2	9	5	10	8

By applying Johnson's rule the optimal sequence for the above setup is

B - A - C - D

Find out the make span of each sequence obtained above.

For the first sequence C - B - A - D

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Table 4.24

Job	Time	C	B	A	D
Machine1	In	0	1	3	6
	Out	1	3	6	10
Machine2	In	1	5	6	10
	Out	5	7	9	13
Machine3	In	5	9	10	13
	Out	9	10	13	16
Machine4	In	9	11	13	16
	Out	11	13	16	18

The make span time is 18. For the second sequence C - A - D - B

Table 4.25

Job	Time	C	A	D	B
Machine1	In	0	1	4	8
	Out	1	4	8	10
Machine2	In	1	5	8	11
	Out	5	8	11	13
Machine3	In	5	9	12	15
	Out	9	12	15	16
Machine4	In	9	12	15	17
	Out	11	15	17	19

The make span time is 19. For the third sequence B - A - C - D

Table 4.26

Job	Time	B	A	C	D
Machine1	In	0	2	5	6
	Out	2	5	6	10
Machine2	In	2	5	8	12
	Out	4	8	12	15
Machine3	In	4	8	12	16
	Out	5	11	16	19
Machine4	In	5	11	16	19
	Out	7	14	18	21

The make span time is 21.

Decision Table

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Table 4.27

S.no.	sequence	Make span	Selection
1	C-B-A-D	18	v
2	C-A-D-B	19	Ö
3	B-A-C-D	21	Ö

Among the feasible sequences C-B-A-D is the best sequence with the make span of 18 minutes.

Review Question:

1. Explain the two phases of scheduling.
2. Which priority rule is the best rule for sequencing for a single machine problem where the customer satisfaction is an important objective?

4.5 PROJECT SCHEDULING

In the previous sections you have seen how do you schedule the mass production, job shop production. In this section you can see how do you schedule project type of production. To schedule project type of production, during the World War II US defense people developed a technique known as PERT, stands for Program Evaluation and Review Technique to develop a missile.

Here the development of a missile is a project and to plan and schedule the above said project, US defense personnel developed a PERT technique. After developing PERT technique, US defense people developed another technique known as CPM. CPM stands for Critical Path Method to plan and schedule of certain type of projects.

PERT techniques is a applied mainly for new project at which you don't have any experience that is why the time estimate for each activity of the project revolves around three time estimate (e.g.) PERT usually applied for the following projects,

- Planning and scheduling of new product.
- Development of missile.
- Development of launching of rockets.

But **CPM** is applied for known projects like

- The construction of building.
- The manufacture and assembly of motors.
- The maintenance project.

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Difference between PERT and CPM

Table 4.28

S.No	Characteristics	CPM	PERT
1.	Type of projects	Known	Unknown
2.	Time estimate	Single time estimate	Three time estimate
3.	Time	Non random variable	Random variable
4.	Nature of the time estimate	Deterministic	Probabilistic
5.	Type of network	Activity oriented network	Event oriented network

A project as already mentioned consists of many activities. The activities are interlinked together to achieve the common objectives like time, cost and standard of performance. CPM and PERT techniques are considered to be project management techniques which enable the project manager to plan and schedule the project. They are also called project network planning and scheduling technique. In the next section you can know about the network planning and scheduling.

4.5.1 Planning

Jobs to be carried out in the planning

- 1) List the activities involved in the project,
- 2) Estimate the time requirement and cost requirement for each activity,
- 3) Find the relationship between the activities,
- 4) Based on the relationship draw the precedence diagram,
- 5) Draw the network based on the precedence diagram.

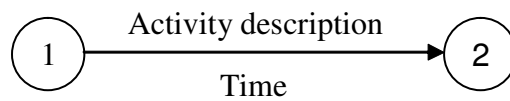
The output of the planning activities will be as follows :

Precedence relation with time and cost data

Table 4.29

Activities	Immediate predecessor	Cost	Time
a.	-	5000	4
b.	-	4000	5
c.	-	10,000	1
d.	a, b	7000	3
e.	c	6000	2
f.	e	10,000	5

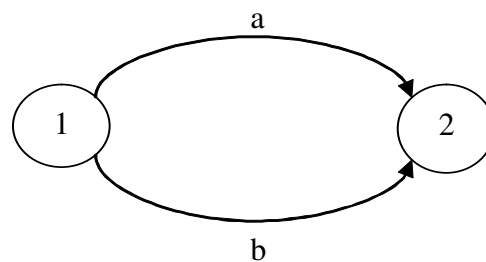
In a project, the activity is represented as follows:

Figure 4.2

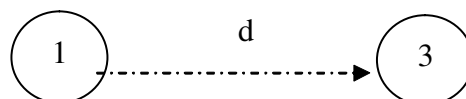
Suppose an activity consists of test marketing. This is represented as

Figure 4.3

1. The tail node of the arrow should carry small number than the head of the arrow. In this case tail node carry number1 and the head node carry number2.
2. Two activities should not have common initial node and common end node.

Figure 4.4

This is not permitted if this kind of situation arises, then you should introduce a dummy activity as follows:

Figure 4.5

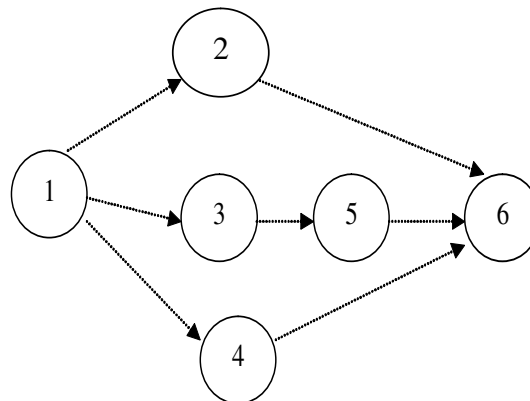
‘d’ is the dummy, it does not consume any resources. It is introduced just to show the relationship.

1. When you draw the network, all the starting activities should start at one starting node. Similarly at the end all the ending activities should culminate at one node.

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Figure 4.6



In the above network, all the starting activities are emanating from node 1 and all the ending activities are namely (2 - 6, 5 - 6, 4 - 6) are culminated at node 6.

4.5.2 Project network scheduling

In this phase, you should decide about whether the network is treated as an activity oriented network or event oriented network.

An event is nothing but, a milestone of a network. A project network could be treated as an activity oriented network, only when, as a project manager, you should know in detail about the every activity of the project, namely, the estimated time of the each activity, and how to complete each activity etc. Otherwise, if you are not so experienced with the project, then you should treat the project as an event oriented project. In the event oriented project, you don't bother about the progress of the activity. You should bother about the starting and completion time of the activity and then the project. For example- Test marketing. If you treat this job as an activity then the description is test marketing. Then you should find out the earliest starting time, latest starting time, earliest finishing time and latest finishing time. Suppose you treat the test marketing as an event oriented one, then you should find out the earliest and latest starting time, the earliest and latest finishing time of the test marketing event.

With this information, now you can see what you should do in the scheduling of the project network.

Steps:

1. Find the earliest starting time, earliest finishing time for activity, and latest starting time and latest finishing time for activity oriented network.
2. Find the earliest starting time, earliest finishing time for event, and latest starting time and latest finishing time for event, for event oriented network.

Forward pass Method

In forward pass method, the earliest starting time and earliest finishing time are calculated.

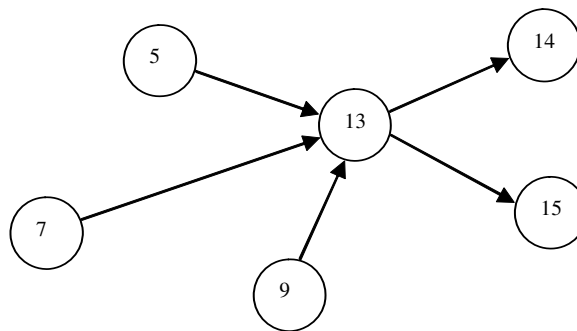
$$EF_{ij} = ES_{ij} + t_{ij}$$

= Earliest finish time of activity i,j

ES_{ij} = Earliest starting time of activity i,j

t_{ij} = Time duration of the activity i,j

You may have problem in calculation of ES of scheduled activity only when many activities lead into a particular node and one or many activities emanating from that particular node as shown below:

Figure 4.7

Assume

Table 4.30

Activity	Earliest Start (ES)	Earliest Finish (EF)	Time Duration
5-13	4	7	3
7-13	7	11	4
9-13	6	8	2

Earliest start of activity 13 – 14

$$(i.e) \quad ES_{13-14} = \max \left\{ \begin{matrix} EF_{5-13} \\ EF_{7-13} \\ EF_{9-13} \end{matrix} \right\} = \max \left\{ \begin{matrix} 7 \\ 11 \\ 14 \end{matrix} \right\} = 14$$

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The reason for considering the maximum time is that as per the technological constraint the succeeding activity will be started only after the completion of all the preceding activities.

Backward pass method

In the backward pass method, from the end node of the project the latest start and the latest finish are calculated. You should start with the earliest completion time of the project as the latest completion time of the project then you should work backward, so that you can deduce the latest starting time for each activity.

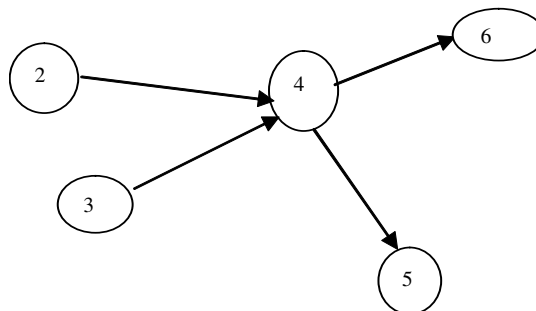
$$LS_{ij} = LF_{ij} - t_{ij}$$

LS_{ij} = Latest starting time for the activity $i-j$

LF_{ij} = Latest finishing time for the activity $i-j$

t_{ij} = Time duration of the activity $i-j$

In the latest finish time calculated, you may face some problem because many activities may emanate from a particular node as shown in the diagram.



Assume

Table 4.31

Activity	Latest Start (LS)
4-6	15
4-7	20
4-5	18

Now, to find the latest finish of activity 2-4 and 3-4, consider all the latest start time of all the activities emanating from the node four and consider the minimum latest starting time because, In the worst case, if all the succeeding activities starts at the latest starting time then the lowest latest starting time of the succeeding activity becomes latest finishing time of the preceding activities.

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(i.e)

$$\text{Similarly } LF_{34} = \min \begin{cases} LS_{4-6} = 15 \\ LS_{4-7} = 20 \\ LS_{4-5} = 18 \end{cases} = LF_{2-4} = 15$$

3. Identify the critical path. **The critical path is the longest path in the network.**
4. Identify the float or slack for each activity/ event of the network.
5. Carry out the time- cost trade off and if possible crash the project.
6. Carry out the resource scheduling.

In scheduling to carry out the above activity, you need to apply (PERT/ CPM) techniques. First you can see the application of the critical path method in the following example. **Why a manager should know about latest start and latest finish of each activity of a project?** This is because sometimes more than one activity may compete for one resource. In this case, if you know the latest start and latest finish, the resource which is in question will be immediately allocated to the activity which could not be delayed, rather than to the activity which could be delayed. This is one of the reasons for the usage of float.

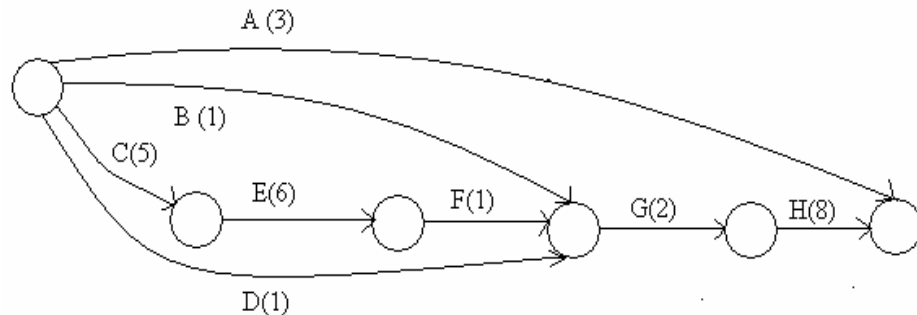
Identification of float:
 $LF_{2-4} = \min \begin{cases} LS_{4-6} = 15 \\ LS_{4-7} = 20 \\ LS_{4-5} = 18 \end{cases} = LF_{2-4} = 15$
 Float is the leeway available for the manager to schedule the scarce resources to the activity based on the float availability. This means, if an activity has zero float, that activity should be given preference in terms of allocating the resources, that too, when the other activities which possess float compete for the same resources.

Now, you can see how the above explained project network planning and scheduling is elucidated with an example.

Problem statement**Table 4.32**

Consider the product development project. This project consists of following activities.

Activity	Symbol	Preceding Activity	Time estimate (days)
Demand estimation	A	-	3
Development of pricing strategy	B	-	1
Product design	C	-	5
Conduct, promotional cost analysis	D	-	1
Manufacture prototype model	E	C	6
Perform product cost analysis	F	E	1
Perform final pricing analysis	G	B,D,F	2
Conduct Market test	H	G	8

NOTES**Solution
Figure 4.9**

Earliest starting and finishing time calculation using forward pass method:
 $ES_i = \max [0, ES_{(i-1)}]$, $EF_i = ES_i + \text{time duration}$.

Table 4.33

Activity	Early start (ES_i)	Early finish (EF_i)
A	0	3
B	0	1
C	0	5
D	0	1
E	5	11
F	11	12
G	12	14
H	14	22

Since three activities B, F and D are to be completed before G, we have to select the maximum of all the three early finish time of the predecessors. $ES_g = \max [EF_b, EF_f, EF_d]$

Latest starting and finishing time calculation using forward pass method:

$LS_a = \text{Total completion time of the project} - T_a$, $LF_a = TC_a$

Table 4.34

Activity	Latest start (LS_i)	Latest finish (LF_i)
A	19	22
B	10	11
C	0	5
D	10	11
E	5	11
F	11	12
G	12	14
H	14	22

Total float for each activity 'i' = $LS_i - ES_i$ (or) $LF_i - EF_i$

NOTES

Table 4.35

Activity	Total Float
A	19
B	10
C	0
D	10
E	0
F	0
G	0
H	0

The above method of planning and scheduling a network is called **Critical Path Method**. The critical path for the mentioned problem is C- E- F-G-H. (The path in the project which has the maximum completion time).

PERT:

Suppose, if a project planner treats the problem, which is discussed in the previous section, as an unknown project in some other new product launch, the project planner has to estimate "three time estimate", instead of "one time estimates". The three time estimates for each activity are called optimistic time (t_o), the most likely time (t_m), pessimistic time (t_p).

- Optimistic time(t_o): It is the minimum time taken to complete the activity, if every thing goes well.
- Pessimistic time(t_m): This is the maximum time to complete an activity, if most of the things go wrong.
- Most likely time (t_p): In real life situation, not everything goes completely right or wrong. The most likely is the time with a more chance to complete the activity.

For example, consider the following activity.

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Figure 4.10

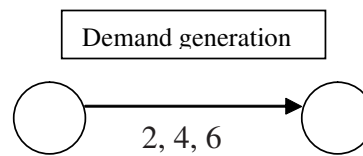


Table 4.36

Symbol	Activity	Probability
t_o	2	0.2
t_m	4	0.7
t_p	6	0.1

Beta distribution

Figure 4.11

It is proved that the time estimate in the PERT method follows a Beta distribution. So the mean of the Beta distribution is

$$T_{\text{expected}} = T_e = (t_o + 4 \times t_m + t_p) / 6$$

Variance for the activity,

$$\sigma^2 = ((t_p - t_o) / 6)^2$$

A project planner, in addition to the estimation of standard, should know the variance of each activity; variance is a measure to measure the uncertainty about that activity. If the variance is high, this means that the project manager may not have much idea about the progress and completion of the activity.

Let us see the application of PERT – model for the previous problem, with the information provided in the following table.

Table 4.37

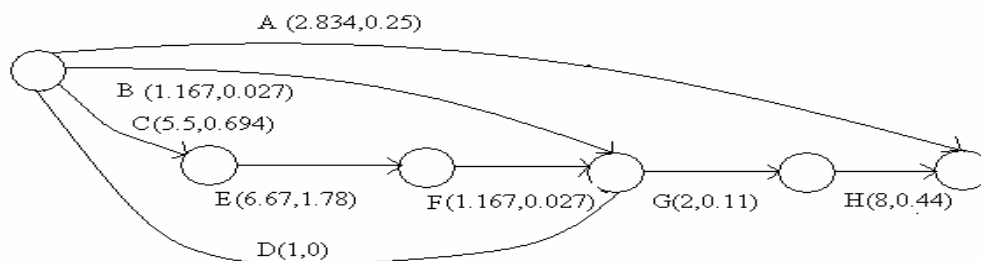
Activity	Symbol	Time estimate (days)		
		Optimistic (t_o)	Most likely (t_m)	Pessimistic (t_p)
Demand estimation	A	1	3	4
Development of pricing strategy	B	1	1	2
Product design	C	4	5	9
Conduct, promotional cost analysis	D	1	1	1
Manufacture prototype model	E	4	6	12
Perform product cost analysis	F	1	1	2
Perform final pricing analysis	G	1	2	3
Conduct Market test	H	6	8	10

Step 1: Estimate the expected time and variance for each activity. Using 1 and 2 Table 4.38

Table 4.38

Activity	E_T	V_T
A	2.834	0.25
B	1.167	0.027
C	5.5	0.694
D	1	0
E	6.67	1.78
F	1.167	0.027
G	2	0.11
H	8	0.44

Step 2: Network model:

Figure 4.12

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Step 3:

Earliest starting and finishing time calculation using forward pass method:
 $ES_i = \max [0, ES_{(i-1)}]$, $EF_i = ES_i + \text{time duration}$.

Table 4.39

Activity	Early start (ES _i)	Early finish (EF _i)
A	0	2.834
B	0	1.167
C	0	5.5
D	0	1
E	5.5	12.17
F	12.17	13.34
G	13.34	15.34
H	15.34	23.34

Since three activities B, F and D are to be completed before G, we have to select the maximum of all the three early finish time of the predecessors. $ES_g = \max [EF_b, EF_f, EF_d]$

Latest starting and finishing time calculation using forward pass method:

$LS_a = \text{Total completion time of the project} - T_a$, $LF_a = TC_a$

Latest starting and finishing time calculation using backward pass method:

$LS_a = \text{Total completion time of the project} - T_a$, $LF_a = TC_a$

Table 4.40

Activity	Latest start (LS _i)	Latest finish (LF _i)
A	20.50	23.34
B	11.00	12.17
C	0	5.5
D	11.17	12.17
E	5.5	12.17
F	12.17	13.34
G	13.34	15.34
H	15.34	23.34

Step 4:

Identify the critical path. The critical path is the longest path in the network. The expected critical path is C – E – F – G – H. The duration is 23.34 days. The variance of the critical path is 3.051 days. Therefore standard deviation is equal to 1.746.

Step 5:

Identify the float or slack for each activity/ event of the network.

Identification of float:

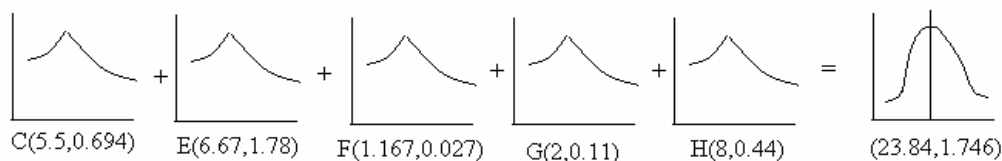
Total float for each activity 'i' = $LS_i - ES_i$ (or) $LF_i - EF_i$

Table 4.41

Activity	Total Float
A	20.50
B	11.00
C	0
D	11.17
E	0
F	0
G	0
H	0

You cannot claim that, the completion time of the project is 23.34 days in this case, because this is the expected completion time attached with the probability. The expected completion time is the sum of the expected completion time of the activity C, E, F, G and H. But timing of each activity follows beta distribution. Now the summation of all the time follows the normal distribution with the summation of all variance. This principal is arrived based on the central limit theorem. It is shown in the figure4.13.

Figure 4.13



From this above figure; you can answer for the following questions.

1. What is the probability that the project will be completed within the mean time?
2. What is the probability that the project will be completed within the specified time period?
3. What is the probability that the project will be completed above the specified time period?
4. To complete within the particular probability, how much time will be required?

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5. To complete above the particular probability, how much time will be required?

Let us determine the following probabilities for the above mentioned problem.

A. The project will be completed in 22 days or less.

B. The project will be completed by its earliest expected completion date.

C. The project will be completed in more than 30 days.

D. The project will be completed between 25 and 30 days.

To answer the above problems you should find the Z- values using normal distribution tables as follows.

Solution:

A. $X_i = 22$, (X_i = Project due date)

$\bar{X} = 23.34$ (\bar{X} = Project completion time)

$= 1.746$ ($=$ standard deviation of the project completion time)

$Z = (X_i - \bar{X}) /$

$Z = (22 - 23.34) / 1.746$

$= -1.053$

Corresponding value for this Z from the normal tables is 0.1469

So the probability of completing the project with in 22 days is 14.69%

B. $X_i = 23.34$,

$\bar{X} = 23.34$

$= 1.746$

$Z = (X_i - \bar{X}) /$

$Z = (23.34 - 23.34) / 1.746$

$= 0.00$

Corresponding value for this Z from the normal tables is 0.5

So the probability of completing the project with in expected completion time is 50 %.

C. $X_i = 30$,

$\bar{X} = 23.34$

$= 1.746$

$Z = (X_i - \bar{X}) /$

$Z = (30 - 23.34) / 1.746$

$= 3.5281$

Corresponding value for this Z from the normal tables is 0.99978.

Therefore to complete the project beyond 30 days = $1 - 0.99978$ (ie) = 0.00022

So the probability of completing the project beyond 30 days is 0.022%

D.

$$\begin{aligned}
 X_i &= 30, \\
 \bar{X} &= 23.34 \\
 &= 1.746 \\
 Z &= (X_i - \bar{X}) / \\
 Z &= (25 - 23.34) / 1.746 \\
 &= 0.66437
 \end{aligned}$$

Corresponding value for this Z from the normal tables is 0.7357.

Therefore to complete the project between 25 and 30 days = $0.99978 - 0.7357 = 0.26408$

So the probability of completing the project beyond 30 days is 26.41%

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4.6 RESOURCE SCHEDULING

As it is mentioned in the project scheduling, resource scheduling is another important activity of project scheduling. As resource are scarce, the project manager efficiency and effectiveness can be measured through the way in which he allocates the resource in various activities of the project but not much extending the completion time of the project. Resource scheduling consists of two phases. Phase 1, deals about the resource allocation and Phase 2 deals about the resource leveling.

Resource allocation

It is the allocation of the resources for the activities that are critical in nature. If some resources are required by more than one activity at a time, the resources are to be allocated to the activity which is critical in nature and thereby delaying non critical activity. Any how you should see that the critical activities are getting importance in allocating the resources rather than the non critical activity. This is done based on the availability of the float for each activity and this does not effect the project completion time. If you proceed in this manner you will come across the situation in which all activities become critical and resources allocation becomes a problem. In such a situation, the efficiency of a project manager even could be measured through how judiciously he allocates the resources and at the same time without much extending the completion time of the project.

Resource leveling

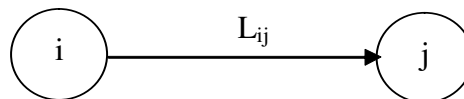
As the name indicates if you draw a curve between the time Vs resource requirement, the profile of the curve is almost constant then you need not carry out the leveling of the resources because all the time almost you need to make use of a constant resource requirement. This paves the way for continuous employment for the people involved in the project. Suppose the profile of the resource requirement Vs time has more peak & valley then you have to level the peak & valley of the resource requirement in such a manner that throughout the project period you are going to use constant

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resources with little variation. The process of doing so is called Project leveling. In this the case of project leveling the project completion time should not be extended but the objective of allocating constant workforce in all the days is achieved through a simple logic that the activities which are having floats are to be moved front and back without violating the precedence relationship. This is done with an objective of having constant resource in all the project days. When you move the activity front and back based on the availability of free float of each activity, that means the highest free float activity is moved front and back to ensure constant resources in all the days.

Free float for an activity is calculated as follows

Figure 4.14



Free float for activity i-j = $t_j - (t_i + L_{ij})$

Where t_i - is the earliest end time of the event i

t_j - is the earliest end time of the event j

L_{ij} - time duration of the activity i and j

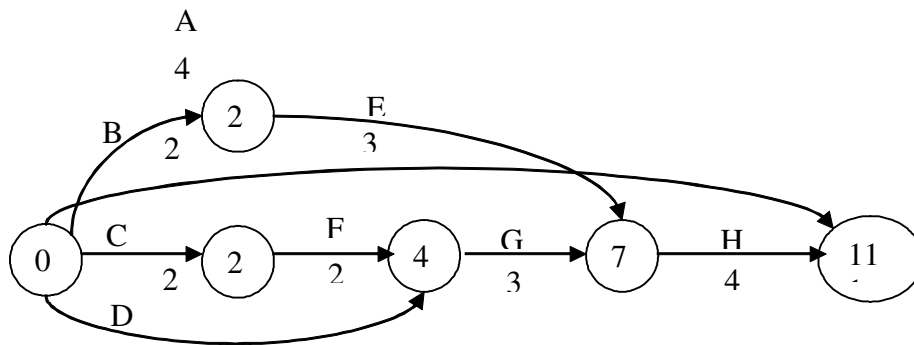
Example 4.2

Consider the following network

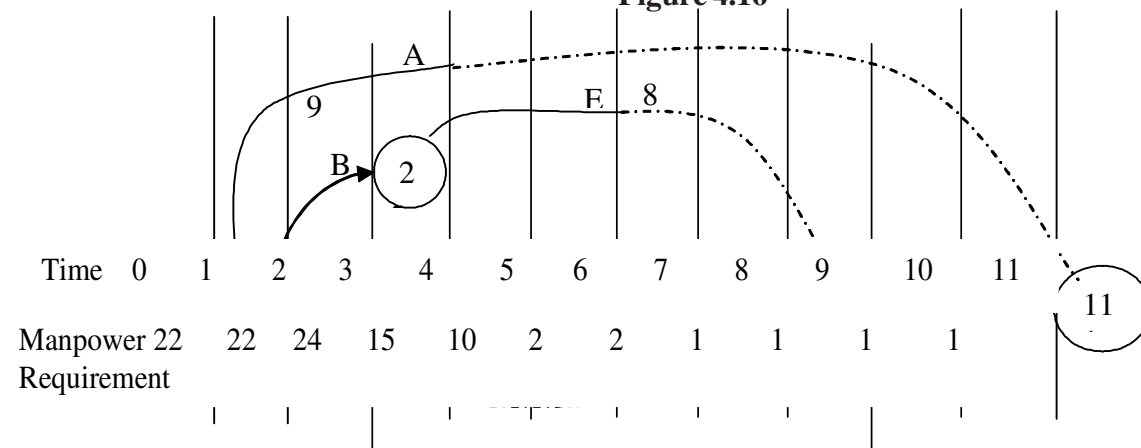
Table 4.42

Activity	Immediate predecessor	Manpower requirement	Time duration
A	-	9	4
B	-	3	2
C	-	6	2
D	-	4	2
E	B	8	3
F	C	7	2
G	F, D	2	3
H	E, G	1	4

Step1: -Draw the network and post the network in a time scale.

Figure 4.15

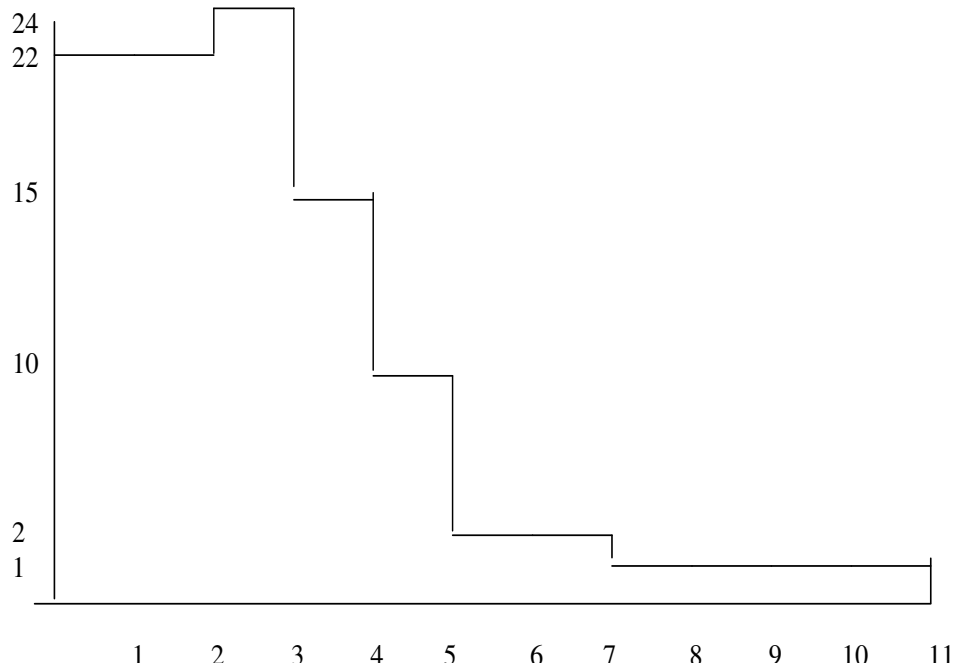
You can verify that the path C-F-G-H is the critical path. Next you should draw it in time scale. To draw this, first you should post the critical path.

Figure 4.16

The number appears above the arrow indicates that the manpower requirement.

Step2: - Draw the resource requirement Vs time profile

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NOTES**Figure 4.17**

If you see the above resource requirement profile, this profile has more peak & valley. So this is to be leveled to have constant work force requirement.

Step3: - Find the float using the formula mentioned already for all the activities .This is shown in the table.

Table 4.43

Activities	Free float
A	7
B	0
C	0
D	2
E	2
F	0
G	0
H	0

Step 4: - Find the total requirement for all the days, this is equal to 101. Now divide this by the number of days to find constant resource requirement

$$\text{Constant resource requirement} = 101/11=9.1$$

Every day you should see that the number of resources requirement should not exceed 10. For doing so, you should give preference for the activity which has least free float.

Day1
Table 4.44

Activity	Free float requirement	Resource performed	Action to be
B	0	3	Scheduled
C	0	6	Scheduled
D	2	4	Postponed
A	7	4	Postponed

In the day1, even though the free float for activity D is more than B. You should give preference to D because if you allot 'D' and 'C' on day1 it perfectly matches the maximum resources requirement 10.

Day2
Table 4.45

Activity	Free float requirement	Resource performed	Action to be
B	0	3	Postponed
C	0	6	Continued
D	2	4	Continued
A	6	9	Postponed

Day3
Table 4.46

Activity	Free float requirement	Resource performed	Action to be
F	0	7	Scheduled
B	0	3	Scheduled
E	2	8	Postponed
A	5	9	Postponed

Day4
Table 4.47

Activity	Free float requirement	Resource requirement	Action to be performed
F	0	7	Continued
B	0	3	Continued
E	1	8	Postponed
A	4	9	Postponed

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Day5
Table 4.48

Activity	Free float requirement	Resource performed	Action to be
E	0	8	Scheduled
G	0	2	Scheduled
A	3	9	Postponed

Day6
Table 4.49

Activity	Free float requirement	Resource performed	Action to be
E	0	8	Continued
G	0	2	Continued
A	2	9	Postponed

Day 7
Table 4.50

Activity	Free float requirement	Resource performed	Action to be
E	0	8	Continued
G	0	2	Continued
A	2	9	Postponed

Day 8
Table 4.51

Activity	Free float requirement	Resource performed	Action to be
A	0	8	Scheduled
H		0	2 Scheduled

Day 9
Table 4.52

Activity	Free float requirement	Resource performed	Action to be
A	0	8	Continued
H	0	2	Continued

Day10
Table 4.53

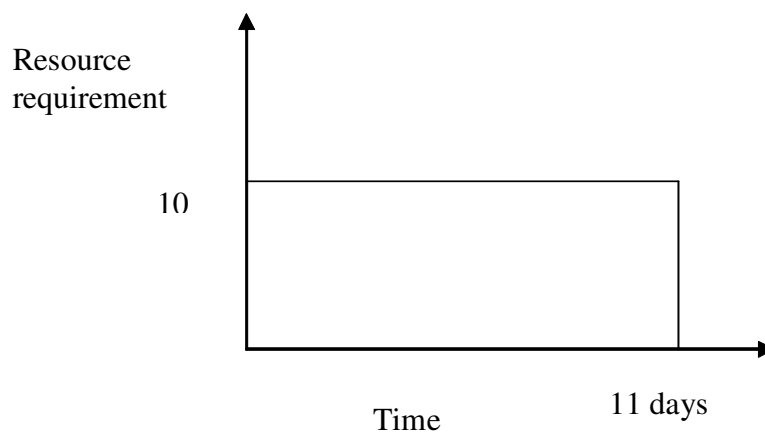
Activity	Free float requirement	Resource performed	Action to be
A	0	8	Continued
H	0	2	Continued

Day11
Table 4.54

Activity	Free float requirement	Resource performed	Action to be
A	0	8	Continued
H	0	2	Continued

Since for all the days the resources are scheduled as per the procedure mentioned. The requirement Vs time profile graph is as follows:

Figure 4.18



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Summary

In this unit, the job shop scheduling for single machine n jobs, two machine n jobs, 3 machine n jobs and n job m machine are discussed. The project scheduling techniques namely the critical path method, program evaluation review technique are elaborated. The application of float is interpreted and appreciated. The resource leveling is also highlighted.

Review Questions:

1. Draw the network for the given precedence diagram.

Table 4.55

Activities	Immediate predecessor
a	-
b	-
c	b
d	a,c

2. How would you calculate the expected time and variance in the PERT model?
3. Expand CPM and PERT?

UNIT V

NOTES

FACILITY, LAYOUT LOCATION AND WORK MEASUREMENT

5.1 Introduction

5.2 Learning Objectives

5.3 Facility Location:

5.3.1 Selection of location:

5.3.1.1 Phase I:

5.3.1.2 Phase – II

5.4 Plant location selection

5.4.1 Rating Plan Method To Evaluate The Factors For Plant Location:

5.4.2 Cost analysis method:

5.5 Types of Layout

5.5.1 Fixed Product Layout

5.5.2 Product Layout

5.5.3 Group Layout

5.5.4 Process Layout

5.5.5 Design of Process Layout

5.6 Line Balancing

5.7 Time Study and Work Measurement

5.7.1 Time Study

5.7.2 Work sampling

5.8 Learning Curve

5.9 Productivity

NOTES**UNIT - 5****FACILITY, LAYOUT LOCATION AND
WORK MEASUREMENT****5.1 INTRODUCTION**

The unit deals about one of the strategic decisions in the operations management, namely plant location decision, the characteristics of different layouts are discussed. The different techniques available to design the layout are also introduced. Work measurement technique like time study, work sampling and methods time measurement are elaborated to fix the standards for organizational activities. The impact of learning curve on the standard and productivity improvement is also discussed.

5.2 LEARNING OBJECTIVES

1. To comprehend the factors to be considered for selecting the location.
2. To know the characteristics of different types of layout.
3. Understand the techniques to be adopted in designing the layout.
4. To establish the standards for different activities using standard techniques.
5. To construct learning curve and to comprehend the impact of learning curve in standards and productivity.

5.3 FACILITY LOCATION

Facility location i.e. identifying the best location is a strategic decision in operation management. This is a decision like any other strategic decisions like identifying the product, choosing the technology, deciding the capacity etc. It is a long term decision. Once the resources are committed taken back the resources involves more cost because of change in the decision later. So you should be careful while identifying the various locations and choosing the best one.

Need for the Decision

1. Research and development department of an organization come up with a new product, to manufacture the product you need to incur the decision.

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2. For the existing product, there is a lot of market potential so to tap the untapped market you have to expand the capacity. To expand the capacity, you have to identify the location.
3. Markets are served in a particular region, more competitions and high escalation of cost. It is difficult to survive then identifying the location where there is untapped market in the different regions.
4. Relocation required because of Tsunami, fire, flood, earthquake natural holocaust etc.

5.3.1 Selection of location

Selection of the best location involves two phases:

5.3.1.1 Phase 1

In the phase I a preliminary feasibility study is carried out to assess the production input, process technology, infrastructural facilities, social and cultural conditions and legal and government considerations.

Production Input:

Raw material:

It is important to assess the availability of raw material. The assessing is to be carried out in the point of view of the transportation cost and the amount or deposit. Suppose if you start a cement or aluminium industry the deposit of ore and how long it will be lost, that is to be assessed. You have to see the present requirements and future requirements and choose the place where the above conditions are fulfilled. The raw material supplier is far away then the transportation cost dominates the price that makes you less competitive.

Labour inputs:

When you assess the labour input, the quality of the labour is important. You may find the labours with fewer wages but the productivity of that labour may be low. So in addition to bothering about that wages, you should assess then the skill level also.

You can see now more foreign IT companies source India. The main reasons are those companies identify abundant IT skills in India at comparatively lesser cost. So they source India.

Process Technology:

Some times the technology restricts the choice of location e.g. to start a pulp and paper mills. You need water for processing so most of the pulp and paper mill industry are started in the river banks.

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Infrastructural facilities:

A study is very much required to assess well connected and land roads, parts, out parts, railway lines telecommunication facilities etc. This is important because it reduces the transportation cost and lead time. Lead time reduction shows a lot of saving in other costs. It helps the organization to be a cost competitive.

Legal and political considerations:

Governments woo the corporate to start industry in their respective countries or state through providing free land, exemption of taxes, subsidized power tariffs, less cumbersome licensing procedures. In addition, the prospective person has to see that the legal formalities and complication. He / she has to study the government stipulation about the pollution standards to be exercised, zoning codes to be adopted import and export regulations prescribed and construction specifications etc.

Social and cultural conditions:

This is the process of exploring the attitude of the people towards the plant to be started over there. This study involves the skill availability and accessibility.

This study also involves the study about their demographic variables like the age distribution, income distribution, their status, their life conditions their tradition. Here, you should explain in detail to make them aware of the usefulness of plant to uplift them both economically and socially. At present, in India, since this process not carried out systematically and scientifically, many important projects are stalled by the people in many states like West Bengal, Orissa, Tamil Nadu, to state a few.

5.3.1.2 Phase – II

If there is a problem in the first phase, the second phase may not see the lime light. In the phase 1 macro analysis is over, in the second phase the region, community and site selection take place. Region include country to country or state-to-state within a country or within a state different regions. The factors to be considered in the selection of region, community and site are shown in the table.

The factors are considered under different major heading like infrastructure, market, supply, and environment and internal. You should note that most of the factors are considered in all the regional, community and site selection. For example, customer concentration and trends are considered in all region, community and site selection.

Table 5.1

Regional selection	Community Decision Infrastructure	Site Decision
Transportation network and their costs	Transportation network and their costs	Proximity to transportation system
Utilities supply and costs	Utilities supply and costs	Utilities supply and costs
	Market	
Customer concentration and trends.	Customer concentration and trends.	Customer concentration and trends.
	Supply	
Materials and supplies availability & accessibility	Materials and supplies availability & accessibility	Materials and supplies availability & accessibility
Labour availability & accessibility	Labour availability & accessibility	
Land and construction cost	Site availability cost & construction cost	
		Size of the site
		Site costs
	Environment	
The intensity of unionization towards the new facilities	Community attitudes	Zoning restrictions
Climate taxes	Community service & industry	Proximally to related
	Banking services	Environmental impact
Government SOPS	Government SOPS	
Environmental regulations	Environmental regulations	
	Internal	
	Preference of the management	

NOTES**5.4 PLANT LOCATION SELECTION**

The selection of the plant is characterized by the subjective factors as well as the objective factors. But it is very difficult to quantify subjective factors. The plant location evaluation is done by considering both subjective and objective factors through a subjective evaluation known as Rating Plan Method. You can see in the following section, how the rating plan is applied to choose a place, where to start a Bio technology plant, in India.

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To start a biotechnology plant what factors you consider and how do you evaluate the same using rating plan method.

Selection Criteria

The important considerations for selecting a suitable location are given as follows:

- a. Natural or climatic conditions.
- b. Availability and nearness to the sources of raw material.
- c. Transport costs-in obtaining raw material and also distribution or marketing finished products to the ultimate users.
- d. Access to market: small businesses in retail or wholesale or services should be located within the vicinity of densely populated areas.
- e. Availability of Infrastructural facilities such as developed industrial sheds or sites, link roads, nearness to railway stations, airports or sea ports, availability of electricity, water, public utilities, civil amenities and means of communications are important, especially for small scale businesses.
- f. Availability of skilled and non-skilled labour and technically qualified and trained managers.
- g. Banking and financial institutions are located nearby.
- h. Locations with links: to develop industrial areas or business centers result in savings and cost reductions in transport overheads, miscellaneous expenses.
- i. Strategic considerations of safety and security should be given due importance.
- j. Government influences: Both positive and negative incentives to motivate an entrepreneur to choose a particular location are made available. Positive includes cheap overhead facilities like electricity banking transport, tax relief, subsidies and liberalization. Negative incentives are in form of restrictions for setting up industries in urban areas for reasons of pollution control and decentralization of industries.
- k. Residence of small business entrepreneurs want to set up nearby their homelands.

One study of the locational considerations from the small-scale units revealed that the native place or homelands of the entrepreneur was the most important factor.

Heavy preference to homeland suggests that small-scale enterprise is not freely mobile. Low preference for Government incentives suggests that concessions and incentives cannot compensate for poor infrastructure.

In the rating plan method, ideal rating is considered for the factors, then how much rating each location scores against each factor is assessed and best location is chosen based on the highest total point.

Table 5.2 - Rating Plan Method To Evaluate The Factors For Plant Location:

Factors	Ideal Point	Lucknow	Bangalore	Pune
• Availability of technically qualified skilled labor.	30	25	28	20
• Availability and nearness to the source of material.	20	15	17	15
• Market Potential	15	13	11	10
• Access to the market	5	4	5	4
• Competitive Analysis	5	5	2	3
• Site Economics	10	10	5	6
• Positive Govt. Influences	10	10	6	6
• Strategic consideration of safety and security	2	2	2	2
• Rent or buy the property	3	3	2	1
TOTAL POINT	100	87	78	67

In the above table, Lucknow scores more than the Pune and Bangalore.

5.4.2 Cost analysis method:

In the previous section, you saw how the rating plan method is applied, to choose the location. In this section, you can see a method, where only the objective factor is considered, namely the cost factors i.e., to start a plant in a particular location, based on the labour availability and accessibility, material availability and accessibility, you may have different variable cost as well as fixed cost for each location. Now based on the estimated fixed cost and variable cost, you can formulate for each location, a different a total cost equation. Once the total cost equation is arrived for each location by applying the cost volume profit analysis, you can estimate the range of production quantity at which the locations are preferred. You can understand above method through exapmle5.1.

Example 5.1

Consider a corporate office, which wants to identify the best location. They have identified 3 locations after a preliminary survey. They are locations A, B and C. The corporate has estimated the variable cost and fixed cost and then the total cost for the each location against the production quantity. This is shown in the table.

NOTES

NOTES

Table 5.3

SITE	Fixed cost (Rupees in lakhs)	Variable cost (Rupees per unit)
A	2.5	1000
B	3	750
C	4	500

Solution:

Considering site A and B,

the total cost for site A for 'x' quantities = $250000 + 1000x$. ——— (1)

the total cost for site B for 'x' quantities = $300000 + 750x$. ——— (2)

Therefore from (1) and (2),

$$x = (300000 - 250000)/(1000 - 750) \\ = 200 \text{ units.}$$

Considering site B and C,

the total cost for site B for 'x' quantities = $300000 + 750x$. ——— (3)

the total cost for site C for 'x' quantities = $400000 + 500x$. ——— (4)

Therefore from (3) and (4),

$$x = (400000 - 300000)/(750 - 500) \\ = 400 \text{ units.}$$

Result,

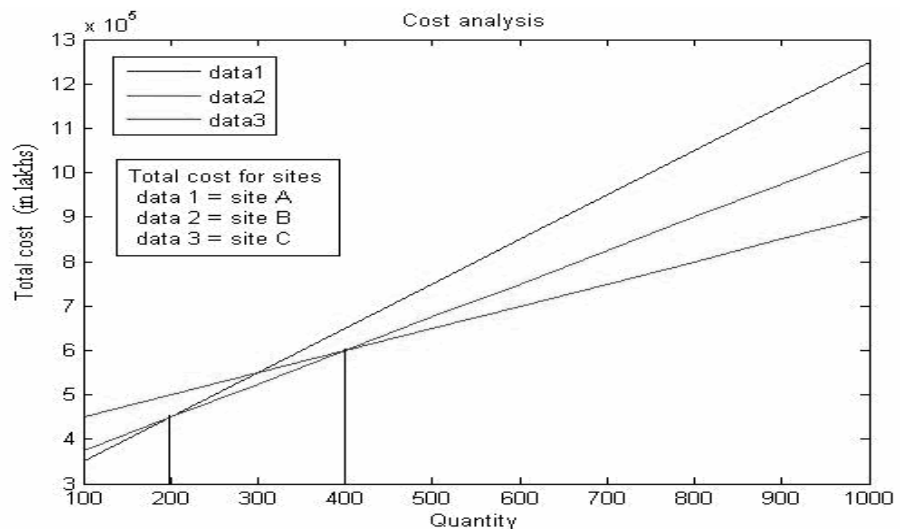
If 'x' < 200 units, select site A as it has minimum fixed value.

If $200 < 'x' < 400$ units, select site B as it has minimum variable cost compared to A and minimum total cost compared to C.

If 'x' > 400 units, select site C as it has the least variable cost.

Graphical representation:

Figure 5.1



Review Questions:

- 1) Define facility location.
- 2) When will you go for facility location?
- 3) What are the phases in the facility location?
- 4) What the methods used for plant location selection?

1.3 TYPES OF LAYOUT

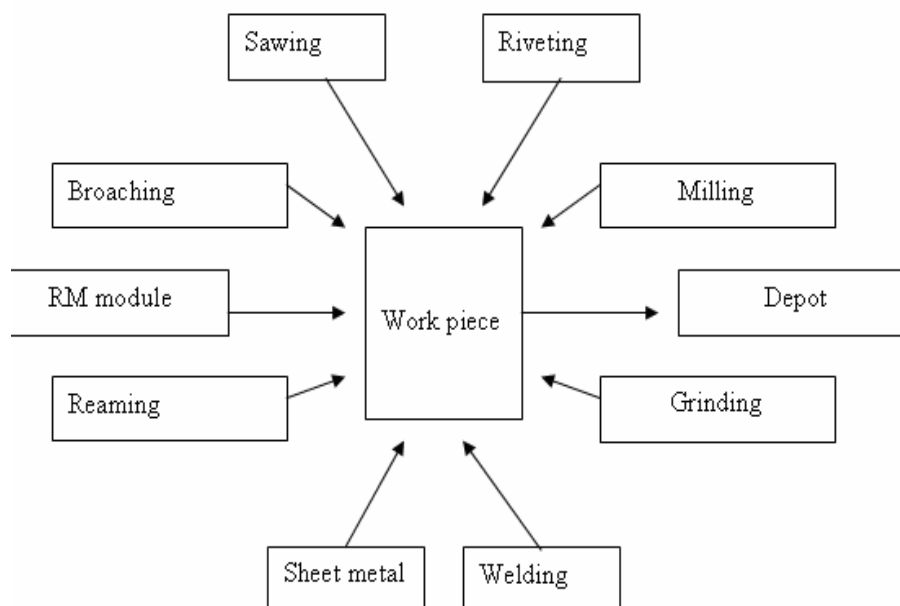
After selecting the plant location, based on the type of production system to be adopted, the layout has to be decided. The types of layout are:

1. Fixed product layout
2. Product layout
3. Group (flexible) layout
4. Process layout

5.5.1 Fixed Product Layout

The fixed product layout is developed by locating the workstations or production centers on the fixed job. Fixed layout type is used when the job size is large. Logistics are involved in ensuring that the right processes are brought to the product at the right time and at the right place. This has been mainly used in electronic industry to support computer systems integration and test; materials, sub assemblies, components, peripherals are brought to the single workstation where finished system is built. This type of layout requires generally higher number of personnel and equipments than the other types, since the work piece remains stationary.

Figure 5.2 – Fixed Product Layout

**NOTES**

NOTES

Advantages:

1. This method is highly flexible and any changes in product design and product mix can be easily accommodated.
2. Since work centers are independent, scheduling results in achieving minimum total production time.
3. The teams of personnel are responsible for continuity of operations.
4. Movement of materials is reduced.
5. Job enlargement could be promoted by allowing individuals or teams to perform the whole job.

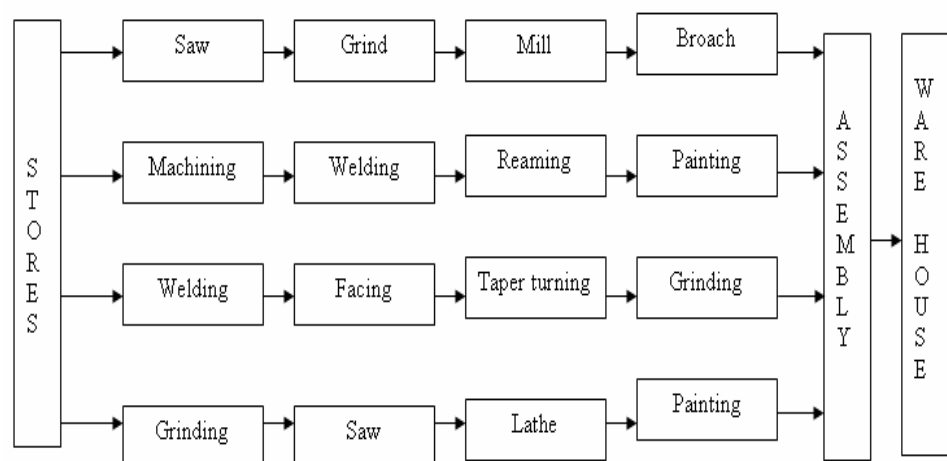
Limitations:

1. Skilled labour is required.
2. Supervision is required.
3. Positioning of material and machinery is costly and complex.
4. Equipment duplication may occur.
5. Utilization of equipment is required.

5.5.2 Product Layout

In this layout the machines are arranged according to the processing sequence of the product. Material flows directly from one workstation to other workstation. Machines are not shared by the products. This type of layout is used for high volume production. For proper utilization of machines sufficient production volume is required. Since the processes are located closed together in the production sequence, the layout minimizes the distance between the work center.

Figure 5.3 – Product Layout



Advantages:

1. The total production time is short.
2. The material handling is reduced because of the location of the machines to minimize the distances between the consecutive operations.

NOTES

3. Less skilled operator is required. Thus training is simple and short.
4. Less space is occupied by work in transit and temporary storage.
5. The flow is smooth and logical flow line results.
6. Small in process inventory as the work is directly fed from one process to other.

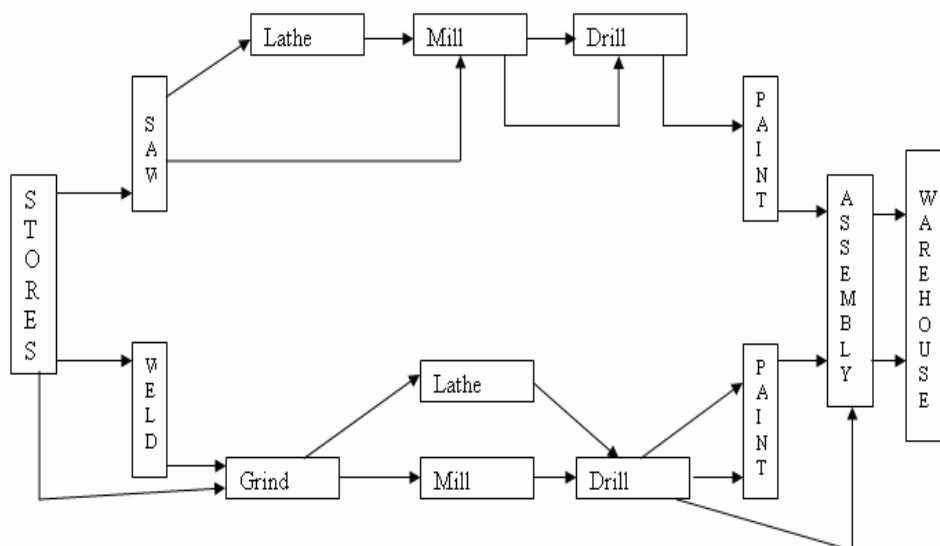
Limitations:

1. The production time is determined by the slowest machine.
2. A general supervision is required.
3. Since identical machines are arranged at various locations, initial investment is high.
4. A change in the product design requires an entire change in the layout.
5. A break down of one machine lead to complete stoppage of entire production.

1.5.3 Group Layout

When production volume is not sufficient for product layout, group layout is used. Here products are grouped in to logical product families. The groups of processes are called **cells**. So it is also called as **cellular layout**. It is a compromise between product and process layout. Since products are grouped into families this technology is also called as group technology with each individual cells are called GT cells.

Figure 5.4 – Group Layout



Advantages:

1. This supports the use of general purpose equipments.
2. This is a compromise between product and process layout.
3. Shorter travel distances and smoother flow lines than process layout.

NOTES

4. Team attitude and job enlargement tend to occur.
5. Utilization of each machine is increased.

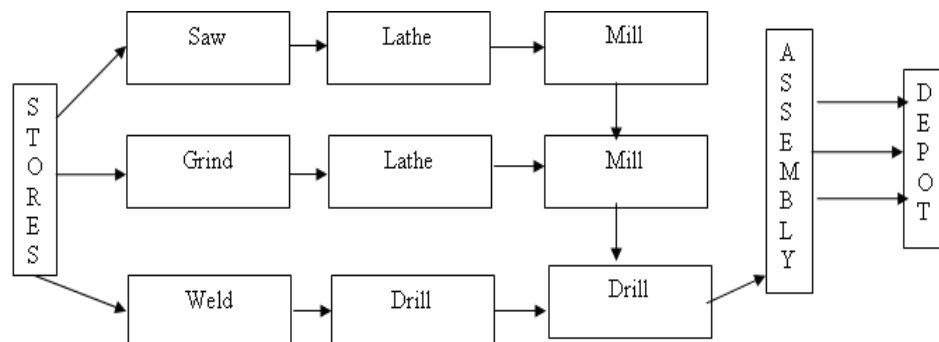
Limitations:

1. Higher skilled employees are required
2. General supervision is required.
3. It depends on the balanced material flow through the cell otherwise buffers and WIP storage are required.

1.5.3 Process Layout

In this type the machine are grouped and the product passes from one group to other group based on the sequence of production. The groups of processes are called cells. The process layout is used in the rapid changes in the product mix or production volume as well as when both product and group layout cannot be used. Typically job shop employs process layout due to the variety of products manufactured and their low production volume. It has high degree of inter departmental flow.

Figure5.5 – Process Layout



Advantages:

1. Since the machines are grouped, only fewer machines are required; thus minimum investment is required.
2. Better utilization of machines could be achieved.
3. High degree of flexibility exists.
4. Supervision could be specialized.
5. The working personnel find the job more satisfying and interesting since there is a diversity of tasks.

Limitations:

1. Highly skilled labour is required.
2. Work in process inventory is increased.

3. Total production time is longer
4. Planning and control of production system turns out to be tedious.
5. Space and capital are tied up by the work in process.
6. Material handling is more expensive because of longer flow line.

NOTES

5.5.5 Design of Process Layout

To design a process layout there are some computerized techniques available. Computerized techniques are classified into:

- Techniques which select the best process layout based on the material cost comparison.
- Other computerized techniques which select the best process layout based on the qualitative factors namely the closeness between the departments.

Closeness ratings are as follows:

- A – Absolutely essential
- E – Ordinary closeness
- I – Important
- O – Ordinary importance
- U – Un important
- X – Not desirable.

CRAFT (Computerized Relationship Allocation of Facilities Techniques)

CRAFT algorithm was originally developed by Armour and Buffa. CRAFT is more widely used than ALDEP and CORELAP. It is an improvement algorithm. It starts with an initial layout and improves the layout by interchanging the departments pairwise so that the transportation cost is minimized. The algorithm continues until no further interchanges are possible to reduce the transportation cost. The result given by CRAFT is not optimum in terms of minimum in majority of applications. Hence, CRAFT is mainly a heuristic algorithm. Unfortunately, plant layout problem comes under combinatorial category. So, usage of efficient heuristic like CRAFT is inevitable for such problem.

CRAFT Requirements:

1. Initial layout.
2. Flow data.
3. Cost per unit distance.
4. Total number of departments.
5. Fixed departments.
 - Number of such departments
 - Location of those departments
6. Area of departments.

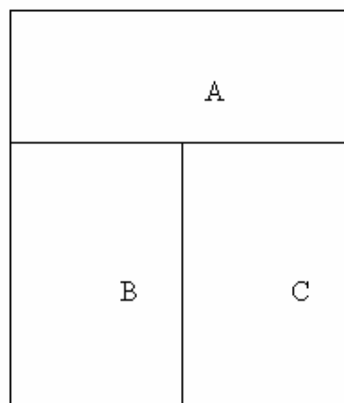
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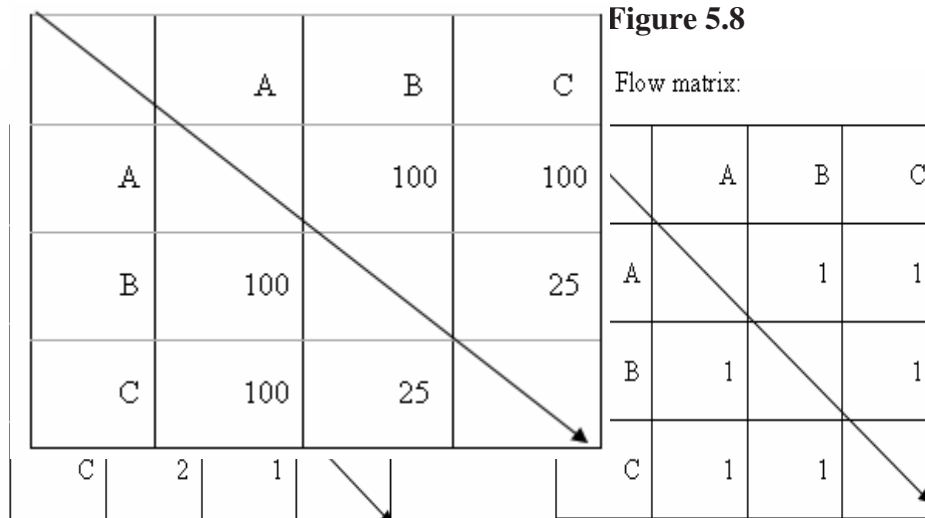
CRAFT Procedure

The steps of CRAFT algorithm are summarized below:

- Step 1. Input: 1. Number of departments
2. Number of interchangeable departments
3. Initial layout
4. Cost matrix
5. Flow matrix
6. Area of departments
- Step 2. Compute centroids of departments in the present layout.
- Step 3. Form distance matrix using the centroids.
- Step 4. Given data on flow, distance and cost, compute the total handling cost of the present layout.
- Step 5. Find all the possible pairwise interchanges of departments based on common border or equal area criterion. For each possibility, interchange the corresponding centroids and compute approximate costs.
- Step 6. Find the pair of departments corresponding to the minimum handling cost from among all the possible pairs of interchanges.
- Step 7. Is the cost in the previous step less than the total cost of the present layout? If yes, go to step 8. If not go to step 11.
- Step 8. Interchange the selected pair of departments. Call this as the NEW LAYOUT. Compute centroids, distance matrix and total cost.
- Step 9. Is the cost of new layout less than the cost of the present layout? If yes, go to Step 10. If not, go to Step 11.
- Step 10. The new layout is hereafter considered as the present layout. Its data on centroids, layout matrix and the total cost is retained. Go to step 5.
- Step 11. Print the present layout as the FINAL LAYOUT.
- Step 12. Stop

LAYOUT:
Figure 5.6





- 1) Iteration 1: calculate the distance matrix.

Distance between two departments = $|x_1 - x_2| + |y_1 - y_2|$

Where,

(X1, y1) is the centre of department 1

Centroids of A,B and C,

A(50,125)

B(25,50)

C(75,50)

DISTANCE MATRIX:

Figure 5.9

	A	B	C
A		100	100
B	100		25
C	100	25	

- 1) Determine the total cost for all possible movements between each department.

Cost between two departments = Distance matrix X Cost matrix

NOTES

NOTES**Figure 5.10**

	A	B	C	
A		400	100	500
	200		50	250
C	200	25		225
	400	425	150	975

TOTAL COST : 975

- 1) Re allocation of departments,
In this step the departments are interchanged. For interchanging
 1. Both departments should have the same area (or)
 2. Both departments should share common boundary
- 2) After reallocating find the new centroid and repeat step 2 and 3.

ITERATION 2

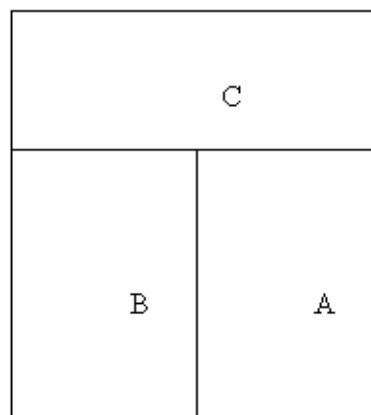
Interchange A and C (Because A and C have common border and same area)

Therefore new Centroids are,

C (50,125)

B (25,150)

A (75, 50)

Figure 5.11

DISTANCE MATRIX:**Figure 5.12**

	A	B	C
A		25	100
B	25		100
C	100	100	

COST MATRIX:**Figure 5.13**

	A	B	C	
A		100	100	200
	50		200	250
C	200	100		300
	250	200	300	750

TOTAL COST: 750

ITERATION 3:

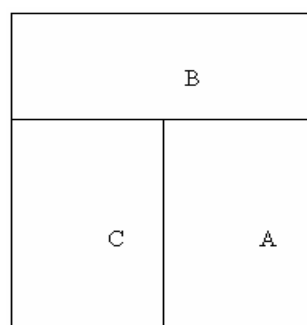
Interchange B and C (Because B and C have common border and same area).

Therefore new centroid are,

B (50,175)

C (25, 50)

A (75, 50)

Figure 5.14**NOTES**

NOTES

DISTANCE MATRIX:

Figure 5.15

	A	B	C
A		100	25
B	100		100
C	25	100	

COST MATRIX:

Figure 5.16

	A	B	C	
A		400	25	425
	200		200	400
C	50	100		150
	250	500	225	975

TOTAL COST: 975

- 5) Check total cost for all the possible reallocations and select the layout with minimum total cost.
- 6) Repeat the iterations till the least total cost is achieved. This layout is optimum solution.

In the given problem layout seems to be optimal compared to other two layouts. Now taking layout 2 as base layout, continue further iterations to find the least cost. That layout is the optimal solution.

Corelap Algorithm

Input data requirement

1. Relationship chart and closeness rating.
2. Building description is given by maximum length to width ratio.

Objective

1. Maximizing overall closeness rating.

How the software programs works

First he found out the closeness rating between the departments. It has to be placed in layout. If there is any type select the department which is high in closeness rating. If there is again tie select the department which is larger in area. If the tie still exists then select any department randomly.

Output

Computer printout shows final layout.

Determination of placement order of department:

For the purpose of finding the order of placing the departments the following data are needed.

REL- chart and closeness ratings:

REL –chart:

Table 5.4

1	-						
2	E	-					
3	O	U	-				
4	I	E	U	-			
5	O	I	U	I	-		
6	U	I	O	U		-	
7	U	U	U	U	I	E	-
	1	2	3	4	5	6	7

CLOSENESS VALUES:

A=6, E=5, I=4, O=3, U=2, and X=1

Using the closeness rating TCR (total closeness rating) is calculated thus:

NOTES

NOTES**Table 5.5**

Dep.	Closeness relationship.						TCR
1	E	O	I	O	U	U	19
2	E	U	E	I	I	U	22
3	O	U	U	U	O	U	14
4	I	E	U	I	U	U	19
5	O	I	U	I	A	I	23
6	U	I	O	U	A	E	22
7	U	U	U	U	I	E	17

The following steps are carried out to select the placement order of the departments.

1. Department with the largest TCR is selected for the first placement. In case of ties, the department with the largest area is selected. Department 5 is selected.
2. Review the closeness relationship of department 5 with other departments to find the department that has the highest closeness relationship with department 5.

Table 5.6

1	2	3	4	6	7
O	I	U	I	A	I

Department 6 has the highest closeness relationship with the department 5.
So it has to be placed next to department 5.

3. Check the closeness relationship for both the departments.

Table 5.7

Departments	1	2	3	4	7
Closeness with 5.	O	I	U	I	I
Closeness with 6.	U	I	O	U	E

In the above study department 7 has high closeness rating with 6. Thus it has to be placed in the layout next.

Similarly, if there is a tie in closeness rating, then select the department with the highest TCR.

If there is a tie again, then select a department with larger area. In case of tie in both conditions, then select a department randomly. Order of placement:

5 → 6 → 7 → 2 → 1 → 4 → 3

PLACEMENT OF DEPARTMENTS IN THE LAYOUT:

Table 5.8

						5								

1. The first department to be placed is 5. it is placed in the centre of a (7x 15) layout. Each cell has an area of 6000 sq.mt.
2. The second department from the list is department 6. It is thus placed.

Table 5.9

				6	6									
					5									

(Department 6 has two squares. It can be placed thus...)

NOTES

NOTES

3. Department 7 has to be placed. It has two squares. It can be placed thus in three ways.

Table 5.10

7	7		
	6	6	
	5		

Table 5.11

	6	6	7
		5	7

Table 5.12

	6	6	
7	7	5	

In the above case we have to find the weighted rating for each department.

WEIGHTED DEPARTMENT RATING

Table 5.13

Closeness relationship	Weighted rating.
A	243
E	81
I	27
O	9
U	1
X	-729

- a. Department 7 with department 6 = E = 81,
Therefore placement rating = 81.
- b. Weighted rating of 7 with 6 = 81
Weighted rating of 7 with 5 = 27

$$\text{Total} = 108$$

Similarly, for the other layout also, the rating is 108.
Thus we have to select either b. or c. layouts... let us take c. layout...

1. Next department 2 has to be placed.

Table 5.14

2	6		6
7	7		5

PLACEMENT RATING = $(27+1) = 28$.
 No other allocation has maximum placement rating...

2. Next department 1 has to be placed. It has the following four possibilities.

Table 5.15

1	1		
2	6	6	
7	7	5	

a.**Table 5.16**

2	6	6	
7	7	5	
	1	1	

b.**Table 5.17**

1	2	6	6
1	7	7	5

c.**Table 5.18**

2	6	6	1
7	7	5	1

d.

PLACEMENT RATING:

- A. Weighted rating with department 6 and 2 = 82
- B. Weighted rating with department 6 and 5 = 10
- C. Weighted rating with department 7 and 5 = 10
- D. Weighted rating with department 7 and 2 = 82

Table 5.19

1	1		
2	6	6	
7	7	5	

The above arrangement is selected randomly (between A. & D.)

6. Next department 4 has to be placed. It has the following five possibilities.

NOTES

NOTES**Table 5.20**

4	1	1	
4	2	6	6
	7	7	5

Table 5.21

	1	1	
4	2	6	6
4	7	7	5

Table 5.22

	1	1	
	2	6	6
	7	7	5
		4	4

Table 5.23

1	1		
2	6	6	4
7	7	5	4

Table 5.24

1	1	4	4
2	6	6	
7	7	5	

e.

PLACEMENT RATING:

- A. Weighted rating with department 1 and 2 = 108
- B. Weighted rating with department 2 and 7 = 82
- C. Weighted rating with department 7 and 5 = 28
- D. Weighted rating with department 6 and 5 = 28
- E. Weighted rating with department 1 and 6 = 28

Table 5.25

4	1	1		
4	2	6	6	
	7	7	5	

The above arrangement is selected.(A.)

1. The last department to be placed is department 3.

Table 5.26

4	1	1	3	
4	2	6	6	
7	7	5		

The above placement of department 3 has maximum placement rating. (Based on REL). Thus the layout is allocated with all the departments as follows.

NOTES

Table 5.27

				4	1	1	3							
				4	2	6	6							
					7	7	5							

Total Score of The Layout:

Total score of the layout is the sum of the products found by multiplying the length of the shortest path between all departments and the numerical closeness value for the pairs.

$$\text{Total score} = \sum_{\text{For all pairs}} (\text{Closeness rating} \times \text{length of shortest path})$$

The path is calculated by the rectilinear distance from the border of one department to the border of the other one.

Therefore, if two departments are adjacent, they will have common border. The path length will be zero.

Total score of the above layout is given as follows:

NOTES

Table 5.28

	Department to	Distance	Closeness	Score
1	2	0	-	-
1	3	0	-	-
1	4	0	-	-
1	5	2	3	6
1	6	0	-	-
1	7	1	2	2
2	3	2	2	4
2	4	0	-	-
2	5	2	4	8
2	6	0	-	-
2	7	0	-	-
3	4	2	2	4
3	5	1	2	2
3	6	0	-	-
3	7	2	2	4
4	5	3	4	12
4	6	1	2	2
4	7	1	2	2
5	6	0	-	-
5	7	0	-	-
6	7	0	-	-
Total				46

Thus the procedure to find the total score ends with this step. One can repeat the procedure with different scales and pick up the best layout with the **MINIMUM TOTALSCORE...**

ALDEP (Automated layout Programming):

ALDEP is a construction type algorithm. This algorithm uses basic data on facilities and builds a design by successively placing the departments in the layout. After placing all the departments in the layout, a score is computed. This is nothing but the sum of the closeness rating values of different neighbouring departments in the layout. This algorithm is repeated for a prespecified number of times and the best layout is selected based on the maximum layout score.

The basic data required for this algorithm are listed below.

1. Total number of departments.
2. Area of each department .
3. Length and width of layout.
 1. Closeness ratings of various pairs of departments in the form of Relationship Chart.
 2. Minimum department preference (MDP) value.
 3. Sweep width.
 4. Number of iterations to be performed.
 5. Location and size of each restricted area in the layout if present.

Steps to be followed:

Step 0.INPUT:

- 1) Number of departments in the layout.
- 2) Area of each department.
- 3) Length and width of the layout.
- 4) REL-CHART (Relationship chart).
- 5) MDP value.
- 6) Sweep width.
- 7) Number of iterations to be carried (N).
- 8) Current iteration number(I),1.
- 9) Locations and sizes of fixed departments if present.
- 10) 10.score of the current layout (It is assumed as a very high negative value before performing the first iteration).

Step 1. Select a department randomly and place it in the layout.

Step 2. Scan the relationship (REL) – chart and classify the unselected departments into two lists, namely List A and List B.

List A contains the unselected departments whose relationship values in relation to the lastly selected department are less than the MDP value.

List B contains the unselected departments whose relationship values in relation to the lastly selected department are greater than or equal to the MDP value.

Step 3. Is the List B empty? If so , go to step 4;otherwise,go to step 5.

Step 4. Select a department randomly from List A and place it in the layout.
go to step 6

Step 5. Select a department from List B which has the maximum REL value in relation to the lastly selected department and place it in the layout.

Step 6. Whether all the departments are placed in the layout? If not go to step 2; if yes, go to step 7.

Step 7. Compute the score of the layout.

NOTES

NOTES

Step 8. Is the score of the layout more than the score of the current best layout? If yes, update the new layout as the current best layout and store the corresponding score. otherwise, drop the new layout.

Step 9. Is the current iteration number $I=N$? if yes, go to step 10; otherwise, increment the iteration number by one ($I=I+1$) and then go to step 1.

Step 10. Print the current best layout and the corresponding score.

STEPS OF ALDEP:

1. Get the inputs. (REL chart, Department area, layout plan)

(A=64, E=16, I=4, O=1, U=0, X=-1024)

The REL diagram for a plant with 11 departments is as follows:

Table 5.29

	1	2	3	4	5	6	7	8	9	10	11
1											
2	A										
3	E	E									
4	U	E	U								
5	O	U	O	O							
6	U	U	U	E	O						
7	X	U	O	O	U	U					
8	U	U	O	O	U	O	A				
9	U	U	O	O	U	I	O	O			
10	U	U	O	O	I	O	O	O	O		
11	U	O	U	A	I	E	A	A	E	I	

- 1) Based on the area of all the departments, fix an appropriate scale. Based on the scale divide the departments in to number of square blocks.

Table 5.30

DEPARTMENT	AREA	NO. OF SQUARES
1	600	12
2	400	8
3	350	7
4	150	3
5	350	7
6	150	3
7	200	4
8	800	16
9	200	4
10	350	7
11	5000	50

NOTES

(SCALE: 1: 50, i.e. each cell in the layout is assumed to be a square of area 50 sq. units).

1. Draw an initial layout based on the layout area or based on the total area of all the departments. Divide the departments in to the basic number of squares. (Sum of all department squares).

1) **ITERATION-1:**

- a. Initially assume a closeness rating of “0”.
- b. Fix a cut-off value for the department selection. (i.e.) “A” or “E” or “I”...
- c. Initially place a department randomly or the department with the max. area.
- d. Then from the candidate (remaining) departments, select a department with the maximum cut-off value with the previously placed department.

2) **SERPENT TYPE ALLOCATION:**

While allocating/placing each department in the layout, it has to be laid out in the following sequence. (Each cell is area of 50 in sq. units... based on the scale).

NOTES**Table 5.31**

Table 5.32

11	11	11	9	10	2	2	7	7	0	0
11	11	11	9	10	2	2	7	0	0	0
11	11	11	9	10	2	2	7	0	0	0
11	11	11	9	10	2	2	8	0	0	0
11	11	11	6	10	1	3	8	0	0	0
11	11	11	6	10	1	3	8	0	0	0
11	11	11	6	10	1	3	8	0	0	0
11	11	11	4	5	1	3	8	0	0	0
11	11	11	4	5	1	3	8	0	0	0
11	11	11	4	5	1	3	8	0	0	0
11	11	11	11	5	1	3	8	0	0	0
11	11	11	11	5	1	8	8	0	0	0
11	11	11	11	5	1	8	8	0	0	0
11	11	11	11	1	1	8	8	0	0	0

- 6) If in there is a tie or no department satisfies the cut-off value during the selection of candidate department, then place a department randomly.
- 7) Calculation of TCR (Total Closeness Rating):
- a. Once all the departments are placed, then the next step is to calculate TCR.

- b. Make a note of all the pair of departments sharing common border with each other. (Note a pair only once i.e. either 1-3 or 3-1).
- c. Now add up all the pairs' REL points...
- d. Then multiply it by 2.

Table 5.33

Pairs	REL points
11-1	0
11-9	16
11-6	16
11-4	64
11-5	4
9-10	1
9-64	
6-10	1
6-4	16
4-5	1
10-2	0
10-5	4
5-1	1
2-8	0
2-3	16
2-1	64
1-3	16
1-8	0
3-8	1
7-8	64
2-7	0
290	

Thus the Total Closeness Rating is $(290 \times 2) = 580$

- 7) This is the TCR value for the initial layout.
- 8) Keeping this as the minimum value continue the steps (4-7) for all the possible layouts and calculate the TCR value for all the layouts. Once iteration results in a TCR value less than the immediately previous layout's TCR value then that layout is the optimal solution.

NOTES

NOTES**Table 5.34**

11	11	11	8	8	6	9	1	1	0	0
11	11	11	8	8	6	9	1	0	0	0
11	11	11	8	8	6	9	1	0	0	0
11	11	11	8	8	4	9	1	0	0	0
11	11	11	8	8	4	3	1	0	0	0
11	11	11	8	8	4	3	1	0	0	0
11	11	11	7	8	5	3	1	0	0	0
11	11	11	7	8	5	3	1	0	0	0
11	11	11	7	8	5	3	1	0	0	0
11	11	11	7	8	5	3	1	0	0	0
11	11	11	11	10	5	3	1	0	0	0
11	11	11	11	10	5	2	2	0	0	0
11	11	11	11	10	5	2	2	0	0	0
11	11	11	11	10	10	2	2	0	0	0
11	11	11	11	10	10	2	2	0	0	0

Total Closeness Rating:

Table 5.35

Pairs	REL points
11-8	64
11-7	64
11-10	4
8-7	64
8-10	1

8-6	1
8-4	1
8-5	0
10-5	4
10-2	0
6-9	4
6-4	16
4-5	1
4-9	1
4-3	0
5-2	0
5-3	1
9-1	0
9-3	1
3-2	16
3-1	16
1-2	64
319	

NOTES

Thus the Total Closeness Rating is $(319 \times 2) = 638$.

Thus Iteration 2 shows that layout 2 has high TCR value compared to layout 1. Thus layout 2 is an optimal one compared to layout 1. Similarly, iterations are continued to find the optimal layout.

a. LINE BALANCING

This is a technique applied to design workplace of a plant, which adopts flow line production system. You know that the productive system of flow line production produces less variety and standardized products. So the capacity of the system is to be established first or the no. of units produced per day.

NOTES

Figure 5.17 – Line Balancing



Objective: To design an effective and efficient workplace.

Input:

Capacity:

The capacity as it is mentioned already that the capacity is measured through the output. In an automobile industry it may be number of cars to be produced in a day. To decide the capacity you need to have the information about the demand for the product. Yearly demand has been converted into day to day capacity requirement.

Technological constraints:

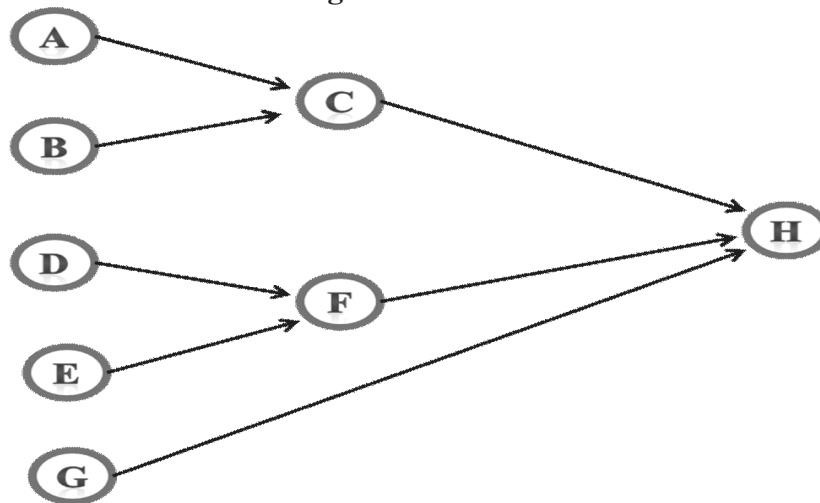
Technological constraint that means when you are manufacturing a product, there is a sequence in which the operation on the components is to be carried out then the produced components are assembled according to the particular sequence. For example in the case of electric motor manufacturing activity the activities and immediate predecessor activity to be carried out are given below:

Table 5.36

Activities	ImmediateActivities	Min
A Axle manufacturing	-	700
B Rotar manufacturing	-	800
C Rotar assembly	A, B	400
D Stator manufacturing	-	200
E Stator cashing manufacturing	-	400
F Stator assembly	D, E	300
G Protective shield manufacturing	-	500
H Final assembly	C, E, F	300

The above relationship could be shown in a network form as follows for clear understanding.

Figure 5.18

**Available Working time:**

The available working time is the total working hours available based on the time frame. Example: if the capacity calculation is done for the day then the available hour's calculation is done for day. If there is one shift of 8 hours duration then the available time in seconds is calculated as $8 \times 60 \times 60$ second.

$$= 28,800 \text{ seconds}$$

Technological constraint continuation:

Each activity is considered to be an element. An element is a distinct that of a specified job. This is done for the purpose of observation, measurement and analysis. Against each element the time for completing the activity is also estimated.

Output:**Number of stations:**

Based on the available working time per day, the no. of units to be manufactured, and the total work content, the no. of stations are calculated as follows:

$$\text{No. of stations} = 3600 \times 35 \text{ units}$$

$$\begin{aligned}
 &= \frac{[\text{Total work content per unit}] [\text{Desired no. of units per day}]}{\text{Total productive time available per day}} \\
 &= 8 \times 60 \times 60 \\
 &= 4.375 \\
 &= 5 \text{ stations}
 \end{aligned}$$

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Maximum allowable time:

From this you can calculate the maximum allowable time for each station

$$= \frac{\text{Total available hours}}{\text{Desired no. of units per day}}$$

$$= 8 \times 60 \times 60 / 35$$

$$= 823 \text{ seconds.}$$

Minimum Allowable time:

This is the highest elemental time. In this example the highest elemental time is 800 seconds. The maximum and minimum allowable time helps you to assess the efficiency and effectiveness of the proposed designs.

Assignment of the job elements to the workstations:

A method is to be adopted to assign the jobs to workstations. The method may be an optimal method or heuristic method. In heuristic method, you may get best solution but there is no guarantee that you may get a solution. But it helps to get nearer to best solution. One such a procedure is the longest operation time (LOT) Remaining. Longest Operation time remaining means after assigning a particular task to a work station. You should find out the remaining unassigned elements and choose the element with highest operation time. Then add the element with the already assigned element. You should be careful enough that the total element time in a particular workstation should not exceed the cycle time established. Suppose the element considered for assigning could not be assigned because the total elemental time at the workstation increased beyond the cycle time, then in such case, you should look for the next highest remaining elemental time. The above mentioned caution is to be followed before assigning the element to the work station. Thus process is continued till all the elements are assigned.

Assignment of elements for 823 seconds work station cycle time

Table 5.37

B	A	C & E	D & F	G & H
I WS	II	III	IV	V
	WS	WS	WS	WS

WS – Work

Station I:

Consider the highest elemental time. This is element B it could be straight away assigned to station because it does not have any predecessor. Next 5 highest elemental time is 700 that is element A. But element A could not be assigned because if you assigned A the stations sum of elemental time exceeds the time cycle time 823 seconds. This reason holds good for other remaining elemental times.

Station II:

In Station II you can assign element A. This has elemental time of 700 second. You can not assign any remaining elements to station II because the total elemental time exceeds the cycle time.

Station III:

In Station III the remaining highest elemental time is 500 minutes that is of element G. But before assigning the activities, you should complete other activities as per the technological constraints. So next highest operational elements are C & E, so C & E are assigned to station III. No. other elemental could be assigned to station III.

Station IV:
Table 5.38

Line design for 800 seconds

B	1	2	3	4	5	Effectiveness	Efficiency	
	A	C&D	E&F	G&H	Goal accomplishment		Utilization of employee	
Time required per unit in each station	800	700	600	720	800	$28800/800 = 36$ Units	3620	
Available time each work station	800	800	800	800	800		4000 90.5%	Utilization = $3620/4000 =$
Idle time per cycle	0	100	200	80	0		380	Idle time = $380/4100 =$ 9.26%

Next highest unassigned element is G. For the same reason spelt out previously. They are not allotted to station IV then you can go for allocating next highest elements namely D & F.

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Station IV:

Then In the remaining unallotted elements, element G is allotted first and then H.

The efficiency and effectiveness

The efficiency and effectiveness of the LOT method is shown below:

Suppose if you adopt minimum allowable cycle time 800 seconds. On the basis for the allocation of elements, then the elements to be assigned will be as shown as below:

Next highest unassigned element is G. For the same reason spelt out previously. They are not allotted to station IV then you can go for allocating next highest elements namely D & F.

Station V:

Then In the remaining un allotted elements, element G is allotted first and then H.

The efficiency and effectiveness

The efficiency and effectiveness of the LOT method is shown below:

Suppose if you adopt minimum allowable cycle time 800 seconds. On the basis for the allocation of elements, then the elements to be assigned will be as shown as below:

Table 5.40

B	A	C & D	E & F	G & H
I	II	III	IV	V

Table 5.41

Line design for 800 seconds

B	1 A	2 C&D	3 E&F	4 G&H	5 Goal	Effectiveness accomp- lishment	Efficiency Utilization of employee	
Time requi- red per unit in each station	800	700	820	500	800	$28800/800 = 35$ Units	3620	
Available time each work station	820	820	820	820	820		4100 88.29%	Utilization = $3620/4100 =$
Idle time per cycle	20	120	0	320	20		480	Idle time = $480/4100 =$ 11.71%

NOTES

As you have seen the second design consists of 800, as the cycle time stands better in terms of efficiency and effectiveness compared to the first design. Employee idleness could be reduced tasks. Thus results in reduction in no. of the employee.

Till now it is assumed that the elemental time is deterministic but there is a possibility that the more manual elements involved in the task you can't get the single elemental time, in this case usually the elemental time follows certain distribution. You can design the workplace or product layout by considering the stochastic time elements also.

Review Question:

1. What are the types of layout?
2. What are the techniques used in layout planning?
3. Define line balancing and why is it required?
4. What is minimum allowable time?

5.7 TIME STUDY AND WORK MEASUREMENT

Work study consists of two major phases namely method study and work measurement. In an industry method study is applied with an objective of simplifying the job and finding the best method of doing work. Method study paves the way to reduce the work content due to bad working methods, bad layout, wrong selection of tools etc. Work measurement is applied with an objective to reduce the ineffective time and to set the standards. Usually in the industry the method study is applied to ensure the correct methods, process etc. Then, for the best method - the measurement of the method is carried out.

According to **ILO**, Work measurement is defined as follows:

“Work measurement is the application of techniques designed to establish the time for a qualified worker to carry out the job at a defined level of performance” Now each key term requires a kind of explanation:

Who is qualified worker?

Qualified worker is one who has the requisite physical attributes, requisite intelligence and education, requisite skill and knowledge. With the above mentioned qualities, he can complete the work to meet the satisfactory standards of safety, quality and quantity.

Average worker:

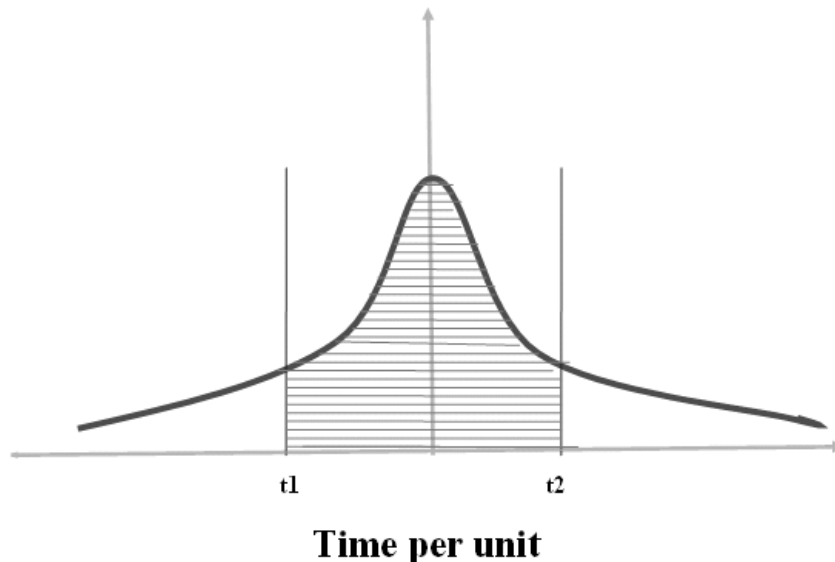
All the recruited workers are qualified workers. But if you analyze their performance. The performance may be the time taken per unit by the worker. Assume that

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there are 500 workers; if you analyze their performance; the performance against the frequency mostly follows the normal distribution.

Figure 5.19

Frequency



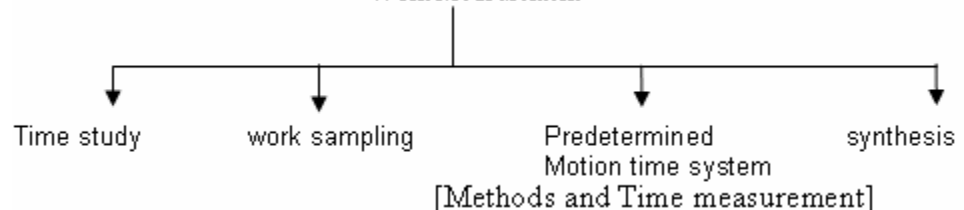
The shaded portion represents the majority of the worker that means more workers take time to produce one unit between t_1 and t_2 . The no. of employee fall in the region you can consider as the qualified average workers. The unshaded portions in the left side represent above average performance and the unshaded portion of the right side represent the below average performer. Since most of the workers performance falls in the shaded area. The organization has to set the time standard for the average workers.

Work Measurement Techniques

There are many techniques available to measure the work. The techniques are listed below:

Figure 5.20

Work Measurement



Procedures to conduct work measurement technique: According to ILO

- SELECT : Select the job to be studied.
RECORD : Record all the relevant facts by direct observations or by means of suitable recording technique.
EXAMINE : Examine critically the recorded elements.
MEASURE : Measure each element by time measurement.
COMPILE : Arrive at the normal time and standard time by adding allowance.
INSTALL : Implement the established standard time.

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5.7.1 Time Study

Select:

First you should select the job to be studied. Situations may lead you to conduct the time study to fix the time standard.

a) SITUATION:

1. Organization requires time standard to introduce incentive scheme
2. To determine the no. of equipment and no. of workers, you need to conduct work measurement technique.
3. To fix the standard cost, particularly to determine the labor cost, you need time standard.
4. To determine the selling price, tender price and to promise the delivery time you need to have time standard.

Record:

After selecting the job you should note down the surrounding conditions like working place, layout condition and see to that the worker adhere to the methods suggested by the method study.

Examine:

Next you should divide the job into different elements. Suppose you have to fix time standard for the job which involves drilling operation. The elements are:

1. Selecting the work piece and placing it in jig.
2. Tightening the screw.
3. Advancing the drill towards the work piece.
4. Drilling.
5. Withdrawing the drill from the operation.
6. Loosening the screw.
7. Removing piece from jig.
8. Removing the chips.

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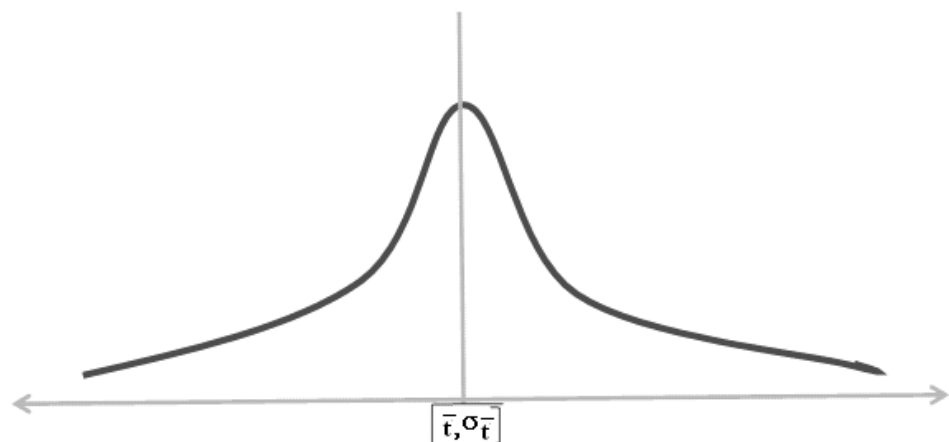
The purposes of the dividing jobs into different elements are to time the elements accurately and also to have a distinguishable starting and ending points for each element.

Measure:

After dividing the jobs into different elements, the number of observations to be made on each elements is to be determined. Here a trade off is to be made between the accuracy of the result and the cost of the time / study. If you take more observations, results in more accuracy in the result. You can know now, how do you determine the sample size statistically.

To determine the sample size statistically you have to specify the desired accuracy and the confidence level. Suppose you need 5 % accuracy result and 95 % confidence level. Assume that the sampling mean follows normal distribution. \bar{t} is the mean.

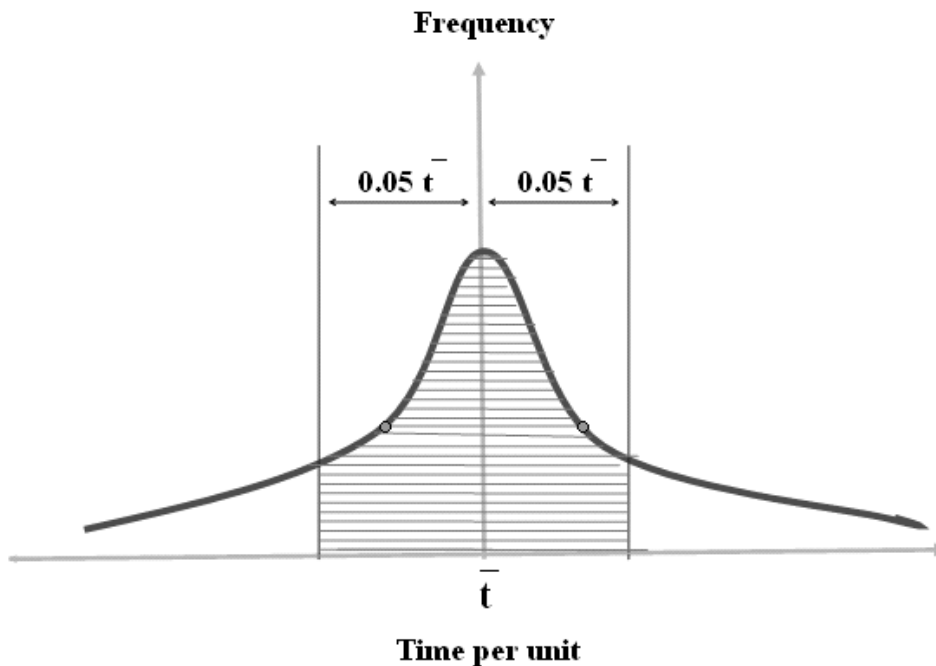
Figure 5.21



Time per unit

Of the elemental time, t is the standard error of the sampling distribution. **A 95 % confidence level and $\pm 5\%$ accuracy level means that the changes are at least 95 out of 100 that the average value for the element will not be in error when you allow more or less 5 % of true element time.**

The above bold statements showed pictorially as below:

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From the above figure, you can arrive $Z \sigma_{\bar{t}} = (\text{accuracy level}) \times (\bar{t})$

At 95% confidence limit and 5% accuracy level, the Z value from the normal distribution is 1.96.

$$1.96 \sigma_{\bar{t}} = .05 \bar{t} \quad \text{————— 1}$$

You know the relationship between the population standard deviation and standard error of the sampling distribution.

$$\sigma_{\bar{t}} = \sigma / \sqrt{n} \quad \text{————— 2}$$

Where n is the sample size, σ is the population standard deviation. Substitute the value of $\sigma_{\bar{t}}$ in equation 1.

$$1.96 \sigma / \sqrt{n} = .05 \bar{t}$$

$$1.96 \sigma / .05 \bar{t} = \sqrt{n}$$

$$n = (1.96 \sigma / .05 \bar{t})^2$$

Here, usually the population standard deviation is not known. In this case is estimated from the pilot study. Suppose the number of samples to be taken is less than pilot study, then you need not go for further sample collection. But the number of samples to

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be determined is more than the pilot study samples, then more sample need to be collected.

This process is continued for each element. But there is a possibility that in each element you may end up with different sample size requirements. In this case you can fix the number of cycles for the all the elements based on the element which demands the highest sample size requirement.

Measure:

In this phase, the elemental time is recorded using stop watch which is specifically designed for the **time study**.

Rating:

While measuring the time for each element, the time study person has to take note of the **pace** in which the operator does the job. The accuracy of the judgment towards the pace of the operator depends upon the experience and training of the time study person. **Rating is defined as the workers rate of working relative to the time study person's concept corresponding to the standard pace.**

Rating is an adjustment factor, because when a time study person choose a qualified, experience, trained worker there is a possibility that the operator may belong to the below average group of that company in this case he may take more time to complete the element. So to bring the time related to the average worker, which observed time has to be multiplied with the adjustment factor i.e. or other wise to lessen the observed time. In this case rating will be less than 1. This case becomes opposite while the supposed selected operator is above average worker. In this case the rating factor takes more than 1 to have higher observed time than what is available.

$$\text{Rating} = \frac{\text{Observed rating}}{\text{standard rating}}$$

$$\text{Standard rating} = 100$$

Compile:

After obtaining the observed time, rating for each element Normal time is calculated.

Normal time for element = observed time for the element x rating factor

All the normal elemental times are added to arrive at the normal time for the operation.

You should not consider this time as standard time because you should add allowances with the normal time. Because allowances are to be given to compensate for the energy that the operator spent while doing the job and also allowances are to be added for meeting his / her personal needs like going for toilets etc. Allowance for these reasons is beyond his control.

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Allowances are personal allowances, fatigue allowances and delay allowances. Personal allowances for meeting his / her personal needs, fatigue allowances are allowed for physical exertion. Delay allowances are due to lack of materials, random inspection visits etc.

Now the standard time is arrived as follows:

Standard time = Normal time x 100 / [100 - % allowance]

5.7.2 Work sampling:

Work sampling is another work measurement technique for measuring the following:

- To measure & control the percentage of idle time of an activity or productive resource
- To establish the standard time
- To determine the performance index of the operator / department / unit

When do you apply work sampling technique:

- Jobs consists of longer lead time
- To measure the team work

Let us consider the first application namely to measure & control the percentage of idle time of an activity or productive resources.

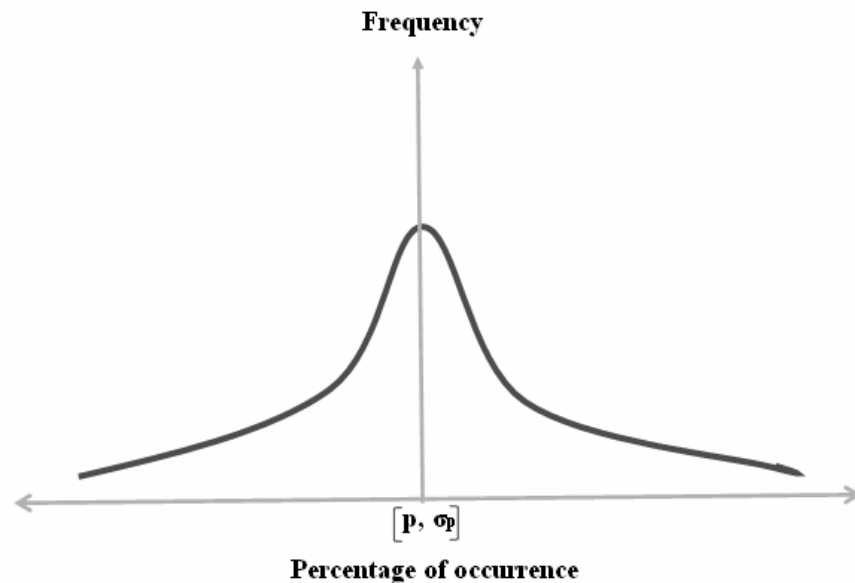
Usually in any organization, the management bothers very much about the utilization of key productive resources. Work sampling study used to identify the percentage of idle time and it helps the management to correct the excessive idle time. It helps in fixing idle time control chart so that management can control the idle time percentage of the so called critical resources every time.

Consider in a hospital X- ray equipment is very critical. The management of the hospital wants to establish a control chart to monitor and control the idleness of the X- ray machine.

To fix this standard, first nothing has to determine how many observations to be made. To determine the no. of observations you should analyze the process of conducting this study. This study is nothing but a random process. There are two outcomes of this random process, one is the X ray machine is working, and another outcome is X- ray machine is not working. So there is every possibility that the outcome to follow a binomial distribution. Based on the percentage of occurrence of activity (in this case idle) 'P' and the no. of trials 'n' binomial distribution is approximated into a normal distribution.

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Figure 5.23



σ_p is the stand error of this sampling distribution

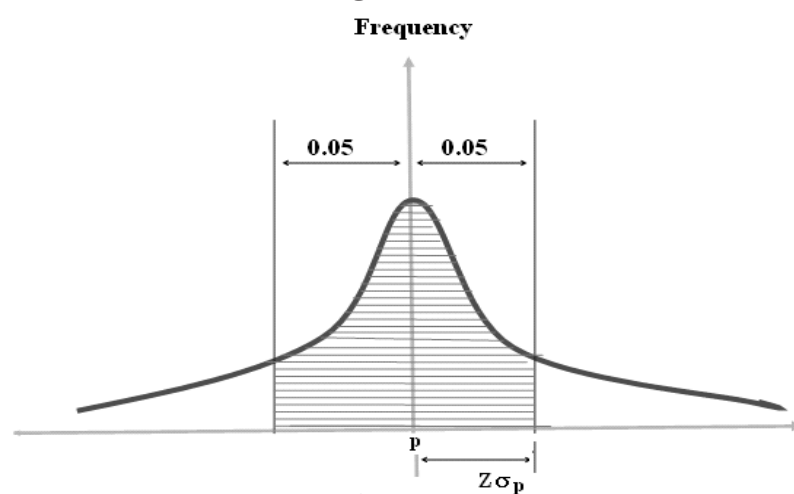
$$\sigma_p = \sqrt{P(1-P)/n}$$

n = sample size

p = percentage of occurrence of the activity to be measured.

As it is required in the Time study, here also to determine the no. of cycles to be determined, you need to specify the two parameters namely the confidence interval and accuracy. Assume 95% confidence limit and 10% accuracy value. 'P' is estimated from the past record that $p = 20\%$ suppose 'P' is not available, then you should conduct a pilot study to determine the 'P' then the sample size is determined as follows:

Figure 5.24



General formula

$$Z \cdot \sigma_p = SP$$

Where S = accuracy level

$$Z \cdot \sqrt{P(1-p)/n} = SP$$

$$n = Z^2 P(1-p) / P^2 S^2$$

$$= [Z^2 / S^2] (1-p) / p$$

For 95% confidence limit and 10% accuracy value

$$n = [1.96/.10]^2 [1 - .20/.20]$$

$$n = 1537 \text{ observation}$$

Timing of the activity to be measured

Next you should decide to schedule the timing of the observation to be measured. For this you should generate random numbers through the computer or random number tables. Assume that the hospital is working for 16 hours. Then generate three digit random numbers. Working time of the hospital is given as below:

Table 5.42

Shifts	Starting time	Break	Ending time
I	8 A.M.	12- 1 P.M.	5 P.M.
II	5 P.M.	9- 10 P.M.	2 A.M.

First digit represents the number of hours after 8 A.M. Second and third digit help us to find the minutes. The following table shows the conversion of random numbers in to timing.

Table 5.43

Random Number	Hours after start	Observation time	Chronological order
712	7.12	3.07	3
473	4.73	12.44	Lunch hour
482	4.82	12.49	Lunch hour
116	1.16	9.01	1
311	3.11	11.07	2

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You can know how do you convert the random number 712 into 3.07 AM. 7 represents the time after the starting of the factory. Namely, 8 AM then it is 3'o clock. Second and third digit represents 1 and 2 represents 0.12 X 60 minutes 7.2 minutes, that means the observer has to observe the position of X ray machine after 3.07 Hrs. Similarly the no. of random numbers are converted into observer observable time. Suppose you have got the results as shown in the table

Table 5.44

Activity	No.of observation
X Ray machine is working	1227
X Ray machine is not working	310
Total Observation	1537

The percentage of idle time is calculated as follows:

$$'p' = 310/1537 = 20\%$$

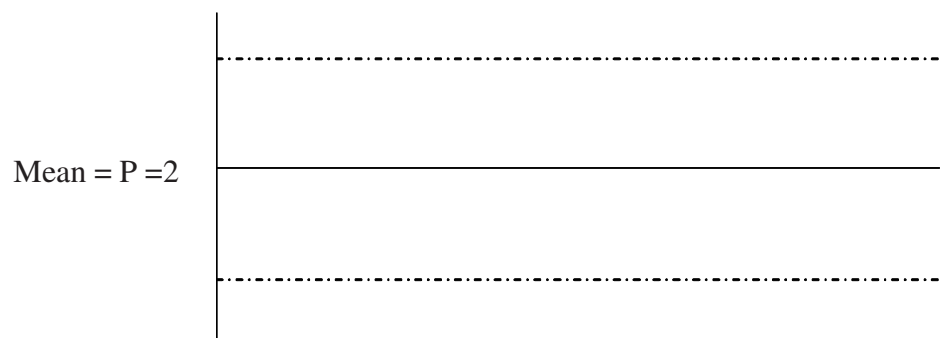
In this case you need not go for further observations. Suppose the obtained 'p' value is more than the allowable limit, then you need to rework to find the no. of observations to be taken. Suppose, if it comes around 1600,m then further (1600 -1537) so 63 observations has to be taken to fix the standard

$$\text{Now } \sigma_p = \sqrt{\frac{-2 \times 8}{1537}} = 0.1$$

You can fix the control limit using P and σ_p value as follows:

Figure 5.25

Upper control limit $P + 3 \sigma_p = 0.23$



Lower control limit $P - 3 \sigma_p = 17$

NOTES

This is kept as a standard and any particular day, proportion of idle time exceeds the limit you have fixed, then the reasons has to be analyzed and corrected. Thus the work sampling techniques used to fix the standard to monitor and control the key resources.

Establishing Time Standard by Work sampling:

Work sampling study in addition to finding the performance index, fixing the control limits for delay and percentage of utilization of activities, it also used for establishing the time standard for operation or for the job.

Data required to be collected:

Assume that an operator does a turning operation in a part. By work-sampling study to determine the time standards the following information is to be collected.

- The percentage of working.
- The total working time.
- The Number of pieces to be produced.
- The average performance index.
- The allowance.

The normal time per unit is calculated using the following formula.

$$\text{Normal Time} = (\text{The percentage of working}) (\text{Total working time}) / \text{No. of Pieces product}) \times \text{Average performance index.}$$

Then standard time is calculated follow as:

Standard time

$$= \text{Normal time} (100/100 - \% \text{ Allowances})$$

E.g.: An operator does a turning operation in a product. An observer collected the following information.

- The percentage of working = 85%
- The total working time = 480 min.
- The no. of pieces produced = 300 units
- The average performance index = 120
- Allowances from the time study manual is arrived at 15%

$$\begin{aligned} \text{Normal time} &= (0.85 \times 480) / 300 (120/100) \\ &= 1.632 \text{ min.} \end{aligned}$$

$$\begin{aligned} \text{Standard time} &= 1.632 \times 100 / (100 - 15) = 1.632 \times 100 / 85 \\ &= 1.92 \text{ min.} \end{aligned}$$

Work Sampling study to establish the performance index:

This study is applied to establish the average performance index. This average performance index of the labour or department helps the management to control the

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labour cost. Let us see how you calculate the average performance index. The work sampling study may be carried out for many periods for data collection. Then from the data collected you can calculate the average performance index as follows:

Average Data per period from the data collected during the study.

- Average no. of pieces produced during the period
- Standard time per unit.
- Average working time.

Performance index = [(Average no. of pieces produced during the period x Standard time

per piece in minutes) / Average hours worked during the
period x 60] x 100

E.g. Assume that a drilling operation is carried out on a product. The organization interested in knowing the average performance index of the operator who does the drilling operation. Work sampling study has been conducted for several weeks. The average data collected from the study are given below:

Average no of pieces produced during a week = 1500

Standard time per piece per min. = 5 min.

Average hours worked during the period = 36 hours

Performance index = $[500 \times 5 / 36 \times 60] \times 100$
= 115 %

The average performance index helps the organization to control the labour cost.

a. LEARNING CURVE

In the case of more labour intensive mass production industry, mostly the labour do repetitive type of job, that results in more learning due to experience of doing the same job because of this, the time taken to produce subsequent units gets reduced compared to the previous units. This phenomenon will not lose for longer period, at some point of the time this learning effect ceases. After the learning effect ceases, the time required to produce one unit or one batch will be the same irrespective of the number of units or batches. The organization has to cash in the relevant range period, the period in which the learning effect is there. During the learning effect period, the standard time per unit is not constant it varies depends upon the quantity of the order you get. Since the learning effect has impact on the standard time that is the reason to study this concept in this section .

Learning Curve Model:

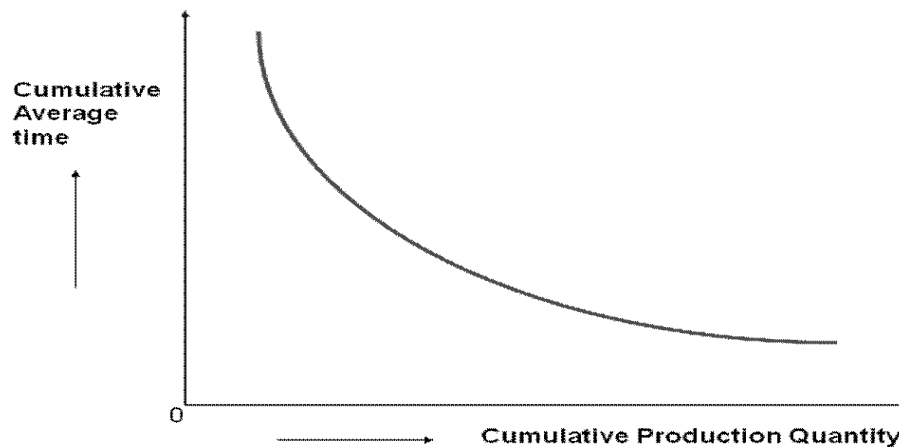
Consider the past data of a company manufacturing Aircraft components. For a particular component the data are taken for ten situations.

Table 5.45

Situation	Quantity (Q)	Production Time (tp)	Cumulative batches (1) Time (2)	Cumulative Production (3)=(2) / (1)	Cumulative Average Time
1	20	164	20	164	8.2
2	30	228	50	392	7.84
3	50	340	100	732	7.32
4	80	453	180	1185	6.58
5	120	655	300	1840	6.13
6	150	767	450	2607	5.79
7	210	863	660	3470	5.26
8	260	1115	920	4595	5
9	330	1488	1250	6083	4.86
10	380	1311	1630	7394	4.37

Using (1) and (3) if you draw the curve, it appears as follows

Figure 5.26



Since the nature of the curve is exponential, the general equation for exponential curve is

$$Y = a \times X^b$$

Y = cumulative average time

X = Cumulative production quantity

a = The time required to produce the first quantity

b = Exponent

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'b' depends upon the operating condition. In the above model, for the particular cumulative production quantity what will be the cumulative average time? This could be easily calculated provided, if you know the two parameters namely 'a' and 'b'. Since the curve is exponential in nature, if you take the logarithm for the X value and Y value then you can get a linear curve as follows:

$$\text{Log (Y)} = \text{Log (a)} + b \times \text{Log(X)}$$

Thus the curve is of the form

$$Y = a + bx$$

Where

$$y = \text{Log (Y)}$$

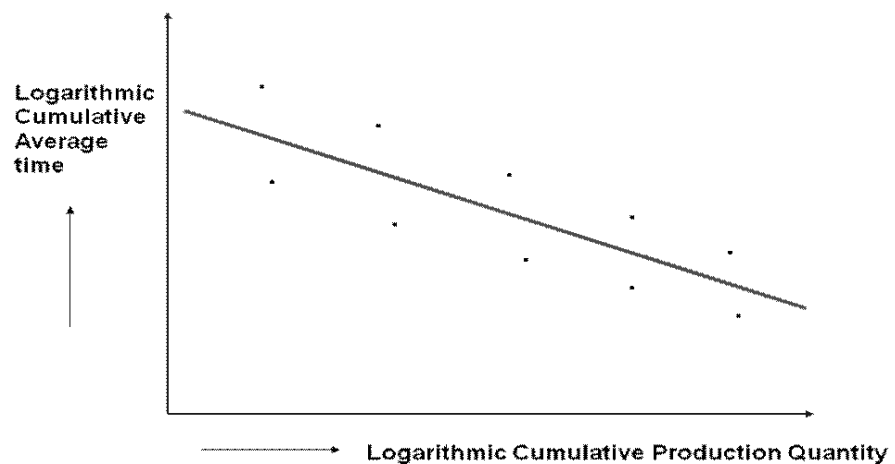
$$x = \text{Log(X)}$$

So using the simple regression analysis you can find the values of 'a' and 'b'. For the given data, shown in the table, let us try to estimate the regression model,

Table 5.46

log X	log Y
2.995	2.104
3.401	2.059
3.912	1.99
4.382	1.884
4.787	1.813
5.01	1.756
5.347	1.66
5.56	1.609
5.799	1.581
5.94	1.513

If we solve
Figure 5.27



$$\log Y = 2.7555 - 0.263 \ln x.$$

Where,

$$R^2 = \text{Coefficient of determination} = 0.985$$

$$R^2_{\text{adjusted}} = 0.983$$

Since R^2 value is approximately 99%, which means 99% of the variations in the original data have been captured by the estimated regression line. Thus show that the estimated line is the best fit for the original data.

Cumulative average time

$$\ln Y = 2.7555 - 0.203 \ln X$$

You know that

$$b = \ln \text{ learning curve percent} / \ln 2.$$

$$-0.203 = \ln \text{ learning curve percent} / \ln 2.$$

$$\begin{aligned} \ln \text{ learning curve percent} &= \ln 2 * (-0.203) \\ &= 0.6931 * (-0.203) \\ &= -0.1407. \end{aligned}$$

$$\begin{aligned} \text{Learning curve percent} &= \text{Antilog of } [-0.1407] \\ &= 86.88\% \\ &= 87\%. \end{aligned}$$

The practical meaning of learning effect or the learning curve percent is that if the production quantity becomes double, then corresponding required time to produce one unit of that doubled quantity gets reduced to that extent of (1- learning curve percent). This is shown in the following table for the problem discussed already.

Table 5.47

UNIT Assume 20 units = 1 units	Cumulative average time ($Y = a * b$)
20 = 1 units	$Y = 164 (1-0.203)$
40 = 2 units	$Y = 164 (2-0.203)$
60 = 3 units	$Y = 164 (3-0.203)$
80 = 4 units	$Y = 164 (4-0.203)$

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From the above table you can easily identify that when the production quantity becomes double; the average time per unit gets reduced to the extent of 13%. So this is to be taken into account while calculating the standard time for the product. Thus way the standard time gets reduced.

Application of learning curve:

As it is mentioned already the reduced standard time could be made use of estimating the following,

1. Learning curve concept could be applied in pricing the product.
2. This concept could be applied in standard costing.
3. This is applied in budgeting and production planning.

5.9 PRODUCTIVITY

Productivity is the ratio between the output and input. This is an index, the output may be sales and input is the resources utilized for getting the output. Example: the output is sales value and the input is cost of goods sold.

$$\text{Productivity} = \frac{\text{Sales}}{\text{Cost of goods sold}}$$

If the Productivity Index is more than one, you can say that the performance of the organization is good. If it is less than one you can say that the organization is not doing well.

Impact of Learning Curve on the Productivity

Cost of the goods sold is the function of labour, material and overhead cost because of learning effect the time required to produce one unit in the relevant range decreases as the number of units produce is more. The result is less labour and variable overheads. So the denominator decreases that leads to higher productivity. There are many reasons for the improvement in the productivity. The increase may due to quality, methods, materials, better management etc. in addition learning effect also have a source for the productivity improvement.

Summary

This unit would have helped you to know the factors to be considered while selecting a location. The kind of system design, like layout design, work measurement standards are exposed with an objective of complete understanding the nuances of the system design techniques. At last, you are exposed to the construction and the impact of the learning curve on the productivity.

Review Questions:

1. List the various work measurement techniques.
2. List out the procedures to carry out the work measurement.
3. What is time study?
4. Define work sampling?
5. What is impact of learning curve on productivity?

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