POLITEKNIK MALAYSIA

MANUFACTURING SYSTEM AND CONTROL

FOR MALAYSIAN POLYTECHNICS

FIRST EDITION

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for malaysian polytechnics
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Dedication

To our families for their unwavering support, encouragement, and understanding throughout this journey,
and to all students of Politeknik Malaysia — may this eBook guide your learning journey towards excellence and innovation.

PREFACE AND ACKNOWLEDGEMENT

The idea for this eBook emerged when we learned that two separate subjects — Manufacturing System and Manufacturing Control — would be combined into a single integrated course titled Manufacturing System and Control. This integration inspired us to develop a comprehensive reference that could help students understand the new syllabus more effectively and holistically.

As lecturers, we realized that many students needed a resource that bridges theory and practical applications, presented in a concise and accessible way. Hence, this eBook was written to serve as a learning companion, aligning closely with the course outcomes and supporting students in mastering key concepts of manufacturing systems, process layouts, lean operations, industrial robotics, forecasting, production scheduling, and material requirement planning (MRP).

Beyond its academic purpose, this book is also a reflection of our shared intention to contribute to *ilm* (beneficial knowledge) as a form of ongoing charity. The Prophet Muhammad (peace be upon him) reminded us that when a person passes away, all their deeds come to an end except three: ongoing charity, beneficial knowledge, and a righteous child who prays for them. It is our sincere hope that this eBook will continue to benefit students and educators, and that its use will be a continuous source of reward for us and for all who share and teach from it.

We would like to extend our heartfelt appreciation to Politeknik Malaysia, our colleagues at the Department of Mechanical Engineering, and all those who have supported us in the writing and publication of this eBook. Special thanks are due to our students, whose curiosity and enthusiasm for learning continue to inspire us to teach and create better learning materials.
May this humble work serve its purpose — to enlighten, to guide, and to inspire excellence in the study of *Manufacturing System and Control.*

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MRP PROCESS
SALES ORDER
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PLANNED RELEASE
PURCHASING & PRODUCTION

CHAPTER 1

INTRODUCTION TO MANUFACTURING SYSTEM AND OPERATION MANAGEMENT

This chapter introduces the basic concepts of manufacturing systems and operations management. It explains how organizations plan, organize, and manage resources to produce goods efficiently. Students will also learn key organizational principles and structures used in manufacturing environments.

DEFINITION AND CONCEPT OF THE MANUFACTURING SYSTEM

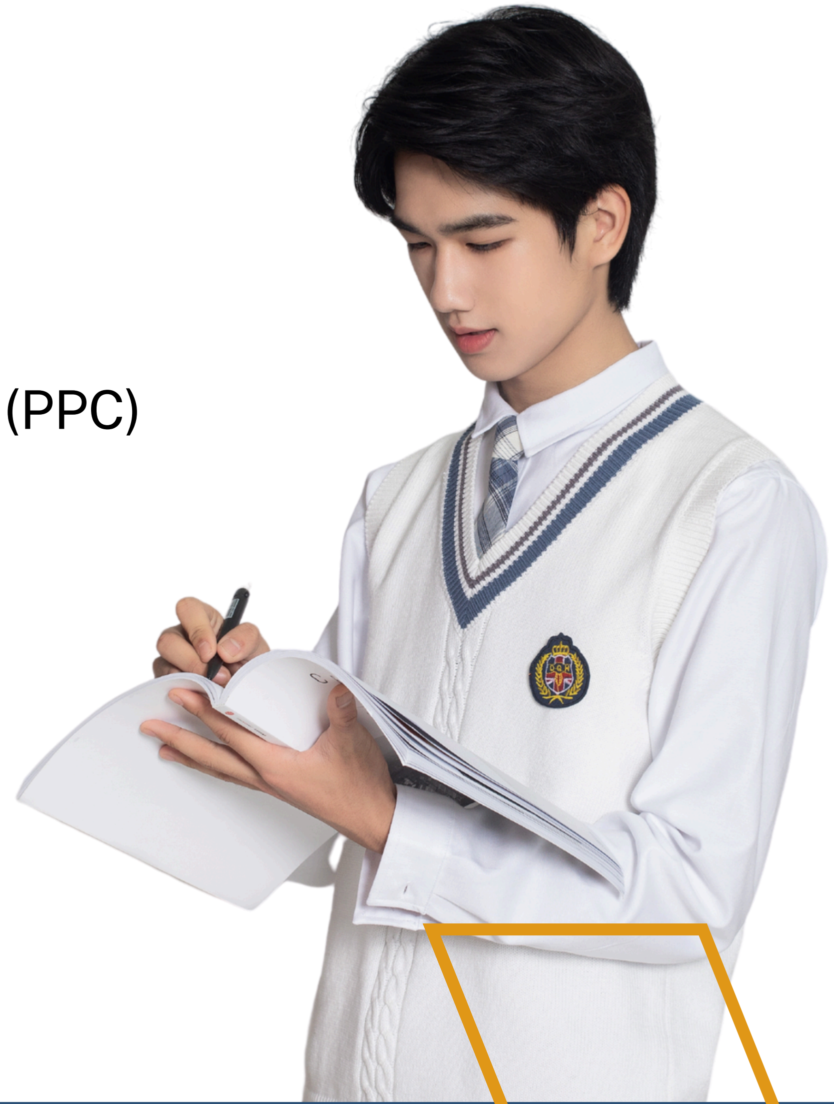
Manufacturing System

A manufacturing system is an integrated arrangement of resources, processes, and activities used to transform raw materials into finished products that meet customer requirements in terms of quality, cost, and delivery time.

It consists of people, machines, materials, methods, information, and energy that work together in a coordinated and controlled environment. The system begins with product design and planning and ends with inspection, packaging, and distribution.

Key Components of a Manufacturing System

1. *Input*
    - Raw materials
    - Labor (operators, engineers, technicians)
    - Machines and tools
    - Information (design data, production schedules)
2. *Transformation Process*
    - Machining, forming, casting, welding, assembly
    - Inspection and quality control
    - Material handling and storage
3. *Output*
    - Finished goods or components
    - By-products or waste
4. *Control System*
    - Production planning and control (PPC)
    - Inventory control
    - Quality management systems



DEFINITION AND CONCEPT OF THE MANUFACTURING SYSTEM

Manufacturing System

Types of Manufacturing Systems

1. *Job Shop Manufacturing* – Low volume, high variety (e.g., custom workshops)
2. *Batch Manufacturing* – Medium volume and variety (e.g., garment production)
3. *Mass Production* – High volume, low variety (e.g., automobile assembly)
4. *Continuous Manufacturing* – Non-stop production (e.g., chemical plants)
5. *Flexible Manufacturing System (FMS)* – Computer-controlled machines capable of producing different products with minimal setup time

DEFINITION AND CONCEPT OF THE MANUFACTURING SYSTEM

Manufacturing System

MANUFACTURING SYSTEM DIAGRAM

INPUT

- RAW MATERIALS
- LABOR
- MACHINE
- INFORMATION
- ENERGY

TRANSFORMATION PROCESS

- MACHINING
- FORMING
- ASSEMBLY
- INSPECTION
- MATERIAL HANDLING

OUTPUT

- FINISHED GOOD
- SEMI-PRODUCT
- WASTE

CONTROL AND FEEDBACK

- QUALITY CONTROL
- PPC
- INVENTORY CONTROL

DEFINITION AND CONCEPT OF THE MANUFACTURING SYSTEM

Manufacturing System

MAIN ELEMENTS OF A MANUFACTURING SYSTEM

Man (Labour)
- Operators, technicians, engineers

Machine
- CNC machines, tools, equipment

Material
- Raw materials, components

Method
- Standard operating procedures (SOP)

Money
- Production cost, investment

Information
- Drawings, schedules, production data

TYPES OF MANUFACTURING SYSTEMS

TYPE	DESCRIPTION	EXAMPLE
JOB SHOP	LOW VOLUME HIGH VARIETY	WORKSHOP
BATCH	MEDIUM VOLUME	CLOTHING FACTORY
MASS PRODUCTION	HIGH VOLUME	CAR ASSEMBLY
CONTINUOUS	NON-STOP PROCESS	OIL REFINERY
FLEXIBLE MANUFACTURING SYSTEM (FMS)	AUTOMATED AND ADAPTABLE	CNC CELL

DEFINITION AND CONCEPT OF THE MANUFACTURING SYSTEM

Importance of Manufacturing

Manufacturing plays a vital role in economic development, technological advancement, and societal growth.

1. *Economic Growth*
   - Contributes significantly to Gross Domestic Product (GDP)
   - Generates employment opportunities
   - Encourages industrialization and national income growth

2. *Value Addition*
   - Converts low-value raw materials into high-value finished products
   - Enhances the market value of natural resources

3. *Technological Advancement*
   - Drives innovation in automation, robotics, CAD/CAM, and Industry 4.0
   - Improves product quality and production efficiency

4. *Support to Other Industries*
   - Supplies machinery, tools, and components to sectors such as:
     - Automotive
     - Construction
     - Electronics
     - Healthcare

5. *Improvement of Living Standards*
   - Produces essential goods such as:
     i. Food products
     ii. Medical equipment
     iii. Household appliances
   - Makes products more affordable and accessible to society

6. *Global Competitiveness*
   - Strengthens a country’s position in international trade
   - Reduces dependency on imports
   - Increases export potential

MANAGEMENT IN MANUFACTURING

Term of management

In manufacturing, the term “management” refers to the **systematic process of coordinating and supervising manufacturing activities to achieve production objectives** efficiently and effectively.

Management **ensures that resources such as men, machines, materials, methods, money, and information are properly utilized to convert raw materials into finished products** that meet quality standards, cost targets, and delivery schedules.

MANAGEMENT IN MANUFACTURING

Basic functions of management

PLANNING

Planning is the process of deciding what to produce, how to produce, when to produce, and how much to produce.

Activities in manufacturing include:

- Production planning and scheduling
- Demand forecasting
- Process planning
- Capacity planning

📌Example: Preparing a weekly production schedule for a machining department.

ORGANIZING

Organizing involves arranging and coordinating resources and tasks to implement the production plan.

Activities include:

- Assigning machines and tools
- Designing plant layout
- Defining job roles and responsibilities
- Establishing workflow

📌 Example: Organizing a production line layout for smooth material flow.

MANAGEMENT IN MANUFACTURING

Basic functions of management

STAFFING

Staffing is the process of recruiting, selecting, training, and placing workers in suitable positions in the manufacturing system.

- Activities include:
- Hiring operators and technicians
- Training employees on machines and safety
- Performance evaluation

📌 Example: Training new operators to handle CNC machines safely.

DIRECTING

Directing involves guiding, supervising, motivating,
and communicating with workers to ensure production activities are carried out properly.

Activities include:

- Giving instructions and supervision
- Motivation and leadership
- Effective communication

📌 Example: A supervisor ensuring workers follow standard operating procedures (SOP).

MANAGEMENT IN MANUFACTURING

Basic functions of management

CONTROLLING

Controlling ensures that actual production performance matches planned targets.
Activities include:

- Quality inspection and control
- Monitoring production output
- Cost control
- Taking corrective actions

📌 Example: Inspecting finished products and correcting defects.

01 Planning

02 Organizing

03 Staffing

04 Directing

05 Controlling

PRINCIPLE OF ORGANIZATION AND PLANNING

Basic principle of an organization and terms of organization

What is Organization and Planning?

- **Organization** = arranging people, tasks, and resources to achieve goals
- **Planning** = deciding what to do, how to do, and when to do it

🎯 Both are important to ensure operations run efficiently and smoothly.

PRINCIPLE OF ORGANIZATION AND PLANNING

Basic principle of an organization and terms of organization

Terms of organization

📌 **1. Authority**

👉 The **power to give orders and make decisions**

- Comes from position (e.g., manager, supervisor)
- Used to direct employees

💡 Example:

A production manager decides the production schedule.

📌 **2. Duties**

👉 The **tasks or work assigned to a person**

- Clearly defined job scope
- Must be completed as required

💡 Example:

Technician duty = maintain machine

📌 **3. Responsibility**

👉 The **obligation to complete assigned tasks**

- You must perform your duty properly
- You are expected to deliver results

💡 Simple idea:

"You are responsible for doing the job"

📌 **4. Accountability**

👉 Being **answerable for the results**

- You must explain success or failure
- Cannot pass blame to others

💡 Simple idea:

"You must answer for your work"

PRINCIPLE OF ORGANIZATION AND PLANNING

Basic principle of an organization and terms of organization

Types of Organization Structure

Product-Oriented Organization

👉 Organization is arranged based on **products or product lines**

📌 Characteristics:

- Each product has its own team
- Focus on product performance
- Faster decision-making

💡 Example: Automotive Company produces different types of vehicles; Sedan cars > Sedan Division; SUVs > SUV Division; Trucks > Truck Division

✅ Advantages:

- Better focus on product
- Quick response to market

❌ Disadvantages:

- Higher cost (duplicate resources)
- Less specialization

Functional-Oriented Organization

👉 Organization is arranged based on **functions or departments**

📌 Common functions:

- Production
- Marketing
- Finance
- Human Resource

💡 Example: All engineers are in one department, all finance staff in another.

✅ Advantages:

- High specialization
- Efficient use of resources

❌ Disadvantages:

- Slow decision-making
- Poor communication between departments

PLANNING HORIZON FOR AN ORGANIZATION

Long-Term Planning

Definition

Long-term planning focuses on decisions made for a long time period, usually 5 years or more. It is concerned with the overall direction and future growth of the organization.

Focus in Manufacturing

- Plant location and expansion
- Capacity planning
- Investment in new technology and automation
- Product development and diversification

Characteristics

- Strategic in nature
- Involves top management
- High risk and uncertainty
- Difficult to change once implemented

Example

- Deciding to build a new manufacturing plant
- Investing in Industry 4.0 technology

Medium-Term Planning

Definition

Medium-term planning covers a time period of 1 to 5 years. It translates long-term strategies into tactical plans.

Focus in Manufacturing

- Aggregate production planning
- Workforce planning
- Material requirement planning (MRP)
- Budgeting and capacity adjustment

Characteristics

- Tactical in nature
- Involves middle management
- Moderate flexibility
- Balances demand and capacity

Example

- Planning annual production volume
- Hiring or retraining workers to meet demand

Short-Term Planning

Definition

Short-term planning focuses on a short time period, usually daily, weekly, or monthly. It deals with day-to-day manufacturing operations.

Focus in Manufacturing

- Production scheduling
- Job sequencing
- Dispatching and shop-floor control
- Inventory and quality control

Characteristics

- Operational in nature
- Involves supervisors and operators
- Highly detailed
- Easily adjustable

Example

- Weekly machine schedule
- Daily work assignments for operators

PLANNING HORIZON FOR AN ORGANIZATION

COMPARISON OF PLANNING HORIZONS

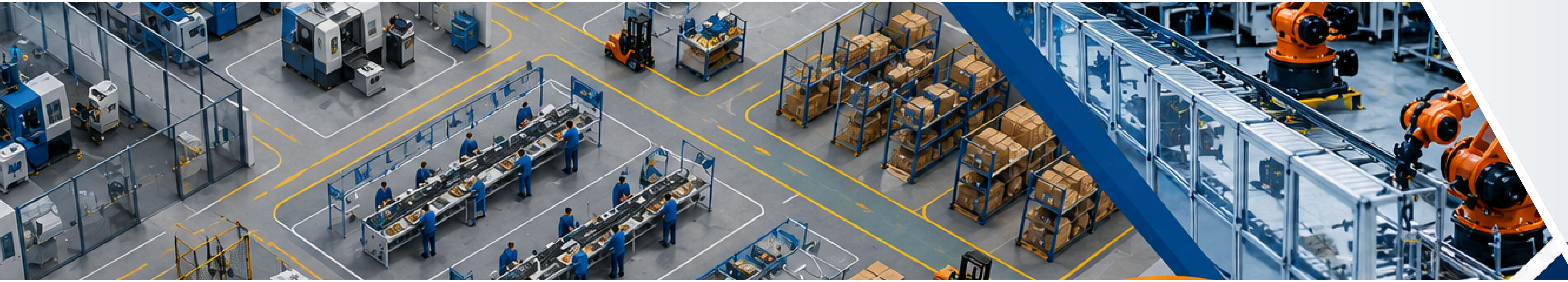
Aspect	Long-Term	Medium-Term	Short-Term
Time Frame	> 5 years	1 – 5 years	Daily – Monthly
Management Level	Top	Middle	Lower
Type	Strategic	Tactical	Operational
Focus	Growth & capacity	Production planning	Shop-floor control
Flexibility	Low	Medium	High

"The planning horizon helps organizations align strategic goals with operational activities. Long-term planning sets the direction, medium-term planning allocates resources, and short-term planning ensures smooth daily operations in manufacturing systems."

CHAPTER 2

PROCESS LAYOUT

This chapter introduces process layout planning and its importance in organizing manufacturing operations efficiently. Students will learn the four basic layout types and explore the concept of Flexible Manufacturing Systems (FMS), including its components, control functions, and industrial applications to improve productivity and manufacturing flexibility.



PROCESS LAYOUT IN MANUFACTURING

LAYOUT PLANNING

"Layout planning involves decisions about the physical arrangement of economic activity centre within a production or service facility. An economic activity centre could be a machine, a worker or group of employees, a workstation etc. It is anything which occupies space and is used in production of an output. Layout planning is an important decision for management as a proper layout has a direct effect on the efficiency of production. The proper and effective arrangement of economic centers ensures the smooth and rapid movement of material, from the raw material stage to the end product stage.

Layout planning is a strategic decision as type of layout selection depends on company's objective of its type of operation selected for production of products or services. A company selects mass production system if its objective is to beat its competition by producing low cost products whereas batch production system is predominantly chosen if objective is to provide customized and high quality products or services. The characteristics of both types of operation system influence designing of layout. It should be noted here that selection of type of layout depends on strategic objectives of a company whereas design of layout is governed by type of production system that is associated with such objectives. For instance, a profit oriented company providing customized products would provide high variety of products but would produce each variety at low volume."

PROCESS LAYOUT IN MANUFACTURING

LAYOUT PLANNING

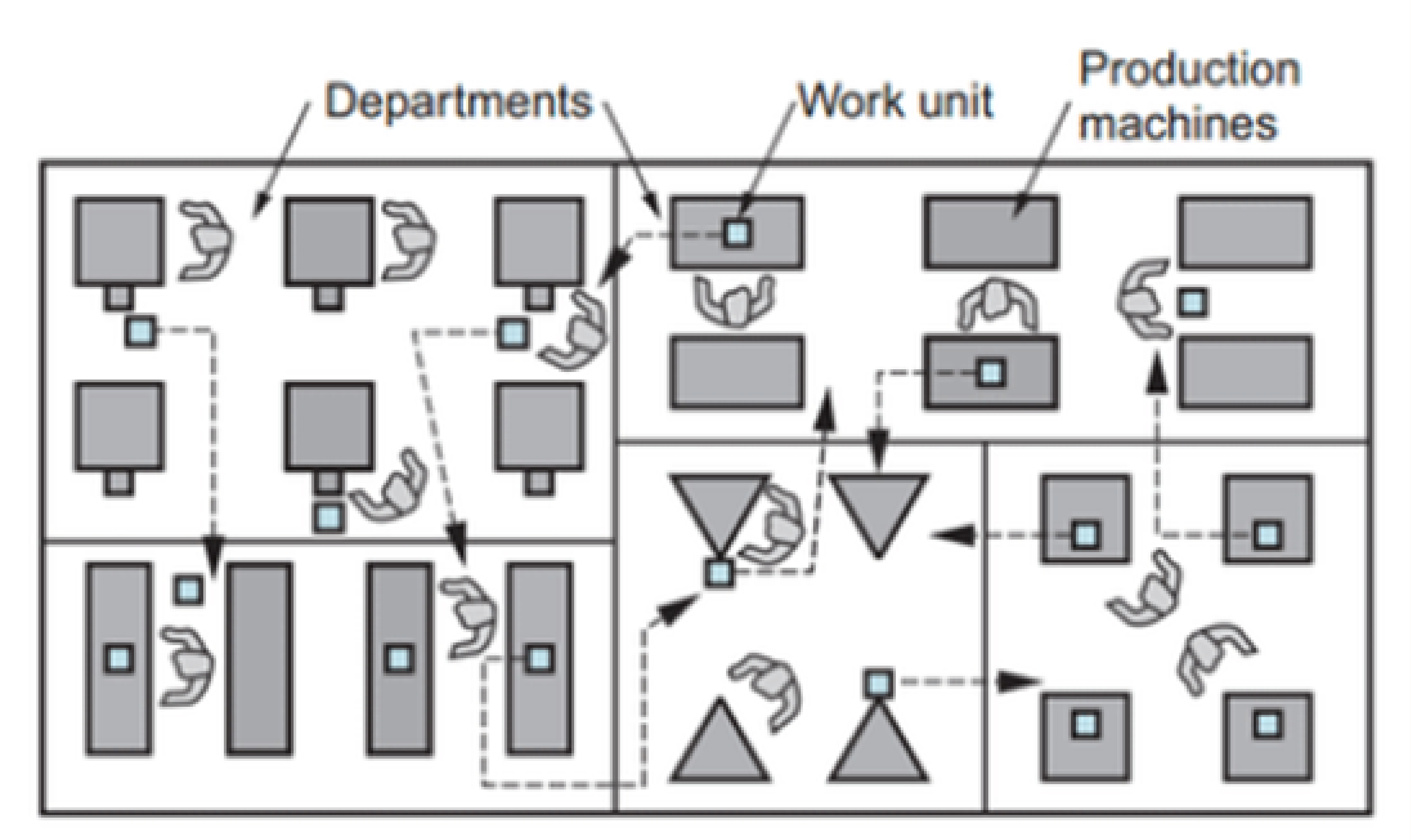
Other goals of layout planning are the following:

- Achieving the appropriate product or service quality
- Eliminating waste through the efficient use of workers and space
- Eliminating bottlenecks in product or service flows
- Minimizing material and manufacturing costs
- Eliminating the movement of materials, workers, and customers that do not add value to the product or service
- Improving productivity
- Maximizing the utilization of production capacity
- Reducing accidents and health hazards to ensure employee safety
- Reducing customer waiting times
- Making supervision and control easier

PROCESS LAYOUT IN MANUFACTURING

TYPE OF LAYOUT: FLEXIBLE-FLOW LAYOUT

Flexible-flow layout: A layout that organizes resources (employees) and equipment by function rather than by service or product.



PROCESS LAYOUT IN MANUFACTURING

TYPE OF LAYOUT: FLEXIBLE-FLOW LAYOUT

- Eliminating waste through the efficient use of workers and space
- Eliminating bottlenecks in product or service flows
- Minimizing material and manufacturing costs
- Eliminating the movement of materials, workers, and customers that do not add value to the product or service
- Improving productivity
- Maximizing the utilization of production capacity
- Reducing accidents and health hazards to ensure employee safety
- Reducing customer waiting times
- Making supervision and control easier

Advantages

- Better utilization of available equipment
- Worker are dealing with only one type of machine, so product quality will be better
- Workers in one section are not affected by the operation carried out in another section

Disadvantages

- The same amount of production, the process layout needs more space.
- Automatic material handling is difficult
- Production control become difficult
- Raw material has to travel a longer distance for being processed to finished goods
- It needs more inspection and efficient co-ordination

PROCESS LAYOUT IN MANUFACTURING

TYPE OF LAYOUT: LINE FLOW LAYOUT

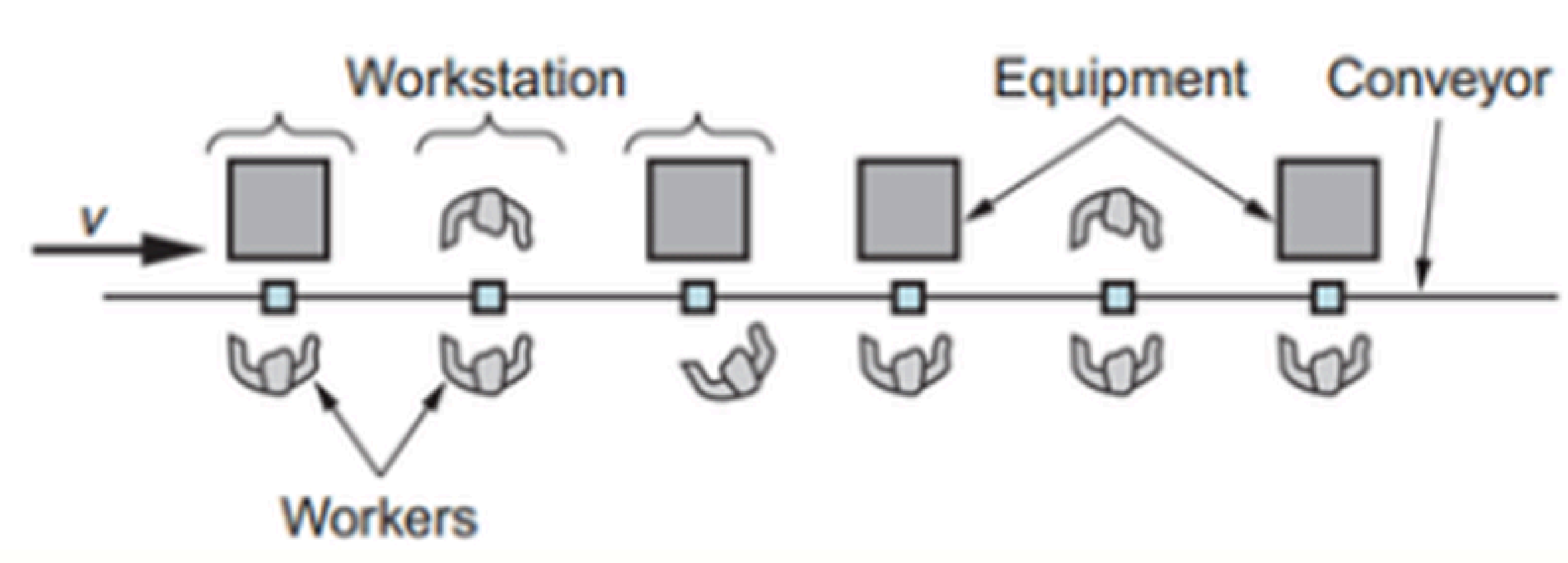
A layout in which workstations or departments are arranged in a linear path. If all the processing equipment and machines are arranged according to the sequence of operations of the product, the layout is called product type of layout. In this type of layout, only one product of one type of products is produced in an operating area. This product must be standardized and produced in large quantities in order to justify the product layout.

Specifically, following are the characteristics of a process layout:

- Volume of product or service produced is low.
- Variety of product or service produced is high.
- General purpose equipment which can perform variety of operations is generally used.
- Layout is flexible as it is less vulnerable to change in product mix. In a process layout same resources can be used to produce different products or services. For example, in retail store grocery department can be replaced by any other department without hindering activities of other departments.
- Equipment utilization is higher as same resource is utilized for production of different products. As demand for one type of product is low so when one machine gets free from producing that product it can be used to manufacture other products.
- Employee skill set is varied and high. For example, in a bank an employee can be used to provide different services. Same employee can be used for cash deposit and also for creating fixed deposits depending on the demand of each kind of service. Thus, skill set of employees' increases as they become proficient in carrying out different services.

PROCESS LAYOUT IN MANUFACTURING

TYPE OF LAYOUT: LINE FLOW LAYOUT



PROCESS LAYOUT IN MANUFACTURING

TYPE OF LAYOUT: LINE FLOW LAYOUT

Advantages

- Less space required for the same volume of production
- Material handling is lesser
- Co-ordination will be better. Production planning, and control will become easier
- Fewer skilled worker can perform the task

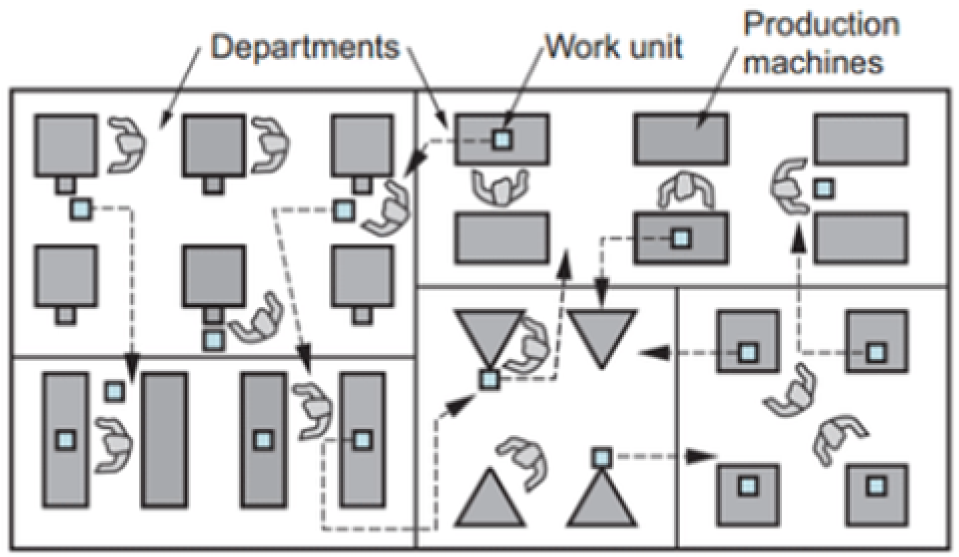
Disadvantages

- A change in product required a major change in layout.
- Rate of production is determined by the output rate of the slowest machine
- It is difficult to increase production beyond the capacities of the production line

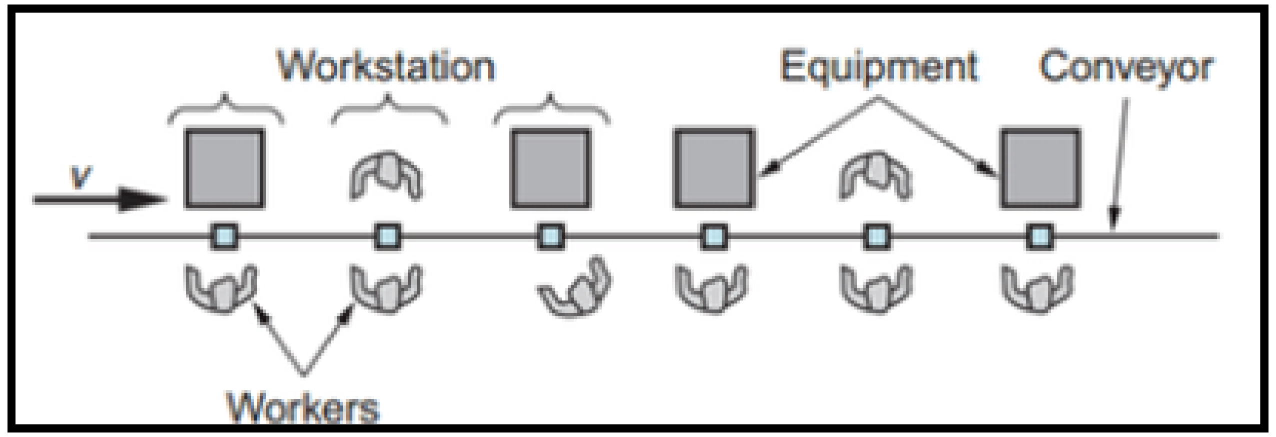
PROCESS LAYOUT IN MANUFACTURING

TYPE OF LAYOUT: HYBRID FLOW LAYOUT

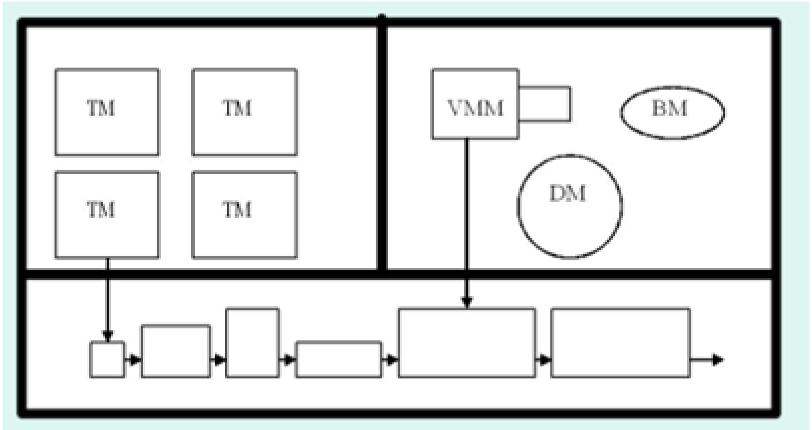
An arrangement in which some portions of the facility have a flexible-flow and others have a line-flow layout.



Flexible Layout



Line Layout



Hybrid Layout

PROCESS LAYOUT IN MANUFACTURING

TYPE OF LAYOUT: HYBRID FLOW LAYOUT

Advantages

- It combine the advantages of Flexible Flow and Line Flow layout
- Hybrid layout can be useful when a number of item are produced in the same sequence but in small number

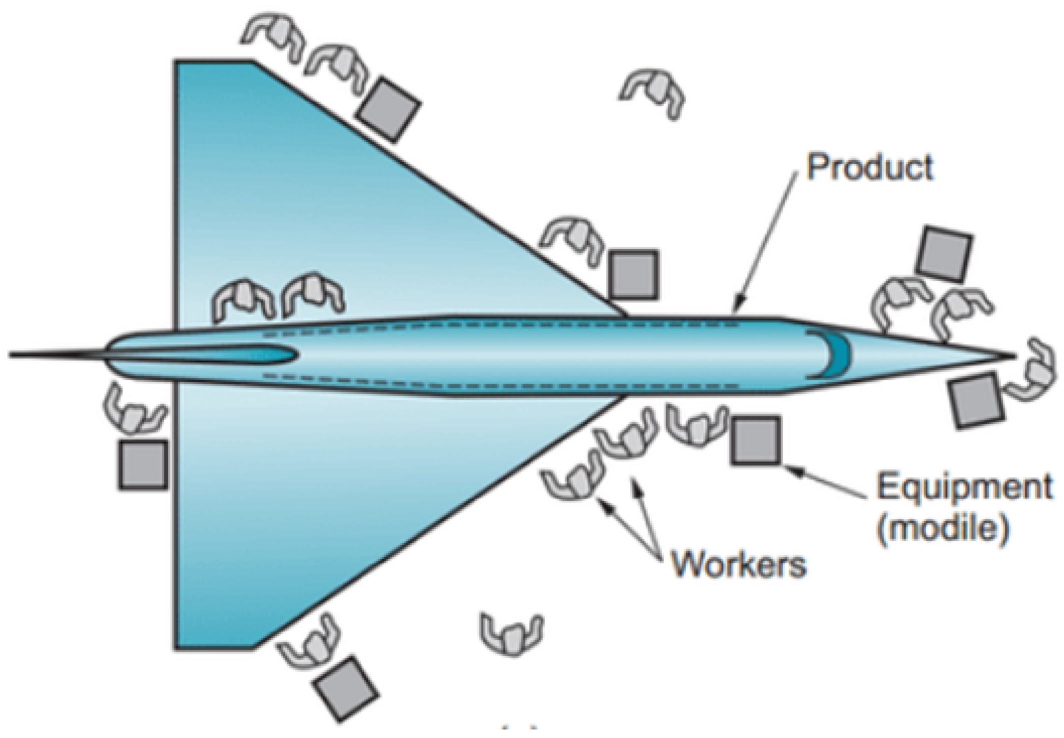
Disadvantages

- It involve a low content of work in progress
- Involves high equipment handling cost

PROCESS LAYOUT IN MANUFACTURING

TYPE OF LAYOUT: FIXED POSITION LAYOUT

An arrangement in which service or manufacturing site is fixed in place; employees along with their equipment, come to the site to do their work.



Advantages

- It is possible to assign one or more skilled workers from the start of a project to finish on order to ensure continuity of work
- Involves the least movement of material
- A number of quite different project can be taken with the same layout

Disadvantages

- It involve a low content of work in progress
- Involves high equipment handling cost

FLEXIBLE MANUFACTURING SYSTEM (FMS)

INTRODUCTION

A Flexible Manufacturing System (FMS) is an individual machine or group of machines served by an automated materials handling system that is computer controlled and has a tool handling capability.

Flexibility means that a manufacturing system is versatile and adaptable, while also capable of handling relatively high production runs.

Versatile means that it can produce a variety of parts and adaptable in that it can be quickly modified to produce a completely different line of parts

To qualify as being flexible, a manufacturing system should satisfy several criteria. The tests of flexibility in an automated production system are the capability to;

- Process different part styles in a non-batch mode
- Accept changes in production schedule
- Respond gracefully to equipment malfunctions and breakdowns in the system
- Accommodate the introduction of new part designs.

These capabilities are made possible by the use of a central computer that controls and coordinates the components of the system. First two criteria are most important while last two are soft criteria and can be implemented at various levels of sophistication. If the automated system does not meet these four tests mentioned above, it should not be classified as a flexible manufacturing system or cell.

FLEXIBLE MANUFACTURING SYSTEM (FMS)

FMS COMPONENTS

An FMS consists of hardware and software that must be integrated into an efficient and reliable unit. It also includes human personnel. In below section, we will learn more about these components and how they are integrated.

Hardware components

FMS hardware includes workstations, material handling system, and central control computer. The workstations are CNC machines in a machining type system, plus inspection stations, parts cleaning and other systems as needed. A central chip conveyor system is often installed below floor level.

The material handling system is the means by which parts are moved between stations. The material handling system usually includes a limited capability to store parts. Handling systems suitable for automated manufacturing include roller conveyors, in-floor towline carts, automated guided vehicles, and industrial robots. The most appropriate type depends on part size and geometry, as well as factors relating to economics and compatibility with other FMS components. Non-rotational parts are often moved in a FMS on pallet fixtures, so the pallets are designed for the particular handling system, and the fixtures are designed to accommodate the various part geometries in the family. Rotational parts are often handled by robots, if weight is not a limiting factor.

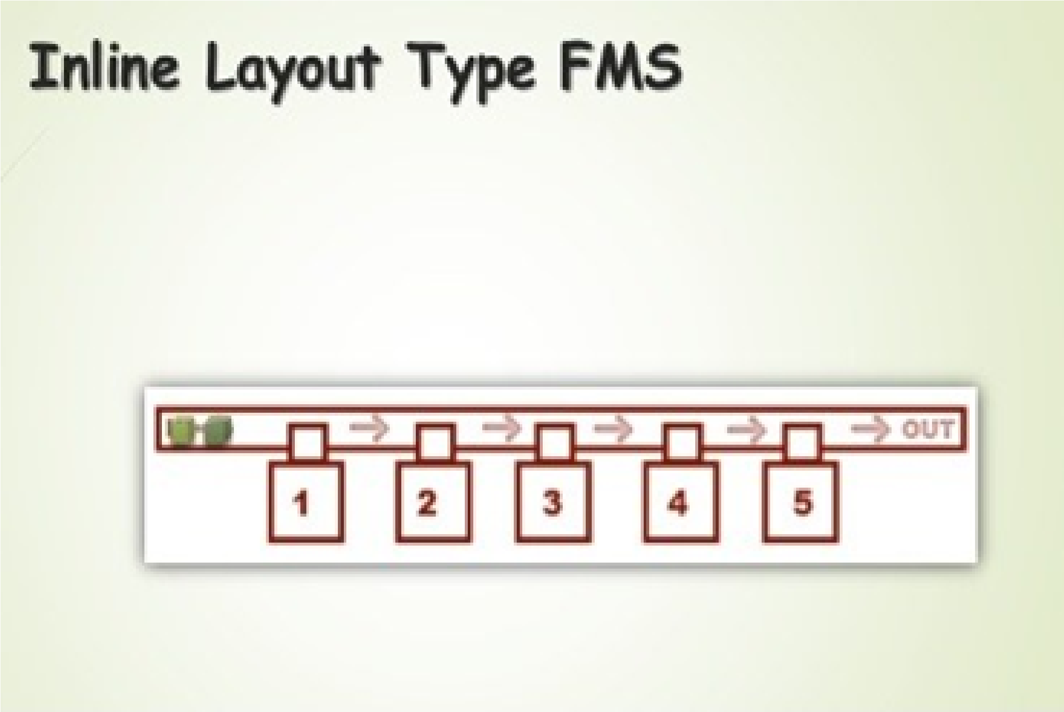
The handling system establishes the basic layout of the FMS. Five layout types can be distinguished:

1. in-line
2. loop
3. ladder
4. open field
5. robot-centered cell

FLEXIBLE MANUFACTURING SYSTEM (FMS)

FMS COMPONENTS

All these basic layouts are shown below in same order.

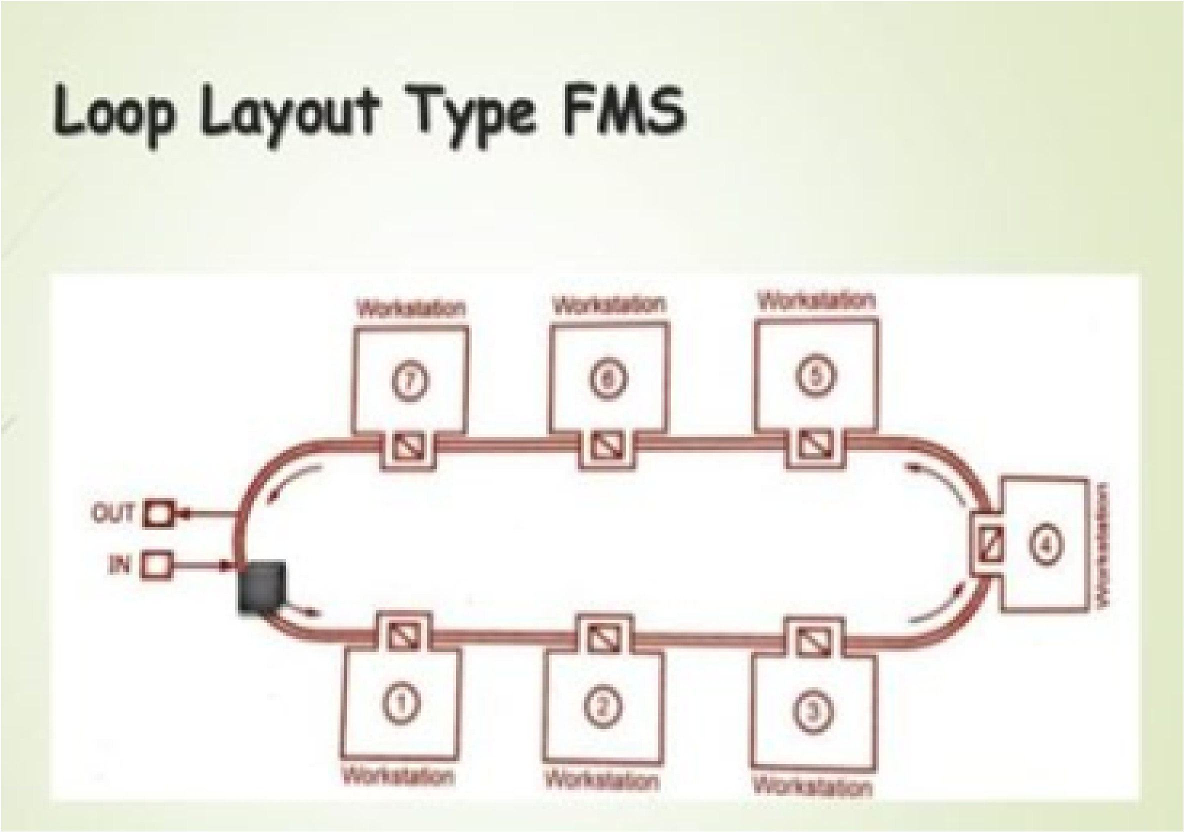


The ***in-line layout*** uses a linear transfer system to move parts between processing stations and load/unload station(s). The in-line transfer system is usually capable of two-directional movement; if not, then the FMS operates much like a transfer line, and the different part styles made on the system must follow the same basic processing sequence due to the one-direction flow. An Automated guided vehicle is most efficient when the movement is in straight-lines along the AGV path in a single-row machine layout. Machines are arranged only on one side of AGV path and in double row machine layout, machines are arranged on both sides.

FLEXIBLE MANUFACTURING SYSTEM (FMS)

FMS COMPONENTS

All these basic layouts are shown below in same order.

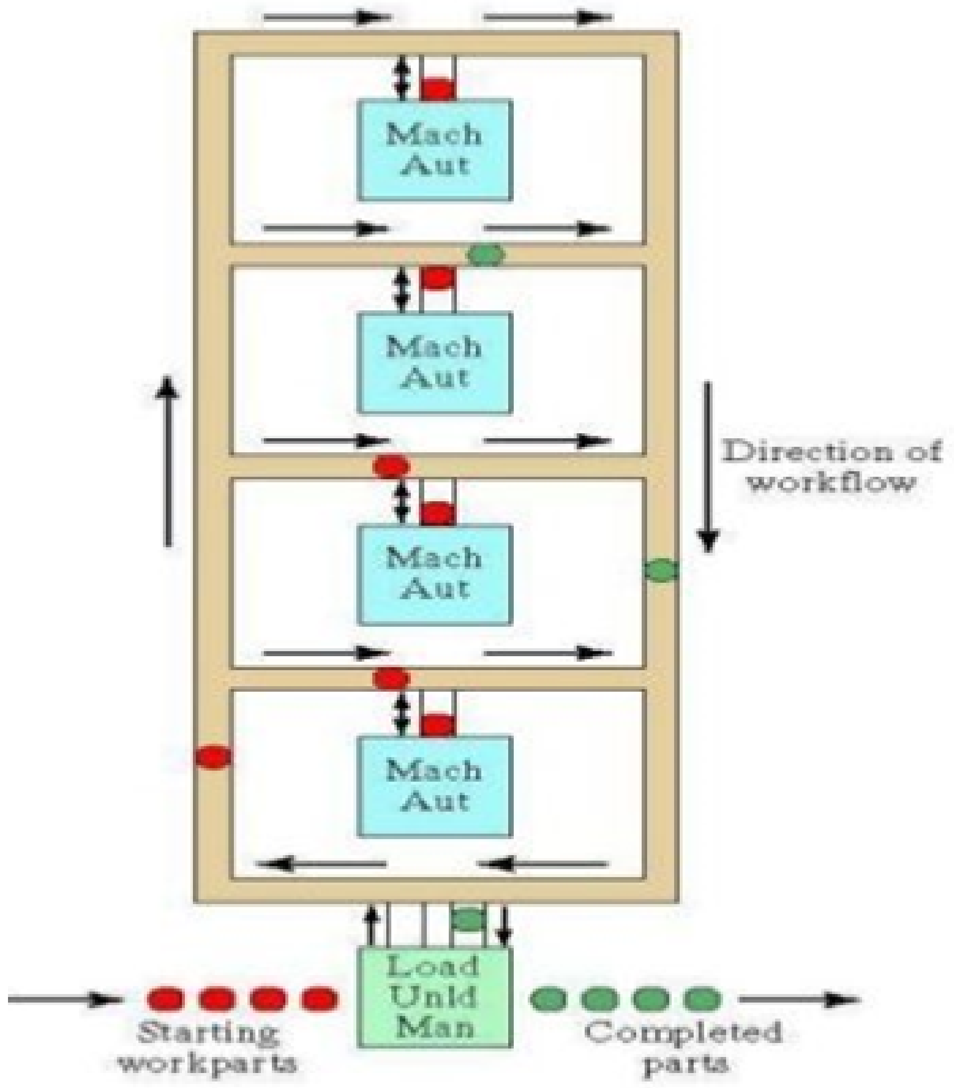


The ***loop Layout*** consists of a conveyor loop with workstations located around its periphery. This configuration permits any processing sequence, because any station is accessible from any other station. The loop layout uses conveyor systems that allow unidirectional flow of parts around the loop. A secondary material handling system is provided at a workstation which permits the flow of parts without any obstruction.

FLEXIBLE MANUFACTURING SYSTEM (FMS)

FMS COMPONENTS

All these basic layouts are shown below in same order.

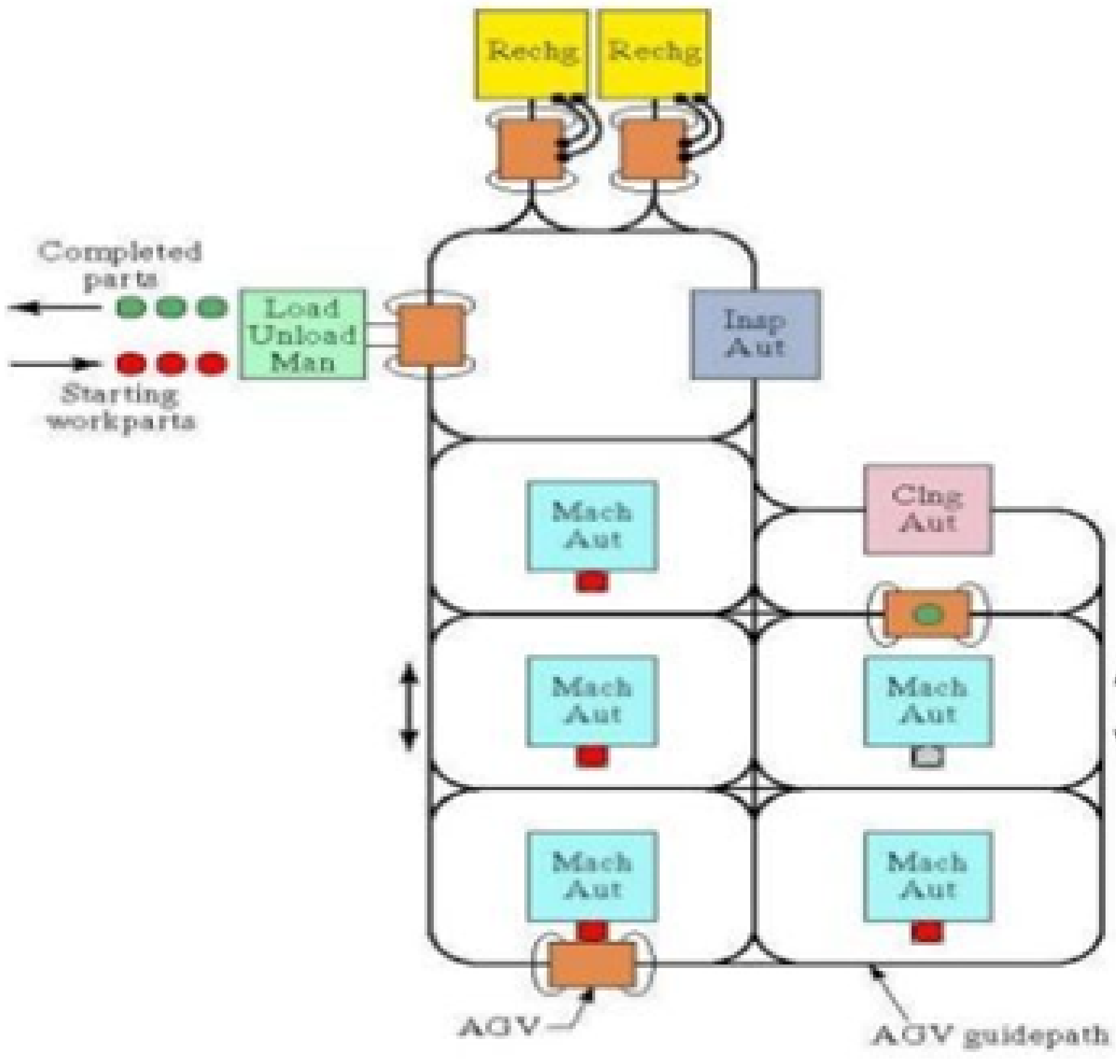


This is also true for the ***ladder layout***, in which workstations are located on the rungs of the ladder Ladder type layout consists of rungs on which workstations are located. This reduces the average travel distance thereby reducing the transfer time between workstations.

FLEXIBLE MANUFACTURING SYSTEM (FMS)

FMS COMPONENTS

All these basic layouts are shown below in same order.

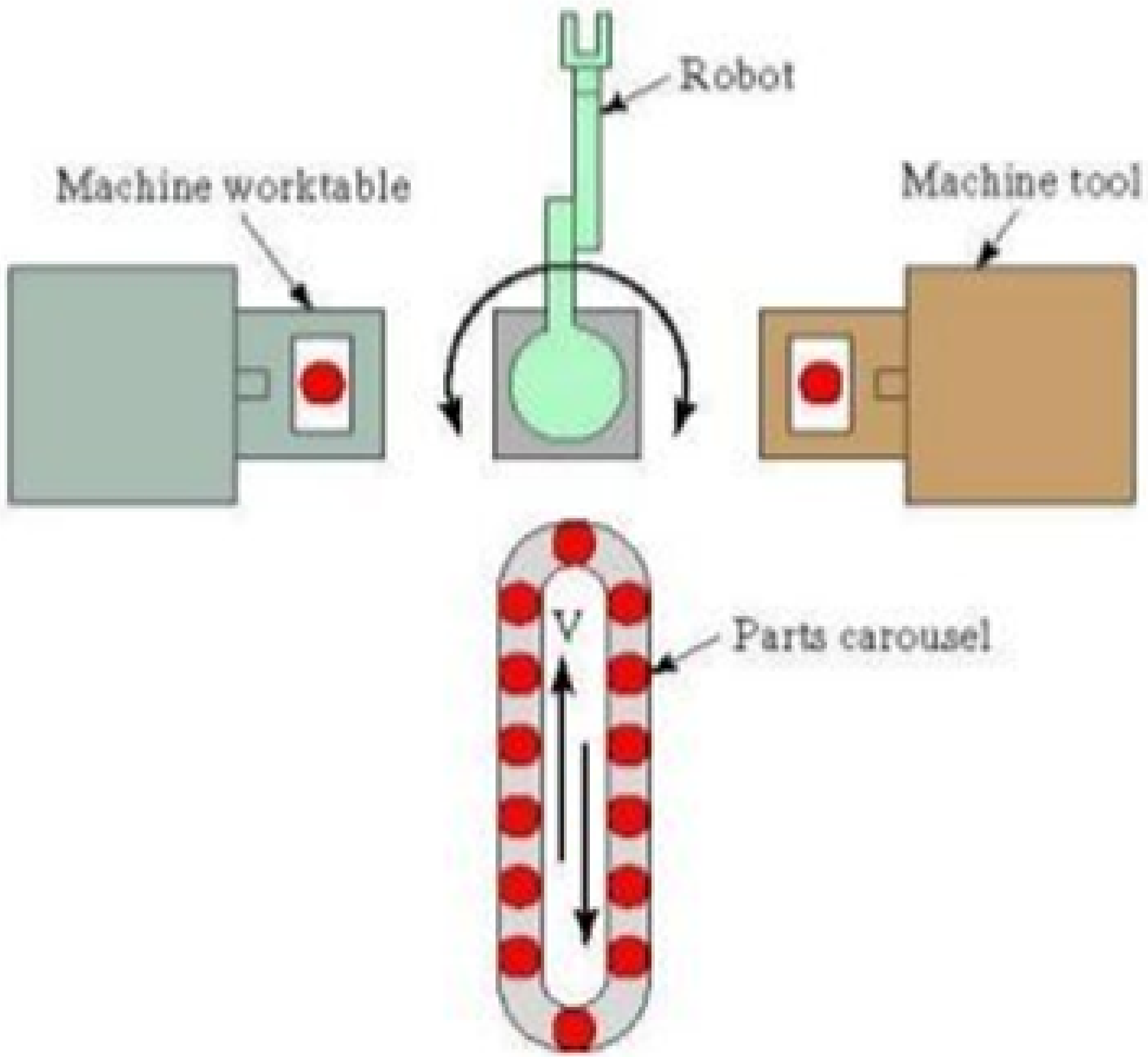


The ***open field layout*** is the most complex FMS configuration, and consists of several loops tied together.

FLEXIBLE MANUFACTURING SYSTEM (FMS)

FMS COMPONENTS

All these basic layouts are shown below in same order.



Finally, the ***robot-centered cell*** consists of a robot whose work volume includes the load/unload positions of the machines in the cell.

FLEXIBLE MANUFACTURING SYSTEM (FMS)

FMS COMPONENTS

FMS Software and Control Functions

FMS software consists of modules associated with the various functions performed by the manufacturing system. For example, one function involves downloading NC part programs to the individual machine tools: another function is concerned with controlling the material handling system; another is concerned with tool management; and so on. Associated with each function is one or more software modules. Terms other than those in our table may be used in a given installation. The functions and given modules are largely application specific.

Human Labor

An additional component in the operation of a flexible manufacturing system is human labor. Duties performed by human workers include;

- loading and unloading parts from the system
- changing and setting cutting tools
- maintenance and repair of equipment
- NC part programming
- programming and operating the computer system
- overall management of the system

FLEXIBLE MANUFACTURING SYSTEM (FMS)

APPLICATIONS OF FMS

The applications of FMS are realized in the following areas:

- **Automotive Industry:** Manufacturers like Ford and BMW use FMS for customized vehicle production, including different models, body styles, and engine types on the same lines. FMS enables quick changeovers between models and production of small batches of specialized components (e.g., carbon fiber parts for racing cars).

- **Aerospace Industry:** FMS is employed to produce complex, high-precision aircraft components (e.g., jet engine parts, satellite components) due to its accuracy and ability to handle specialized designs and stringent quality standards.

- **Electronics Manufacturing:** This sector benefits from FMS's ability to handle rapid product iterations and a high mix of product variations, such as different models of smartphones or integrated circuits on the same line, allowing for quick responses to consumer trends.

- **Medical Device Manufacturing:** FMS is used in the production of diverse, high-precision medical devices, such as surgical tools, implants, and diagnostic equipment, where strict quality control and traceability are critical.

FLEXIBLE MANUFACTURING SYSTEM (FMS)

APPLICATIONS OF FMS

- **Construction and Mining:** FMS is applied in industries that rely on high-quality metal-based elements, such as those used in heavy machinery and structural components..
- **Consumer Packaged Goods (CPG):** FMS allows for quick switching between product variants, flavors, or packaging styles, which is essential for responding to seasonal demands or promotional campaigns in a timely manner.
- **General Machining Operations:** FMS is widely used for various machining processes, including cutting, forming, welding, assembly, testing, and finishing treatments for metal and other parts.

CHAPTER 3

LEAN OPERATIONS

This chapter introduces lean operations as an effective approach to improve productivity and reduce waste in manufacturing and service systems. Students will learn the characteristics of lean operations, including pull systems, quality at the source, standardized work, automation, and 5S practices. The chapter also explores continuous improvement techniques such as Kaizen, Kanban, and Just-in-Time (JIT) to achieve efficient and high-quality operations.

LEAN OPERATIONS AND TYPE OF WASTE IN MANUFACTURING

WHAT ARE LEAN OPERATIONS?

“***Lean***” describes **an approach to business management that delivers the greatest value to the customer with the most efficient use of resources**. The lean philosophy is built on two main principles:

- Identifying and creating value for the customer
- Eliminating waste in processes

Here, “***value***” is defined as anything the customer would be willing to pay for, whether that’s a hard good, a service or time. “Waste” is defined as anything that does not add value to either the customer or the production process. When organizations prioritize these two objectives, they find they are able to do more with less — less time, fewer resources and fewer, more optimized people. As a result of this increased efficiency, profits increase and workforce morale improves.

However, companies that take a too-narrow approach to lean operations risk missing the bigger picture. If they become too focused on the details of their internal processes, customer value can become an afterthought. Every change made under a lean mindset should have a direct effect on increasing value for the customer.
When implemented properly, lean operations creates a perpetual state of continuous improvement, wherein team members are constantly seeking ways to streamline operations even further.

LEAN OPERATIONS AND TYPE OF WASTE IN MANUFACTURING

THE 8 WASTES OF LEAN MANUFACTURING

1. ***Defects (D)***: Products that don't meet quality standards, requiring rework, scrap, or replacement.
2. ***Overproduction (O)***: Making more than the customer needs, leading to excess inventory and storage costs.
3. ***Waiting (W)***: Idle time for people, machines, or materials due to bottlenecks or delays.
4. ***Non-Utilized Talent (U/S)***: Failing to use employees' skills, creativity, and knowledge for improvement.
5. ***Transportation (T)***: Unnecessary movement of materials, parts, or finished goods.
6. ***Inventory (I)***: Holding more raw materials, WIP, or finished goods than needed, tying up capital.
7. ***Motion (M)***: Unnecessary movement of people (walking, reaching, bending).
8. ***Extra-Processing (E/P)***: Performing more work on a product than required by the customer (e.g., unnecessary inspections).

CHARACTERISTICS OF THE LEAN OPERATIONS FOR SERVICES AND MANUFACTURING

Pull Method of Work Flow

- Push method: A method in which production of the item begins in advance of customer needs.
  Example: A buffet where food is prepared in advance.
- Pull Method: A method in which customer demand activates production of the service or item.
  Example: A restaurant where food is only prepared when orders are placed. Lean systems use the pull method of work flow.

Quality at the Source

- Quality at the source is an organization-wide effort to improve the quality of a firm's products by having employees act as their own quality inspectors, and never pass defective units to next stage.
- One approach for implementing quality at the source is to use poka-yoke, mistake-proofing methods aimed at designing fail safe systems that minimize human error.
- Another approach for implementing quality at the source is a practice the Japanese call jidoka, and andon, which gives machines and machine operators the ability to detect when an abnormal condition has occurred.

CHARACTERISTICS OF THE LEAN OPERATIONS FOR SERVICES AND MANUFACTURING

Small Lot Sizes

- Lot: A quantity of items that are processed together.
- Setup: The group of activities needed to change or readjust a process between successive lots of items.
- Single-digit setup: The goal of having a setup time of less than 10 minutes.

Uniform Workstation Loads

- A lean system works best if the daily load on individual workstations is relatively uniform.
- Service processes can achieve uniform workstation loads by using reservation systems (e.g., scheduled surgeries) and differential pricing to manage the demand.
- For manufacturing processes, uniform loads can be achieved by assembling the same type and number of units each day, thus creating a uniform daily demand at all workstations.

CHARACTERISTICS OF THE LEAN OPERATIONS FOR SERVICES AND MANUFACTURING

Standardized Component and work method

- Refers to a documented and structured method that outlines the most efficient and effective way to perform a specific task or operation in a manufacturing or operational process.
- It defines the exact sequence of steps, tools, materials, and timing required to complete a task consistently.
- Is crucial for ensuring consistency in quality, minimizing variability, and improving overall productivity

Close supplier ties

Closing supplier ties means building strong, collaborative, long-term partnerships for mutual benefit, going beyond simple transactions to improve quality, innovation, efficiency, and cost savings, often involving clear communication, trust, and shared goals, but requires careful management to avoid complacency and "groupthink". Key strategies involve setting clear expectations with contracts and KPIs, fostering open communication, ensuring fairness, and focusing on shared growth.

Benefits of <u>Close Ties</u>

- Improved Performance: Better quality, reduced defects, and more efficient supply chains.
- Cost Reduction: Lower costs through efficiency, reduced waste, and better negotiation.
- Innovation: Suppliers become partners in new product development and process improvements.
- Risk Mitigation: Suppliers offer support during disruptions, creating a safety net.
- Flexibility: Easier adaptation to demand fluctuations.

CHARACTERISTICS OF THE LEAN OPERATIONS FOR SERVICES AND MANUFACTURING

flexible workforce

A flexible workforce in lean manufacturing, often called Shojinka, involves cross-training employees to perform multiple tasks, allowing companies to dynamically adjust staffing levels and worker assignments based on real-time customer demand, eliminating waste (like waiting or idle time) and improving efficiency by matching labor to the actual production flow, rather than relying on fixed roles. This flexibility reduces costs, shortens lead times, and enhances overall agility to handle fluctuations in demand and maintain a lean culture.

line flows

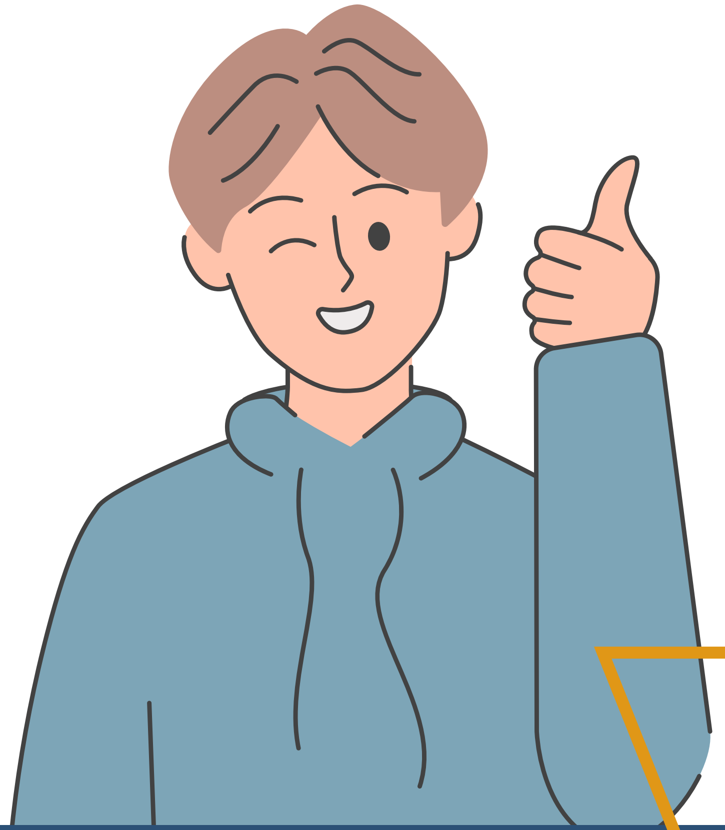
In Lean manufacturing, line flow (or continuous flow) is the principle of moving products or work smoothly, one unit at a time, through every process step without interruption, delays, or batching, aiming to deliver value continuously, minimize waste (like inventory and waiting), and quickly expose problems. It's about creating a steady, uninterrupted rhythm that matches customer demand, contrasting with batch production, and involves designing processes to eliminate bottlenecks and ensure work progresses naturally, like a river flowing.

CHARACTERISTICS OF THE LEAN OPERATIONS FOR SERVICES AND MANUFACTURING

Automation

Automation in lean manufacturing uses smart, flexible technology to enhance lean principles, focusing on eliminating waste (muda), improving flow, and increasing quality by taking over repetitive tasks, reducing human error, and freeing workers for higher-value activities, essentially creating "automation with a human touch" (Jidoka) for better efficiency, safety, and agility, not just replacing people. It involves integrating systems like AGVs, conveyors, and data analytics to achieve precision, real-time monitoring, and continuous improvement.

📖 **Note:**
Muda is a Japanese term not Malay word that used in lean manufacturing that means waste or non-value-added activities in a process. It refers to any activity that consumes time, cost, or resources without adding value to the customer.



CHARACTERISTICS OF THE LEAN OPERATIONS FOR SERVICES AND MANUFACTURING

5S

In Lean, 5S is a **workplace organization methodology** (Sort, Set in Order, Shine, Standardize, Sustain) to boost efficiency, reduce waste, and create a safer, more productive environment by eliminating clutter, organizing tools, cleaning, standardizing processes, and maintaining discipline. It's often the first step in a Lean transformation, establishing a foundation for continuous improvement (Kaizen) by making waste and problems visible.

The 5 S's Explained:

1. ***Sort (Seiri)***: Go through all items in a work area and remove anything unnecessary, keeping only what's needed for the job.
2. ***Set in Order (Seiton)***: Arrange necessary items logically so they are easy to find, use, and return (a place for everything, and everything in its place).
3. ***Shine (Seiso)***: Clean the work area, tools, and equipment regularly, often incorporating inspection to find issues early.
4. ***Standardize (Seiketsu)***: Create consistent procedures and schedules to maintain the first three S's, ensuring everyone follows the same best practices.
5. ***Sustain (Shitsuke)***: Develop the discipline and commitment to make 5S a long-term habit and part of the company culture.

CHARACTERISTICS OF THE LEAN OPERATIONS FOR SERVICES AND MANUFACTURING

Preventive Maintenance

Preventive maintenance is a planned maintenance activity carried out regularly to prevent machine breakdowns and reduce downtime.
In lean operations, machines must operate smoothly because there is very little extra inventory or backup capacity available.
By performing maintenance on schedule, companies can:

- reduce unexpected machine failures
- improve production flow
- reduce repair costs
- increase machine efficiency and safety

Technicians may inspect, clean, lubricate, or replace worn parts before serious damage occurs. This is faster and cheaper than repairing a machine after it breaks down during production.

Operators are also encouraged to take care of their own machines through simple activities such as cleaning, lubrication, and basic inspection. This helps improve machine performance and creates a sense of responsibility among workers.

CHARACTERISTICS OF THE LEAN OPERATIONS FOR SERVICES AND MANUFACTURING

Simple Example

Theme parks such as Walt Disney World perform routine preventive maintenance on rides to avoid breakdowns and ensure visitor safety.

✅ **Benefits of Preventive Maintenance**

- Reduces machine downtime
- Improves productivity
- Increases safety
- Extends machine lifespan
- Supports smooth lean operations

🎯 **Key Idea**

“Prevent problems before they happen.”

CONTINUOUS IMPROVEMENT BY USING A LEAN OPERATION APPROACH

Continuous improvement means making small improvements continuously to increase quality, reduce waste, and improve productivity in manufacturing and service operations.
Lean operations use several important approaches to achieve continuous improvement, such as Kaizen, Kanban System, and Just-in-Time (JIT).

KAIZEN

📌 Definition

Kaizen is a Japanese term that means continuous improvement.

It focuses on making small improvements regularly instead of making one large change at once.

🎯 Main Idea of Kaizen

- Improve work processes continuously
- Reduce waste and errors
- Increase productivity and quality
- Involve all employees in improvement activities

💡 Simple Example

A factory worker suggests rearranging tools closer to the workstation to reduce unnecessary movement and save time.

✅ Benefits of Kaizen

- Better product quality
- Higher efficiency
- Lower production cost
- Improved teamwork

CONTINUOUS IMPROVEMENT BY USING A LEAN OPERATION APPROACH

KANBAN SYSTEM

📌 Definition

Kanban is a visual system used to control the flow of materials and production activities.

The word Kanban means “card” or “signal” in Japanese.

🎯 Main Function

Kanban helps ensure:

- materials arrive when needed
- production is controlled properly
- overproduction is avoided

💡 Simple Example

When a storage bin becomes empty, a Kanban card is sent to request more parts from the supplier or previous workstation.

✅ Benefits of Kanban

- Reduces excess inventory
- Improves workflow
- Prevents overproduction
- Makes production easier to monitor

CONTINUOUS IMPROVEMENT BY USING A LEAN OPERATION APPROACH

JUST-IN-TIME (JIT)

📌 Definition

Just-in-Time (JIT) is a system where materials and products are produced only when needed and in the required quantity.

🎯 Main Objective

- Reduce inventory
- Eliminate waste
- Improve efficiency

💡 Simple Example

A company receives raw materials only a few hours before production starts instead of storing them for weeks.

✅ Benefits of JIT

- Lower inventory cost
- Less storage space needed
- Faster production flow
- Better quality control

CHAPTER 4

INDUSTRIAL ROBOTICS

This chapter introduces industrial robotics and its important role in modern manufacturing systems. Students will learn robot functions, components, design configurations, and programming methods, as well as the advantages of using robots in industry. The chapter also explores various robot applications such as welding, assembly, inspection, testing, and material handling to improve productivity, quality, and automation in manufacturing operations.

DEFINITION OF INDUSTRIAL ROBOTICS

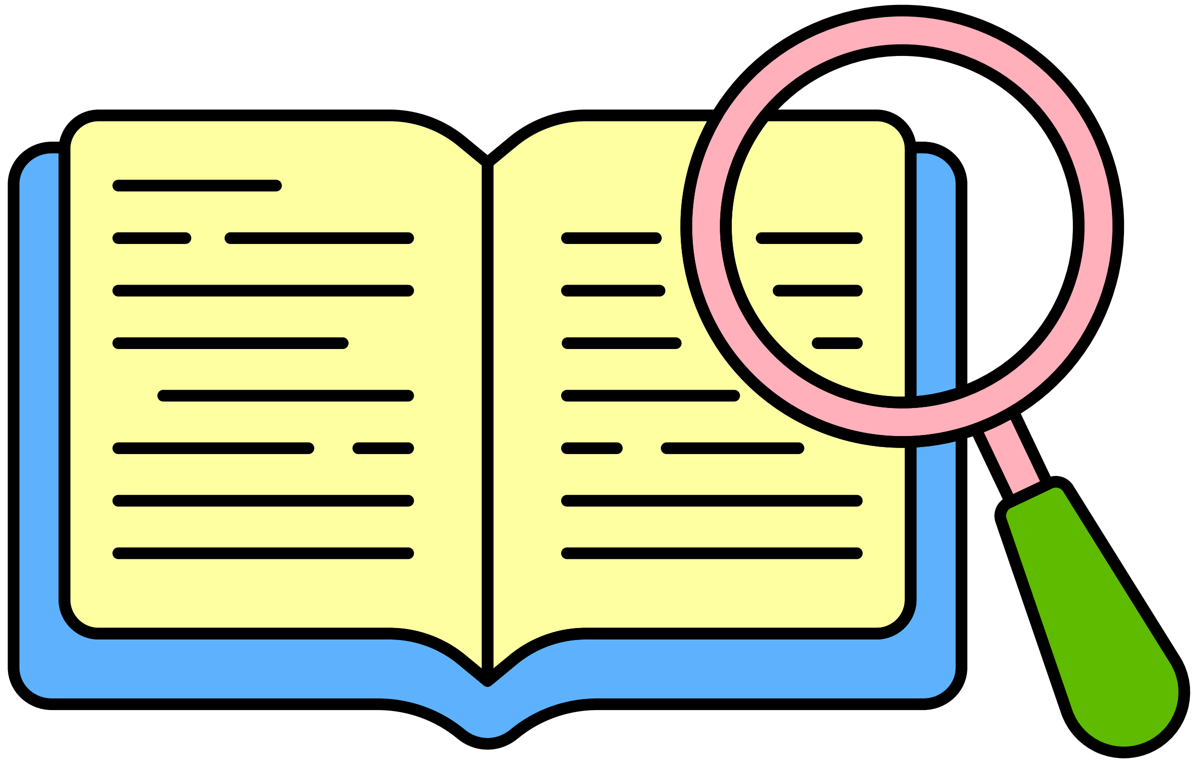
DEFINITION

Based on the ISO 8373:2012 standard, an industrial robot is an "automatically controlled, reprogrammable, multipurpose manipulator programmable in three or more axes" used in industrial automation, which can be fixed or mobile. Key characteristics include being automatically controlled, reprogrammable for different functions, multipurpose through changing tools, functioning as a manipulator with segments and joints, and having three or more axes for complex movements.

Laws of Robotics

Asimov's Three Laws are:

1. A robot may not injure a human being or, through inaction, allow a human being to come to harm.
2. A robot must obey the orders given it by human beings except where such orders would conflict with the First Law.
3. A robot must protect its own existence as long as such protection does not conflict with the First or Second Law.



DEFINITION OF INDUSTRIAL ROBOTICS

FUNCTION OF A ROBOT

Industrial robots perform various functions, primarily manipulating and moving materials, parts, tools, or specialized implements. Common manufacturing functions include material handling, welding and cutting, assembly and disassembly, painting and coating, packaging and palletizing, and inspection and testing using sensors and vision systems for quality control.

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DEFINITION OF INDUSTRIAL ROBOTICS

ADVANTAGES AND DISADVANTAGES OF USING ROBOTS IN THE MANUFACTURING INDUSTRY

Advantages

- Increased Productivity and Efficiency: Robots work continuously without fatigue, leading to higher output.
- Improved Quality and Consistency: They offer high precision and repeatability, reducing errors and ensuring consistent product quality.
- Enhanced Safety: Robots can perform dangerous tasks, reducing risks to human workers.
- Cost-Effectiveness (Long-term): Despite high initial costs, operational expenses are lower over time compared to human labor.

Disadvantages

- High Initial Investment: Purchasing and integrating robots requires substantial upfront capital.
- Maintenance and Upkeep: Robots need regular maintenance and skilled technicians for repairs.
- Complexity and Learning Curve: Programming and operating robots require specialized training.
- Job Displacement: Automation can lead to a decrease in demand for human labor in certain roles.
- Limited Flexibility (in some cases): While good for high-volume tasks, adapting robots to changes in production can be complex and costly.

ROBOT COMPONENT SYSTEM

1. **Base**

The base is the mechanical foundation or "hard point" of the robot. It provides stability and support for the entire manipulator system, anchoring it to a fixed surface like a factory floor or a mobile platform. In industrial robots, the base often houses the first axis of rotation, allowing the robot to pivot left or right.

2. **Manipulator Arm**

The manipulator arm is a programmable mechanical structure composed of a series of rigid segments called links, connected by movable joints.
Function: It mimics the reach and flexibility of a human arm to position the end tool within a workspace.
Structure: It typically includes major sections such as the shoulder, elbow, and wrist.
Degrees of Freedom (DoF): Each independent joint provides a degree of freedom; most industrial arms have six axes to reach any orientation in 3D space.

3. **End Effectors**

Commonly referred to as "End-of-Arm Tooling" (EOAT), the end effector is the "hand" of the robot. It is the specific device attached to the wrist that interacts directly with the environment.
Grippers: Used for picking, holding, and moving objects. Types include mechanical jaws, vacuum suction cups, and magnetic grippers.
Process Tools: Specialized attachments for performing work, such as welding torches, spray guns, drills, or laser cutters.

ROBOT COMPONENT SYSTEM

4. **Actuators**

Actuators are the "muscles" of the robot that convert energy (electric, fluid, or air) into physical motion.

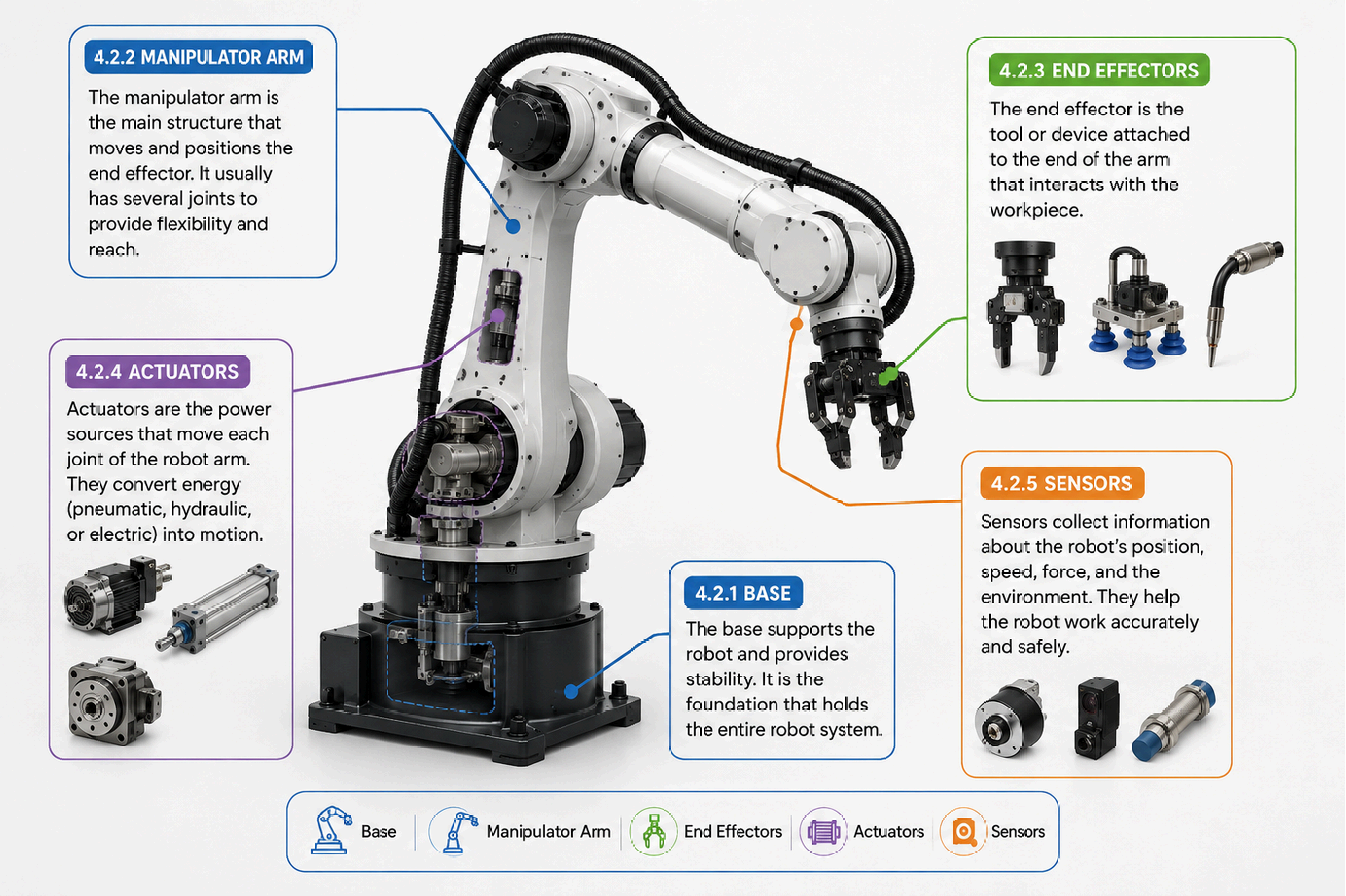
- *Electric Motors*: Most common for precision; include servo and stepper motors.
- *Hydraulic Actuators*: Use pressurized oil to provide high force for heavy-duty lifting.
- *Pneumatic Actuators*: Use compressed air for fast, simple, and lightweight movements.

5. **Sensors**

Sensors act as the "sense organs" of the robot, providing critical feedback to the controller about the robot's state and surroundings.

- *Internal Sensors*: Monitor the robot's own status, such as encoders for joint position and tachometers for speed.
- *External Sensors***:** Allow the robot to perceive its environment, including vision systems (cameras/LiDAR), proximity sensors, and tactile sensors for touch and pressure.

ROBOT COMPONENT SYSTEM



ROBOT DESIGN CONFIGURATION AND ITS WORKPLACE

Robot configurations are commonly classified based on their coordinate systems and joint movements, as illustrated in **Figure 4.1**. In robotics, different types of joints are represented using specific symbols: prismatic joints are labeled as **P**, revolute joints as **R**, and spherical joints as **S**. A robot configuration is described by combining these symbols according to the number and type of joints used. For example, a robot that consists of three prismatic joints and three revolute joints is represented as **3P3R**.

The following are several common robot configurations used to position and control the movement of a robot's end effector:

- **Cartesian / Rectangular / Gantry Robot (3P)**

Uses three prismatic joints to move in straight-line directions (x, y, z axes). Commonly used for pick-and-place and CNC machines.

- **Cylindrical Robot (PRP)**

Uses two prismatic joints and one revolute joint to create a cylindrical working area. Commonly used for machine loading, material handling, and assembly operations.

- **Spherical Robot (P2R)**

Uses one prismatic joint and two revolute joints to create a spherical movement area. Suitable for handling and welding operations.

- **SCARA Robot**

Uses revolute joints for horizontal movement and a prismatic joint for vertical movement. Commonly used in assembly operations because of its fast and accurate movement.

- **Articulated / Anthropomorphic Robot (3R)**

Uses only revolute joints, similar to the movement of a human arm. This is the most widely used industrial robot configuration.

ROBOT DESIGN CONFIGURATION AND ITS WORKPLACE

Robot design configuration refers to the physical arrangement of a robot's joints and links. Different robot configurations produce different movement patterns and work areas (workspace). The selection of robot configuration depends on the type of task, working area, speed, and flexibility required in manufacturing operations.

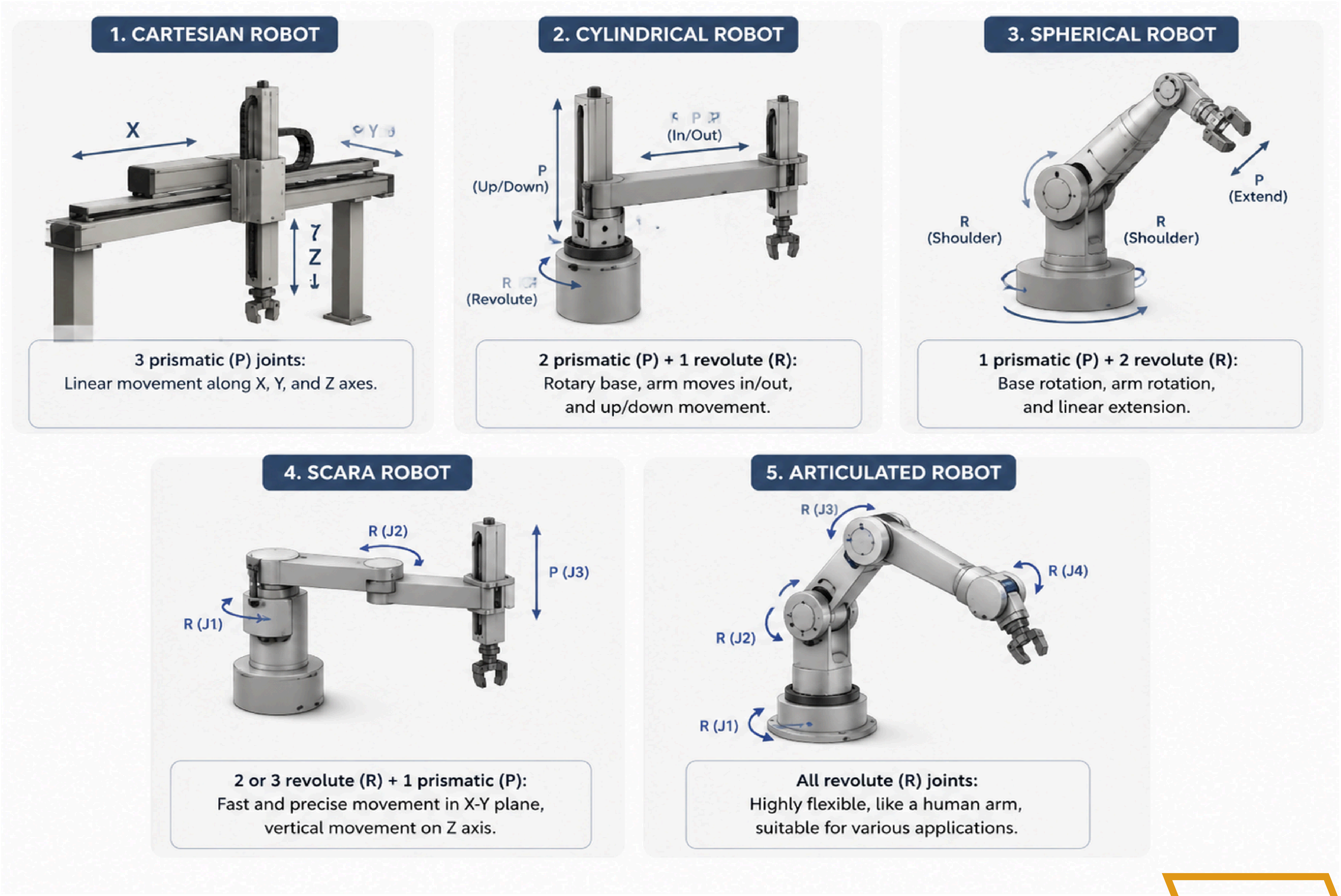


Figure 4.1 Common robot coordinate frame for serial robots

ROBOT DESIGN CONFIGURATION AND ITS WORKPLACE

🤖 COMMON ROBOT CONFIGURATIONS

Cartesian Robot

📌 *Description*

A Cartesian robot uses three prismatic (linear) joints to move along the:

- X-axis
- Y-axis
- Z-axis

Its movement is straight and rectangular.

🏭 *Workplace Shape*

📦 Rectangular / Box-shaped workspace

✅ *Advantages*

- High accuracy
- Simple design and control
- Easy programming

❌ *Disadvantages*

- Limited flexibility
- Requires large installation space

💡 *Applications*

- CNC machines, 3D printers and Pick-and-place systems

ROBOT DESIGN CONFIGURATION AND ITS WORKPLACE

🤖 COMMON ROBOT CONFIGURATIONS

Cylindrical Robot

📌 *Description*

A cylindrical robot uses:

- two prismatic joints
- one revolute joint

The arm moves up/down, in/out, and rotates around the base.

🏭 *Workplace Shape*

🛢 Cylindrical workspace

✅ *Advantages*

- Good vertical movement
- Suitable for machine loading

❌ *Disadvantages*

- Lower flexibility compared to articulated robots

💡 *Applications*

- Material handling
- Assembly operations
- Machine loading

ROBOT DESIGN CONFIGURATION AND ITS WORKPLACE

🤖 COMMON ROBOT CONFIGURATIONS

Spherical Robot

📌 *Description*

A spherical robot uses:

- one prismatic joint
- two revolute joints

The arm moves in a spherical or curved motion.

🏭 *Workplace Shape*

⚪ Spherical workspace

✅ *Advantages*

- Wide working range
- Flexible arm movement

❌ *Disadvantages*

- More difficult to control

💡 *Applications*

- Welding
- Spray painting
- Material handling

ROBOT DESIGN CONFIGURATION AND ITS WORKPLACE

🤖 COMMON ROBOT CONFIGURATIONS

SCARA Robot

📌 *Description*
SCARA stands for:
Selective Compliance Assembly Robot Arm

It uses revolute joints for horizontal movement and a prismatic joint for vertical movement.

🏭 *Workplace Shape*
🍩 Cylindrical / donut-shaped workspace

✅ *Advantages*
- Very fast and accurate
- Excellent for assembly work

❌ *Disadvantages*
- Limited movement range

💡 *Applications*
- Electronic assembly
- Pick-and-place operations
- Packaging

ROBOT DESIGN CONFIGURATION AND ITS WORKPLACE

🤖 COMMON ROBOT CONFIGURATIONS

Articulated Robot

📌 *Description*

An articulated robot uses only revolute joints, similar to the movement of a human arm.

It is the most common industrial robot configuration.

🏭 *Workplace Shape*

🌐 Large flexible workspace

✅ *Advantages*

- Highly flexible
- Can reach complex positions
- Wide range of motion

❌ *Disadvantages*

- More complex programming
- Higher cost

💡 *Applications*

- Welding, Painting, Assembly, and Inspection

ROBOT DESIGN CONFIGURATION AND ITS WORKPLACE

✨ QUICK COMPARISON OF ROBOT CONFIGURATIONS

Robot Type	Joint Type	Workplace Shape	Common Application
Cartesian	3P	Rectangular	CNC, 3D printing
Cylindrical	PRP	Cylindrical	Machine loading
Spherical	PRR	Spherical	Welding, painting
SCARA	RRP	Cylindrical	Assembly
Articulated	RRR	Flexible	Welding, automation

🎯 **Key Point**
Different robot configurations are selected based on workspace shape, flexibility, accuracy, and industrial application requirements.

ROBOT PROGRAMMING OPERATION METHOD

Robot programming is the process of giving instructions to a robot so it can perform specific tasks automatically. Different programming methods are used depending on the application, complexity, and production requirements.

Lead Through Programming

📌 *Definition*

In lead through programming, the operator physically guides the robot arm through the required movements. The robot records these movements and repeats them automatically later.

💡 *Characteristics*

- Easy to learn and use
- Suitable for simple tasks
- Commonly used in welding and spray painting

✅ *Advantages*

- Simple programming method
- No advanced coding required

❌ *Disadvantages*

- Less suitable for complex operations
- Robot must stop during teaching process

ROBOT PROGRAMMING OPERATION METHOD

Walk Through Programming

📌 *Definition*

In walk through programming, the operator uses a control device or teach pendant to move the robot step-by-step without physically touching the robot arm.

💡 *Characteristics*

- Robot movement is controlled electronically
- More accurate than manual guiding
- Common in industrial robots

✅ *Advantages*

- Better accuracy
- Safer than manual handling

❌ *Disadvantages*

- Requires operator training
- Takes time for complex programs

ROBOT PROGRAMMING OPERATION METHOD

Offline Programming

📌 *Definition*

Offline programming is done using a computer without stopping the actual robot operation.

The program is created, tested, and simulated before being transferred to the robot.

💡 *Characteristics*

- Uses simulation software
- Robot can continue production during programming
- Suitable for complex manufacturing systems

✅ *Advantages*

- Reduces production downtime
- Safer and more efficient
- Easy to modify programs

❌ *Disadvantages*

- Requires special software and skills
- Higher cost

ROBOT PROGRAMMING OPERATION METHOD

Online Programming

📌 *Definition*

Online programming is performed directly on the robot while the robot is connected to the production system.

💡 *Characteristics*

- Changes can be tested immediately
- Suitable for simple adjustments
- Common for troubleshooting and setup

✅ *Advantages*

- Immediate testing and correction
- Faster for small changes

❌ *Disadvantages*

- Production may need to stop
- Risk of programming errors during operation

ROBOT PROGRAMMING OPERATION METHOD

✨ SIMPLE COMPARISON

Programming Method	Main Idea
Lead Through	Physically guide robot
Walk Through	Use control device to guide robot
Offline Programming	Program using computer simulation
Online Programming	Program directly on robot

🎯 **Key Point**
Different robot programming methods are used depending on production needs, accuracy, cost, and system complexity.

ROBOT APPLICATIONS IN MANUFACTURING PROCESSES

Industrial robots are widely used in manufacturing because they can perform tasks faster, more accurately, and more consistently than humans. Robots help improve productivity, quality, and workplace safety.

Welding Process

📌 *Definition*
Robots are used to perform welding operations automatically with high accuracy and consistency.

✅ *Advantages*

- Produces consistent weld quality
- Increases production speed
- Improves worker safety from heat and sparks

💡 *Applications*

- Automotive manufacturing
- Metal fabrication industries

Spraying Process

📌 *Definition*
Robots are used for spray painting and coating processes to ensure smooth and uniform surfaces.

✅ *Advantages*

- Better finishing quality
- Reduces paint waste
- Safer working environment

💡 *Applications*

- Car painting
- Furniture coating

ROBOT APPLICATIONS IN MANUFACTURING PROCESSES

Assembly Process

📌 *Definition*

Robots assemble components and products automatically with high precision.

✅ *Advantages*

- Faster assembly process
- Reduces human error
- Suitable for repetitive tasks

💡 *Applications*

- Electronic products
- Automotive assembly lines

Inspection Process

📌 *Definition*

Robots equipped with sensors and cameras inspect products to detect defects or quality problems.

✅ *Advantages*

- High inspection accuracy
- Reduces defective products
- Continuous monitoring

💡 *Applications*

- Product quality inspection
- Surface defect detection

ROBOT APPLICATIONS IN MANUFACTURING PROCESSES

Testing Process

📌 *Definition*
Robots perform automatic testing to ensure products function correctly before delivery.

✅ *Advantages*
- Consistent testing results
- Faster testing process
- Improves product reliability

💡 *Applications*
- Electronic device testing
- Automotive component testing

Pick and Place Process

📌 *Definition*
Robots pick up objects from one location and place them in another location automatically.

✅ *Advantages*
- High speed operation
- Accurate positioning
- Reduces manual handling

💡 *Applications*
- Packaging industries
- Electronic manufacturing

ROBOT APPLICATIONS IN MANUFACTURING PROCESSES

Palletizing Process

📌 *Definition*

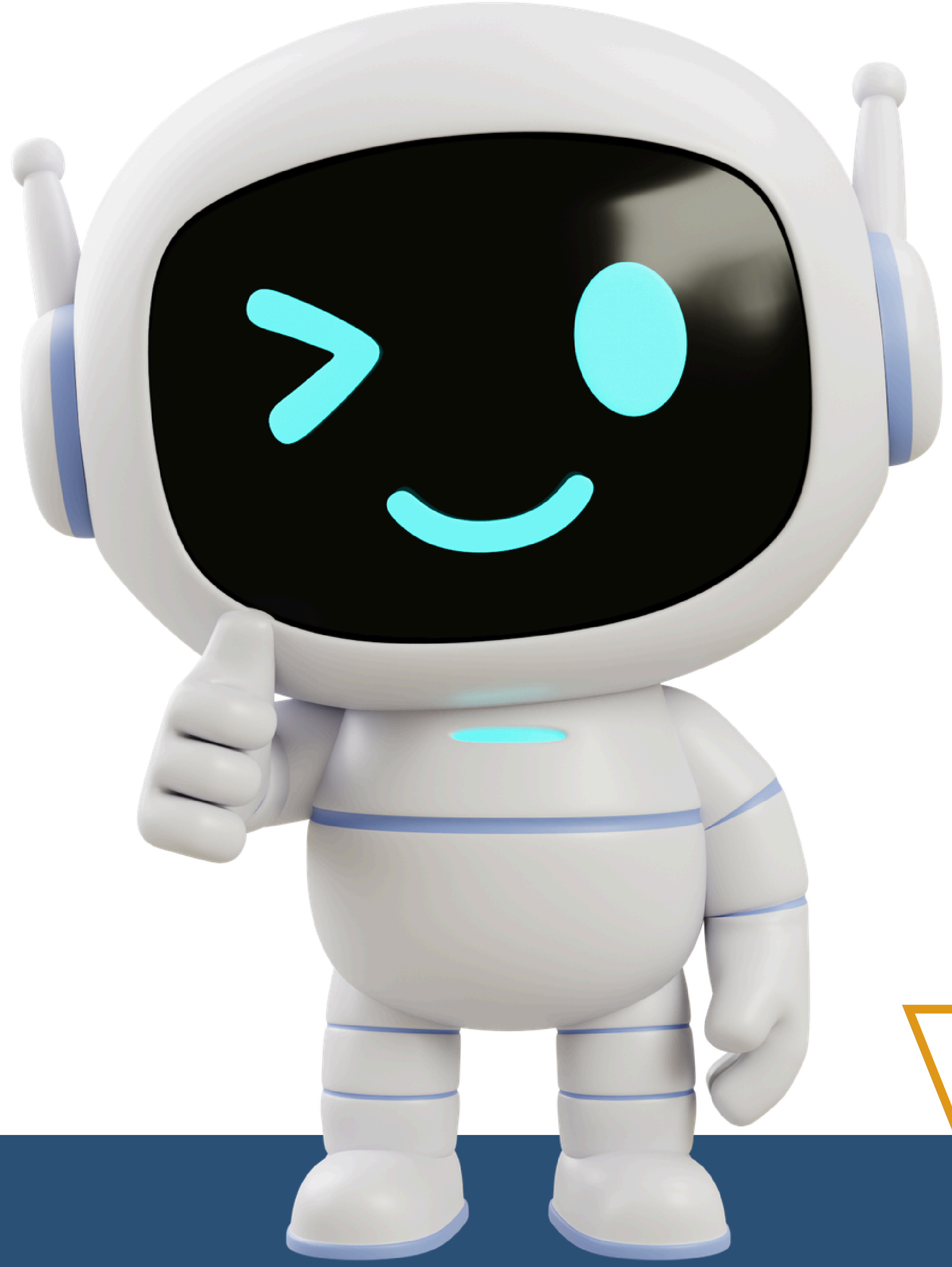
Robots arrange and stack products onto pallets for storage or transportation.

✅ *Advantages*

- Handles heavy loads safely
- Increases productivity
- Reduces worker fatigue

💡 *Applications*

- Warehouses
- Food and beverage industries



ROBOT APPLICATIONS IN MANUFACTURING PROCESSES

✨ SUMMARY OF ROBOT APPLICATIONS

Application	Main Function
Welding	Join metal parts
Spraying	Paint or coat surfaces
Assembly	Assemble products
Inspection	Detect defects
Testing	Check product performance
Pick and Place	Move items automatically
Palletizing	Stack products on pallets

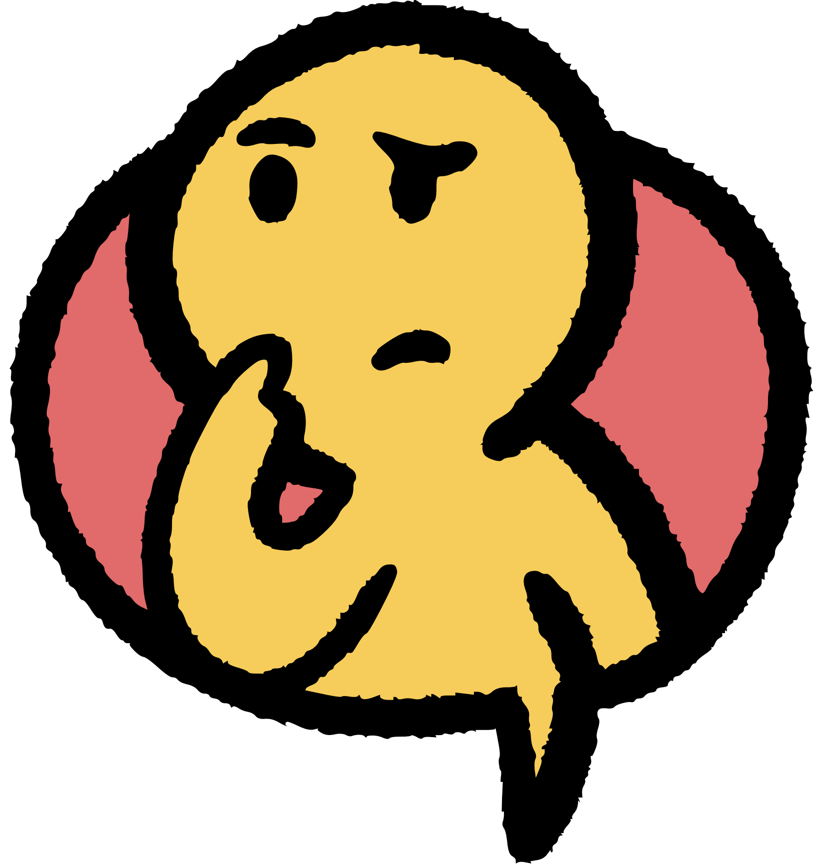
🎯 **Key Point**
Industrial robots improve manufacturing efficiency, product quality, accuracy, and workplace safety by performing repetitive and hazardous tasks automatically.

CHAPTER 5

FORECASTING

This chapter introduces forecasting as a powerful tool to predict future demand in manufacturing. Students will learn time series components and apply practical forecasting methods such as naïve, moving average, weighted moving average, and exponential smoothing. The chapter also covers how to evaluate forecast accuracy using MAD, MSE, and MAPE for better decision-making.

WHAT IS FORECASTING?



Forecasting is the process of **predicting future demand by analyzing historical data and patterns**.
In manufacturing, forecasting is used to estimate:

- how much product will be needed,
- when it will be needed,
- and how resources should be prepared.

Forecasting helps reduce uncertainty and supports better planning and decision-making.

Key Elements of Forecasting

- **Historical Data**
  - Past demand information used as the basis of analysis.
- **Demand**
  - Expected customer requirement for products or services.
- **Prediction**
  - Estimated future value based on analysis and forecasting methods.

Example
If a factory produced 1,000 units last month, forecasting helps estimate **how many units to produce next month**.

THE STRATEGIC IMPORTANCE OF FORECASTING

In manufacturing, product demand forecasting plays a strategic role because it directly affects major operational decisions. An accurate forecast helps organizations plan resources efficiently and reduce uncertainty. The impact of forecasting can be clearly seen in three key activities:

1. Supply Chain Management

- Forecasts determine how much material to order and when to order
- Help suppliers, manufacturers, and distributors coordinate activities
- Reduce problems such as excess inventory or stockouts
- Improve overall supply chain efficiency

✅ Inaccurate forecasts may cause high inventory costs or interrupted production.

2. Human Resources

- Forecasting helps decide the number of workers required
- Supports planning for:
    - Hiring
    - Overtime
    - Training
    - Temporary labor
- Ensures labour availability matches production demand

✅ Poor forecasting can lead to labor shortages or underutilized workers.

THE STRATEGIC IMPORTANCE OF FORECASTING

3. Capacity Planning

- Determines required machine capacity, facilities, and production levels
- Helps management decide whether to:
    - Expand capacity
    - Reduce capacity
    - Maintain current capacity
- Supports long-term investment decisions

✅ Accurate capacity planning avoids bottlenecks and wasted resources.

Summary:

Forecasting is strategically important because it links **expected demand** with decisions on **materials, workforce, and production capacity.**

TIME SERIES FORECASTING

A time series is data collected over time (daily, weekly, monthly, yearly).
Example: sales per month, production per week.

To facilitate understanding and enable accurate prediction of future values, time series data are systematically decomposed into four primary components

1. Trend
Trend is the gradual upward or downward movement of the data over time. Changes in income, population, age distribution, or cultural views may account for movement in trend.
💡 Example:
A factory produces more products every year → upward trend

2. Seasonality
Seasonality is a data pattern that repeats itself after a period of days, weeks, months, or quarters
💡 Example:
i. High sales during Hari Raya
ii. Low production during holiday period

3. Cycles
Cycles are patterns in the data that occur every several years. They are usually tied into the business cycle and are of major importance in short-term business analysis and planning. Predicting business cycles is difficult because they may be affected by political events or by international turmoil.

- No exact repeating pattern
- Usually related to economic conditions

💡 Example:
i. Business goes up during economic growth
ii. Business goes down during recession

4. Random variations
Random variations are “blips” in the data caused by chance and unusual situations. They follow no discernible pattern, so they cannot be predicted.
💡 Example:
i. Machine breakdown
ii. Natural disaster
iii. Sudden drop in demand

TIME SERIES FORECASTING

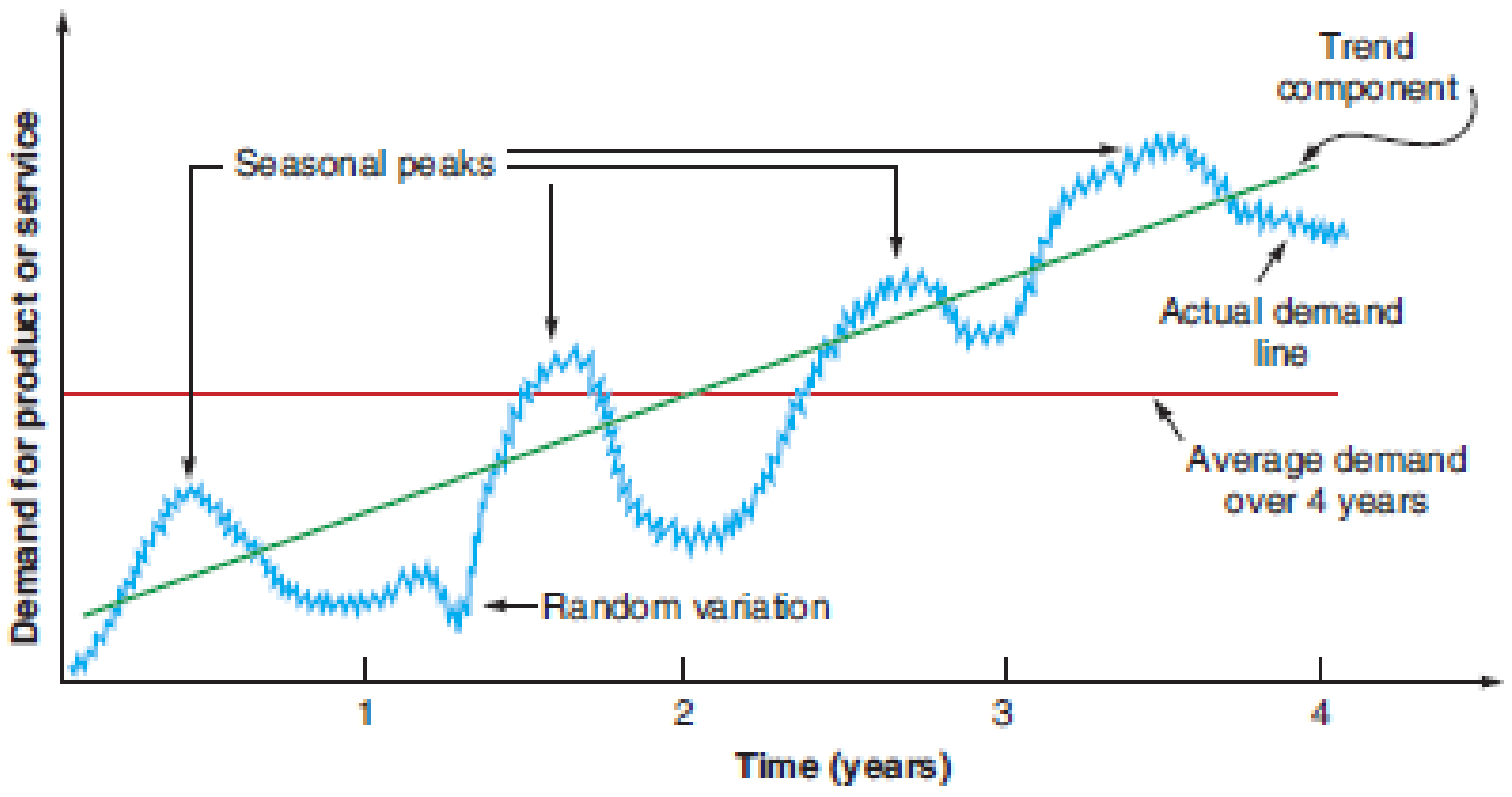


Figure 5.1 Demand Charted over 4 Years, with a Growth Trend and Seasonality Indicated

STUDENT TIP
Forecasting is easy when demand is stable. But with trend, seasonality, and cycles considered, the job is a lot more interesting.

METHOD OF FORECASTING

1 Naïve Approach

👉 Use the last period data as forecast

$$F_t = A_{t-1}$$

💡 Example:

Last month sales = 100 → Forecast = 100

✅ Very simple

❌ Not accurate for long term

2 Moving Average

👉 Average of previous data

$$F_t = \frac{A_1 + A_2 + ... + A_n}{n}$$

💡 Example:

(100 + 110 + 120) / 3 = 110

✅ Smooth data

❌ Slow response to change

3 Weighted Moving Average

👉 Give different weight to each data

$$F_t = (w_1A_1 + w_2A_2 + ... + w_nA_n)$$

💡 Example:

More recent data = higher weight

✅ More accurate than moving average

❌ Need to choose correct weight

4 Exponential Smoothing Forecasting

Uses previous forecast and recent actual data.

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

Where:

α = smoothing constant (0 < α < 1)

Advantages:

✅Simple and efficient

✅Widely used in industry

Example 1: Moving Average Forecasting

A factory records the monthly demand (units) as follows:

Month	Demand
Jan	100
Feb	120
Mar	130
Apr	110
May	140

👉 Determine the 3-month moving average forecast for June.

Solution:

For 3-month moving average, we take the last 3 months data.

👉 For June → use **March, April, May**

$$F = \frac{A_1 + A_2 + A_3}{3}$$

$$F = \frac{130 + 110 + 140}{3}$$

$$F = \frac{380}{3} = 126.67$$

🎯 **Final Answer**

✅ **Forecast for June = 126.67 ≈ 127 units**

METHOD OF FORECASTING

Example 2: Weighted Moving Average Forecasting

A company records the monthly demand (units) as follows:

Month	Demand
Jan	100
Feb	120
Mar	130

👉 Determine the forecast for April using Weighted Moving Average with weights:

- March = 0.5
- February = 0.3
- January = 0.2

Solution:

- More recent data = higher weight
- Total weight must equal 1.0

0.5+0.3+0.2=1.0 ✅

$$F = (w_1 A_1) + (w_2 A_2) + (w_3 A_3)$$

$$F = (0.5 \times 130) + (0.3 \times 120) + (0.2 \times 100)$$

$$F = 65 + 36 + 20$$

$$F = 121$$

🎯 **Final Answer**

✅ **Forecast for April = 121 units**

Example 3: Exponential Smoothing Forecasting

A company has the following data:

- Actual demand for March = 130 units
- Forecast for March = 120 units
- Smoothing constant, α=0.3

👉 Determine the forecast for April.

Solution:

Use Formula

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

$$F_{April} = 120 + 0.3(130 - 120)$$

$$F_{April} = 120 + 0.3(10)$$

$$F_{April} = 120 + 3$$

$$F_{April} = 123$$

🎯 **Final Answer**

✅ **Forecast for April = 123 units**

FORECAST ERRORS

👉 Used to check accuracy of forecast

1. MAD (Mean Absolute Deviation)

👉 Measures average error

$$MAD = \frac{\sum |Actual - Forecast|}{n}$$

2. MSE (Mean Squared Error)

👉 Penalizes large error more

$$MSE = \frac{\sum (Actual - Forecast)^2}{n}$$

3. MAPE (Mean Absolute Percent Error)

👉 Shows error in percentage

$$MAPE = \frac{\sum \left| \frac{Actual - Forecast}{Actual} \right|}{n} \times 100$$

🎯 **Summary**

- Forecasting helps predict future demand
- Different methods give different results
- Accuracy must be checked using MAD, MSE, and MAPE

✨ **Key Message for Students:**

"Forecasting is not guessing — it is using data to make smarter decisions."

FORECAST ERRORS

Example: Forecast Error Calculation

Given Data:

Period	Actual (A)	Forecast (F)
1	100	90
2	120	110
3	130	125
4	110	120

◆ Step-by-Step Calculation Table

Period	A	F	Error (A−F)	|Error|	Error²	|Error| / A
1	100	90	10	10	100	0.1
2	120	110	10	10	100	0.083
3	130	125	5	5	25	0.038
4	110	120	-10	10	100	0.091
Total	—	—	—	**35**	**325**	**0.312**

FORECAST ERRORS

Example: Forecast Error Calculation

Calculate MAD:

$$MAD = \frac{\sum |Error|}{n}$$

$$MAD = \frac{10 + 10 + 5 + 10}{4}$$

$$MAD = \frac{35}{4} = 8.75$$

Calculate MSE:

$$MSE = \frac{\sum Error^2}{n}$$

$$MSE = \frac{100 + 100 + 25 + 100}{4}$$

$$MSE = \frac{325}{4} = 81.25$$

Calculate MAPE:

$$MAPE = \frac{\sum \left|\frac{A-F}{A}\right|}{n} \times 100$$

$$MAPE = \frac{0.10 + 0.083 + 0.038 + 0.091}{4} \times 100$$

$$MAPE = \frac{0.312}{4} \times 100$$

$$MAPE = 0.078 \times 100 = 7.8\%$$

FORECAST ERRORS

Example: Forecast Error Calculation

🎯 Conclusion from the Results:

From the calculation:

- **MAD = 8.75**
- **MSE = 81.25**
- **MAPE = 7.8%**

🔹 **1. Overall Accuracy**

👉 The forecast is quite accurate

- MAPE = 7.8% (less than 10%)
- This shows the error is low

📌 **Simple rule:**

- < 10% → Very good
- 10%–20% → Acceptable
- 20% → Poor

🔹 **2. Error Size**

👉 MAD = 8.75 means:

- On average, forecast is about 9 units off

💡 Interpretation:

"The forecast is close to actual demand"

🔹 **3. Large Errors**

👉 MSE = 81.25

Shows there are some larger errors

But still at a reasonable level

✨ **Final Simple Conclusion**

The forecasting method used is reliable and acceptable because the error values are low. The company can use this forecast for planning production and inventory.

CHAPTER 6

PRODUCTION SCHEDULING

This chapter introduces production scheduling as a key tool to organize and control job sequences in manufacturing and service systems. It covers important performance measures and applies scheduling techniques such as FCFS, EDD, SPT, LPT, Critical Ratio, and Johnson’s Rule to improve efficiency, reduce delays, and optimize overall operations.

SCHEDULING SERVICE AND MANUFACTURING PROCESSES

Scheduling means **planning when and how work should be done**. It is important in both **service industries** and **manufacturing industries**.

In **service industries**, scheduling is more complex because it often involves direct contact with customers.
For example, in a front-office service like a hospital, restaurant, or customer counter:

- Every customer has different needs.
- Workers must be flexible.
- It is hard to predict how many customers will come.

  So, managers must schedule the **right number of employees** at the **right time** to serve customers well.

On the other hand, **back-office services** (like data processing or banking operations) have **less customer contact**.

They usually follow a **fixed routine**, similar to a factory process.

Here, scheduling focuses more on **operation time** and **staff shifts** to make sure work runs smoothly.

SCHEDULING SERVICE AND MANUFACTURING PROCESSES

In **manufacturing**, scheduling helps plan:

- **What products to make**
- **When to make them**
- **Which machines or workers to use**

There are different types of scheduling:

- **Demand scheduling** – plan based on customer orders or demand.
- **Workforce scheduling** – assign workers to the right tasks and time.
- **Operations scheduling** – organize machines, materials, and work sequence.

Even though scheduling gives structure and order, managers still need to **compare many possible plans** to find the best one.
The goal is always to make **operations efficient, timely, and productive** — whether in a service company or a manufacturing plant.

💡 **Tip:**
Good scheduling means **less waiting, less stress, and better performance** — for both workers and customers!

SCHEDULING SERVICE AND MANUFACTURING PROCESSES

PERFORMANCE MEASURES IN SCHEDULING

When we plan or schedule jobs, we need to measure how well the system is working.
Here are some common performance measures used in both services and manufacturing:

🕒 i. **Job Flow Time**
The total time a job spends in the system — from the moment it starts until it is finished.
➡️ *Example: If a product takes 5 hours to move through all the steps in production, its job flow time is 5 hours.*
💡 *Shorter flow time = faster system!*

⏳ *ii.* **Makespan**
The total time needed to complete a group of jobs.
➡️ *Example: If five jobs start at 8:00 AM and the last one finishes at 5:00 PM, the makespan is 9 hours.*
💡 *The smaller the makespan, the more efficient the schedule.*

📅 *iii.* **Past Due (Late Jobs)**
How late a job is compared to its due date — or how many jobs are late in a given period.
➡️ *Example: If a job was due yesterday but finished today, it is 1 day past due.*
💡 *Good scheduling reduces the number of late jobs.*

SCHEDULING SERVICE AND MANUFACTURING PROCESSES

PERFORMANCE MEASURES IN SCHEDULING

⚙️ *iv.* **Work in Progress (WIP)**
Jobs that are not yet finished — they may be waiting, being processed, or moving between machines.
➡️ *Example: Half-built parts or items waiting in a queue are WIP.*
💡 *Too much WIP means the system is overloaded or slow.*

📦 v. **Total Inventory**
The total number of items that are available (on hand) plus those that are already scheduled to arrive or be produced.
➡️ *Think of it as everything the factory currently owns — finished or unfinished.*
💡 Managing inventory helps balance cost and production speed.

🔧 vi. **Utilization**
The percentage of work time that a worker or machine is actually doing productive work.
➡️ *Example: If a machine runs 6 hours out of an 8-hour shift, its utilization is 75%.**
💡 Higher utilization means better use of resources — but too high may cause burnout or breakdowns.

✨ **In short:**
Good scheduling means shorter flow time, smaller makespan, fewer late jobs, less WIP, balanced inventory, and efficient utilization.

JOB SHOP SCHEDULING

PRIORITY RULES

In a **job shop**, many jobs need to be processed, but machines and workers are limited. So, we need **priority rules** to decide **which job should be done first**. These rules help organize work, reduce waiting time, and meet due dates. Here are the common priority sequencing rules used in scheduling:

🕐 i. **First Come, First Serve (FCFS)**
Jobs are processed in the order they arrive — just like waiting in a queue.
➡️ *Example: If Job A comes before Job B, then Job A will be processed first.*
💡 This rule is simple and fair, but not always the fastest.

📅 ii. **Earliest Due Date (EDD)**
The job with the earliest due date is done first.
➡️ *Example: If Job A is due tomorrow and Job B is due next week, do Job A first.*
💡 Helps reduce late jobs and meet deadlines.

⚡ iii. **Shortest Processing Time (SPT)**
Do the job that takes the least time first.
➡️ *Example: If Job A takes 1 hour and Job B takes 4 hours, start with Job A.*
💡 Good for reducing average waiting time.

JOB SHOP SCHEDULING

PRIORITY RULES

🏋️ *iv.* **Longest Processing Time (LPT)**
Do the job that takes the longest time first.
➡️ *Example: If Job A takes 5 hours and Job B takes 2 hours, do Job A first.*
💡 Useful when long jobs are more important or need early attention.

✨ In short:
Each rule gives different results.

- **FCFS** → fair and simple
- **EDD** → meet due dates
- **SPT** → finish jobs faster
- **LPT** → focus on big, important jobs

👉 Good scheduling means choosing the right rule for the situation!

JOB SHOP SCHEDULING

EXAMPLE

The Hamra Workshop Case

The Hamra Workshop repairs and rebores car engine blocks. At the moment, five (5) engine jobs are waiting to be processed. Only one engine expert is available to do the work, so the jobs must be scheduled carefully. Each job has a different processing time and due date (customer pickup time) that was agreed with the customer. The table below shows the information for all jobs as of Monday morning. The workshop operates from 8.00 a.m. to 5.00 p.m. (9 working hours per day). Customer pickup times are measured in working hours from Monday morning.

Tasks:
Using the FCFS scheduling rule:

1. Prepare a job schedule for the engine expert.
2. Calculate the following performance measures:
   i. Average job flow time
   ii. Average hours early
   iii. Average hours past due (late time)
   iv. Average Work-In-Process (WIP) inventory
   v. Average total inventory

ENGINE BLOCK	PROCESSING TIME, (HRS)	SCHEDULED CUSTOMER PICKUP TIME (hrs)
RANGER	8	10
EXPLORER	6	12
DEMAX	15	20
HARRIER	3	18
X70	12	22

JOB SHOP SCHEDULING

FCFS

1) FCFS schedule (start at 0)

Job	Proc (hrs)	Start (hrs)	Finish (hrs)	Due date (hrs)	Due − Finish (hrs)	Lateness (Finish − Due, if >0)
RANGER	8	0	8	10	+2 (early)	0
EXPLORER	6	8	14	12	−2 (late)	2
DEMAX	15	14	29	20	−9 (late)	9
HARRIER	3	29	32	18	−14 (late)	14
X70	12	32	44	22	−22 (late)	22

Makespan (total completion time) = 44 hrs

FCFS

i. **Average job flow time**

= (8 + 14 + 29 + 32 + 44) / 5 = 127 / 5 = 25.4 hrs.

ii. **Average hours early**

= (2 + 0 + 0 + 0 + 0) / 5 = 2 / 5 = 0.4 hrs.

iii. **Average hours past due (average lateness)**

= (0 + 2 + 9 + 14 + 22) / 5 = 47 / 5 = 9.4 hrs.

iv. **Average WIP inventory (engine blocks)**

= (8 + 14 + 29 + 32 + 44) / 44 = 127 / 44 ≈ 2.89 engine blocks

v. **Average total inventory**

= (10 + 23 + 35 +41 + 44) / 44 = 153 / 44 ≈ 3.47 engine blocks.

JOB SHOP SCHEDULING

EDD

Using the EDD scheduling rule:

ENGINE BLOCK SEQUENCE	BEGIN WORK		PROCESSING TIME (hrs)	Job flow time	Scheduled customer pickup time	Actual customer pickup time	Hours early	Hours past due
RANGER	0	+	8	8	10	10	2	-
EXPLORER	8	+	6	14	12	12	-	2
HARRIER	14	+	3	17	18	18	1	-
DEMAX	17	+	15	32	20	32	-	12
X70	32	+	12	44	22	44	-	22

JOB SHOP SCHEDULING

EDD

i. **Average job flow time** = (8 + 14 + 17 + 32 + 44) / 5 = 115 / 5 = 23 hours.

ii. **Average hours early** = (2 + 0 + 1 + 0 + 0) / 5 = 0.6 hours.

iii. **Average hours past due** = (0 + 2 + 0 + 12 + 22) / 5 = 36 / 5 = 7.2 hours.

iv. **Average WIP (engine blocks)** = (8 + 14 + 17 + 32 + 44) / 44 = 115 / 44 ≈ 2.61 engine blocks.

v. **Average total inventory (engine blocks)** = (10 + 14 + 18 + 32 + 44) / 44 = 118 / 44 ≈ 2.68 engine blocks.

JOB SHOP SCHEDULING

SPT

ENGINE BLOCK SEQUENCE	BEGIN WORK		PROCESSING TIME (hrs)	Job flow time	Scheduled customer pickup time	Actual customer pickup time	Hours early	Hours past due
HARRIER	0	+	3	3	18	18	15	-
EXPLORER	3	+	6	9	12	12	3	-
RANGER	9	+	8	17	10	17	-	7
X70	17	+	12	29	22	29	-	7
DEMAX	29	+	15	44	20	44	-	24

JOB SHOP SCHEDULING

SPT

i. **Average job flow time** = (3 + 9 + 17 + 29 + 44) / 5 = 20.4 hours.

ii. **Average hours early** = (15 + 3 + 0 + 0 + 0) / 5 = 3.6 hours.

iii. **Average hours past due** = (0 + 0 + 7 + 7 + 24) / 5 = 7.6 hours.

iv. **Average WIP (engine blocks)** = (3 + 9 + 17 + 29 + 44) / 44 = 2.32 engine blocks.

v. **Average total inventory (engine blocks)** = (18 + 12 + 17 + 29 + 44) / 44 = 2.73 engine blocks.

JOB SHOP SCHEDULING

LPT

let’s now solve the same Hamra Workshop problem using the Longest Processing Time (LPT) rule

Arrange Jobs by Longest Processing Time (LPT)
Order the jobs from longest to shortest processing time:

Order	Job	Processing Time (hrs)
1	DEMAX	15
2	X70	12
3	RANGER	8
4	EXPLORER	6
5	HARRIER	3

So LPT sequence → **DEMAX → X70 → RANGER → EXPLORER → HARRIER**

JOB SHOP SCHEDULING

LPT

Scheduling Table

Order the jobs from longest to shortest processing time:

Job	Proc. Time (hrs)	Start (hrs)	Finish (hrs)	Due (hrs)	Due – Finish (hrs)
DEMAX	15	0	15	20	20 – 15 = +5 (early)
X70	12	15	27	22	22 – 27 = −5 (late)
RANGER	8	27	35	10	10 – 35 = −25 (late)
EXPLORER	6	35	41	12	12 – 41 = −29 (late)
HARRIER	3	41	44	18	18 – 44 = −26 (late)

🕒 **Makespan = 44 hrs**

JOB SHOP SCHEDULING

LPT

Performance Measures

i. **Average Job Flow Time** = (15 + 27 + 35 + 41 + 44) / 5 = 162 / 5 =32.4 hrs.

ii. **Average Hours Early** = (5 + 0 + 0 + 0 + 0) / 5 = 1.0 hr.

iii. **Average Hours Past Due** = (0 + 5 + 25 + 29 + 26) / 5 = 85 / 5 = 17.0 hrs.

iv. **Average WIP Inventory** = (15 + 27 + 35 + 41 + 44) / 44 = 162 / 44 = 3.68 engine blocks

v. **Average Total Inventory** = (20 + 27 + 35 + 41 + 44) / 44 = 167 / 44 =3.80 engine blocks

JOB SHOP SCHEDULING

CRITICAL RATIO

The Critical Ratio (CR) rule helps decide which job should be done next by comparing how much time is left before the due date to how much work time is still needed to finish the job.

◆ **Formula:**

CR=(Due Date−Today's Date)/(Total Shop Time Remaining)

Where:

- Due Date − Today's Date = Time left until the job is due
- Total Shop Time Remaining = Total time still needed to finish the job (includes setup, processing, moving, and waiting time)

◆ **How to Understand the CR Value**

CR Value	Meaning	Action
CR < 1.0	Job is **behind schedule**	Do this job **immediately**
CR = 1.0	Job is **on schedule**	Normal priority
CR > 1.0	Job is **ahead of schedule**	Can be done **later**

💡 The **job with the lowest CR value** is given the **highest priority** and should be scheduled **next**.

JOB SHOP SCHEDULING

CRITICAL RATIO

Using the same Hamra Workshop case lets students clearly compare EDD, SPT, and now CR (Critical Ratio) on the same data set. Let's go step-by-step using Critical Ratio (CR) Rule for the same 5 jobs.

Step – Calculate CR for each job (at Monday 8:00 a.m.)
At the start (today's date = 0), the total shop time remaining = processing time of each job (since no work has started).

Job	Due Date	Today's Date	Shop Time Remaining	CR	Priority
RANGER	10	0	8	(10−0)/8 = 1.25	3rd
EXPLORER	12	0	6	(12−0)/6 = 2.00	5th
DEMAX	20	0	15	(20−0)/15 = 1.33	4th
HARRIER	18	0	3	(18−0)/3 = 6.00	1st
X70	22	0	12	(22−0)/12 = 1.83	2nd

JOB SHOP SCHEDULING

CRITICAL RATIO

➡️ **Lowest CR = HARRIER (6.00 is actually highest, but we pick the lowest number = most urgent job)**

Wait — let's double-check logic:

- Smaller CR → more urgent → schedule first.
- So actual priority order (from smallest CR) is:

Order	Job	CR
1	RANGER	1.25
2	DEMAX	1.33
3	X70	1.83
4	EXPLORER	2
5	HARRIER	6

✅ So the first job to do is RANGER (lowest CR = 1.25).

JOB SHOP SCHEDULING

CRITICAL RATIO

Step – Schedule jobs in CR order

Job	Proc. Time (hrs)	Start (hrs)	Finish (hrs)	Due Date (hrs)	Due – Finish (hrs)
RANGER	8	0	8	10	+2 (early)
DEMAX	15	8	23	20	−3 (late)
X70	12	23	35	22	−13 (late)
EXPLORER	6	35	41	12	−29 (late)
HARRIER	3	41	44	18	−26 (late)

🕒 **Makespan = 44 hours**

JOB SHOP SCHEDULING

CRITICAL RATIO

Step – Performance Measures

Measure	Formula	Result	Interpretation
Average Job Flow Time	(8 + 23 + 35 + 41 + 44) / 5	30.2 hrs	Jobs stay in system longer
Average Hours Early	(2 + 0 + 0 + 0 + 0) / 5	0.4 hrs	Only one job finished early
Average Hours Past Due	(0 + 3 + 13 + 29 + 26) / 5	14.2 hrs	Most jobs are late
Average WIP Inventory	(8 + 23 + 35 + 41 + 44) / 44	151 / 44 = 3.43 engine blocks	Average number of jobs being processed or waiting
Average Total Inventory	(10 + 23 + 35 + 41 + 44) / 44	153 / 44 = 3.48 engine blocks	Average total jobs (WIP + finished) in system

JOB SHOP SCHEDULING

⚖️ QUICK COMPARISON: ALL SCHEDULING RULES

Rule	Job Order	Avg Flow Time (hrs)	Avg Late (hrs)	Avg Early (hrs)	Avg WIP (blocks)	Avg Total Inv (blocks)
FCFS	Ranger → Explorer → Demax → Harrier	25.4	9.4	0.4	2.89	3.47
EDD	Ranger → Explorer → Harrier → Demax	23	7.2	0.6	2.61	2.68
SPT	Harrier → Explorer → Ranger → X70 →	20.4	7.6	3.6	2.32	2.68
LPT	Demax → X70 → Ranger → Explorer →	32.4	17	1	3.68	3.8
CR	Ranger → Demax → X70 → Explorer → Harrier	30.2	14.2	0.4	3.43	3.48

JOB SHOP SCHEDULING

🧠 SUMMARY OF FINDINGS

Rule	Best For	Remarks
FCFS	Fairness	Simple rule, easy to apply, but not efficient.
EDD	Meeting due dates	Best for minimizing lateness.
SPT	Fast job turnaround	Best for minimizing average waiting & flow time.
LPT	Large or critical jobs	Keeps machine busy but causes many late jobs.
CR	Balanced scheduling	Considers urgency & workload, but result depends on due date spread.

✨ **Tip**

- The lower the average flow time, the faster jobs move through the system.
- The lower the average lateness, the better the schedule meets customer deadlines.
- The lower the average WIP/Total Inventory, the less congestion and holding cost.

JOB SHOP SCHEDULING

⚙️ JOHNSON'S RULE (TWO-MACHINE SCHEDULING)

🧩 **What is Johnson's Rule?**

Johnson's Rule is a simple method to find the best job sequence when two machines or workstations are used one after another.
It helps to minimize the total completion time (makespan) — that means finishing all jobs as early as possible.

💡 **This rule is used when:**

- Each job must go through two workstations (e.g., Machine A then Machine B).
- Processing time for every job on both machines is known.
- All jobs are ready at the start.

🛠️ **Basic Idea**

All jobs are processed in the same order on both machines.
So, if Job 1 goes first on Machine 1, it will also be first on Machine 2.

JOB SHOP SCHEDULING

⚙️ JOHNSON'S RULE (TWO-MACHINE SCHEDULING)

🧮 **Steps to Apply Johnson's Rule**

Step 1:
Look at all jobs and find the shortest processing time among both machines (Machine 1 and Machine 2).
If there's a tie, pick any one of them first.

Step 2:
- If the shortest time is on Machine 1, schedule that job as early as possible (toward the front of the list).
- If the shortest time is on Machine 2, schedule that job as late as possible (toward the end of the list).

Step 3:
Remove the scheduled job from the list.
Then, repeat Steps 1 and 2 until all jobs have been scheduled.

JOB SHOP SCHEDULING

⚙️ JOHNSON'S RULE (TWO-MACHINE SCHEDULING)

🧠 **Example**

Let's say you have 5 jobs that must go through Machine 1 and then Machine 2. You look for the shortest time overall:

> The shortest time is 2 hrs. (Job E, Machine 1) → schedule E first.
> Next shortest is 3 hrs. (Job B, Machine 2) → schedule B last.
> Continue until all jobs are placed in order.

This will give you the best sequence that minimizes the total completion time (makespan).

Job	Machine 1 (hrs)	Machine 2 (hrs)
A	4	6
B	7	3
C	5	8
D	6	9
E	2	5

JOB SHOP SCHEDULING

⚙ JOHNSON'S RULE (TWO-MACHINE SCHEDULING)

Step A — Apply Johnson's Rule (find the sequence)

1. Look at all remaining jobs and find the smallest processing time across both machines.
2. If the smallest time is on M1, place that job as early as possible (front of the sequence).
3. If the smallest time is on M2, place that job as late as possible (end of the sequence).
4. Remove that job from the list and repeat until all jobs are scheduled.

Walkthrough

- Smallest time overall = 2 (Job E on M1) → put E at front.
- Remaining jobs: A(4,6), B(7,3), C(5,8), D(6,9).
- Smallest = 3 (Job B on M2) → put B at the end.
- Remaining: A(4,6), C(5,8), D(6,9).
- Smallest = 4 (A on M1) → put A next available front position.
- Remaining: C(5,8), D(6,9).
- Smallest = 5 (C on M1) → put C next front.
- Remaining: D → goes in the remaining slot.

Final Johnson sequence (front → back):
E → A → C → D → B

JOB SHOP SCHEDULING

⚙ JOHNSON'S RULE (TWO-MACHINE SCHEDULING)

Step B — Compute start/finish times on both machines

Job	M1 start	M1 finish	M2 start = max(M1 finish, previous M2 finish)	M2 finish
E	0	2	max(2, 0) = 2	2 + 5 = 7
A	2	6	max(6, 7) = 7	7 + 6 = 13
C	6	11	max(11, 13) = 13	13 + 8 = 21
D	11	17	max(17, 21) = 21	21 + 9 = 30
B	17	24	max(24, 30) = 30	30 + 3 = 33

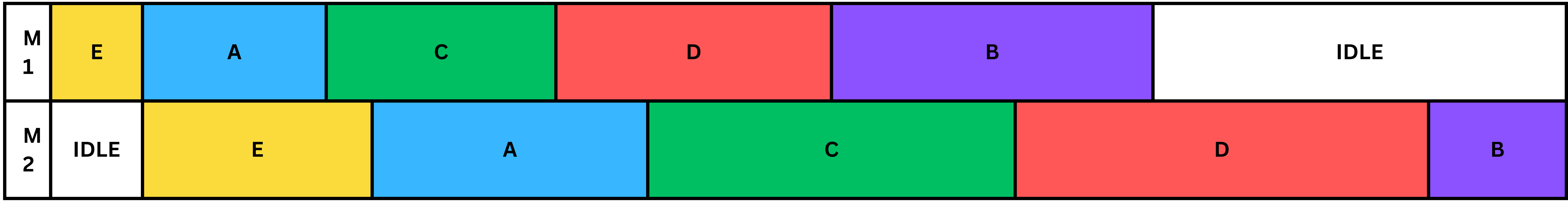
- **Makespan = completion time of last job on M2 = 33 hours.**

(Notice M2 is idle 0–2 before E arrives — that is fine; Johnson minimized the total completion time.)

JOB SHOP SCHEDULING

⚙ JOHNSON'S RULE (TWO-MACHINE SCHEDULING)

Step C — Draw the Gantt Chart



CHAPTER 7

INVENTORY CONTROL AND MATERIAL REQUIREMENT PLANNING (MRP)

This chapter introduces inventory control as a key element in managing materials efficiently in manufacturing systems. Students will learn different types of inventory, apply ABC analysis, and use the EOQ model to balance cost and stock levels. The chapter also explores Material Requirement Planning (MRP), including product structure, time-phase planning, BOM, and MRP tables to ensure the right materials are available at the right time.

🏭 INVENTORY CONTROL IN MANUFACTURING

💡 1. WHAT IS INVENTORY CONTROL?

Inventory Control is the process of **managing and monitoring materials, parts, and products** within a company — from the time they enter (as raw materials) until they are sold (as finished goods).

It helps a company to:
✅ **Have the right materials at the right time**
✅ **Avoid stock shortages or overstocking**
✅ **Reduce waste and cost**
✅ **Keep production running smoothly**

🎯 **Definition:**
Inventory control means **balancing the amount of stock a company holds** so that production is not interrupted, and customer demand can always be met efficiently.

🏭 INVENTORY CONTROL IN MANUFACTURING

⚙️ 2. WHY IS INVENTORY CONTROL IMPORTANT?

As major companies like **Amazon.com** have shown, inventory can make up **as much as 50% of total invested capital** — that's half of the company's money!

Good inventory management helps achieve:

- 💰 **Lower costs (by reducing extra stock)**
- 🚚 **Steady production (no material shortages)**
- 😀 **Happy customers (on-time deliveries)**
- ⚖️ **Balance between cost and customer service**

🧠 **Remember:**
You cannot achieve a low-cost strategy without good inventory management!

Every organization — from **banks** (cash inventory), **hospitals** (blood and medicine), to **manufacturing plants** (raw materials) — uses some kind of **inventory control system**.

🏭 INVENTORY CONTROL IN MANUFACTURING

🧩 3. FUNCTIONS OF INVENTORY

Inventory plays several important roles in keeping operations flexible and efficient.

Function	Purpose / Explanation
🛒 **1. To meet customer demand**	Provides a **selection of goods** and helps manage **fluctuations** in demand.
⚙️ **2. To decouple production processes**	Keeps production running **even if there are delays** from suppliers or between stages.
💸 **3. To gain quantity discounts**	Buying in **large quantities** can reduce **unit costs** and delivery costs.
📈 **4. To hedge against inflation**	Stocking up helps protect the firm from **future price increases**.

🏭 INVENTORY CONTROL IN MANUFACTURING

🏷️ 4. TYPES OF INVENTORY

To support these functions, firms maintain four main types of inventory:

Type of Inventory	Description
🧱 **1. Raw Material Inventory**	Materials that have been **purchased but not yet processed**. Used to **separate suppliers** from the production line.
🧩 **2. Work-in-Process (WIP) Inventory**	Items that are **partly completed** — still moving through production. WIP exists because making a product takes time (**cycle time**). Reducing cycle
🔧 **3. MRO (Maintenance, Repair, and Operating Supplies)**	Supplies needed to **maintain machines and facilities**, e.g. lubricants, tools, spare parts. Demand can be **scheduled or unexpected**.
📦 **4. Finished Goods Inventory**	Completed products **ready for sale or shipment**. Kept because **future demand is uncertain**.

🧠 Tip for Students:
Raw materials → start of the process
WIP → in production
MRO → keeps production running
Finished goods → ready for customer

🏭 INVENTORY CONTROL IN MANUFACTURING

🔍 5. THE OBJECTIVE OF INVENTORY MANAGEMENT

The main goal is to find the perfect balance between:

- 📉 **Inventory Investment (cost of keeping stock)**
- 📈 **Customer Service (availability of products)**

Too much inventory = wasted money 💸
Too little inventory = unhappy customers 😞

Good inventory control means **smart planning, accurate forecasting, and timely ordering**.

🏁 **In Summary**

Key Point	**Meaning**
🎯 **Purpose**	To manage materials efficiently and ensure smooth production flow.
🧠 **Main Functions**	Demand satisfaction, process decoupling, cost reduction, and inflation protection.
📦 **Types**	Raw Material, WIP, MRO, Finished Goods.
⚖️ **Goal**	Balance between inventory cost and customer satisfaction.

🏷️ ABC ANALYSIS METHOD

💡 WHAT IS ABC ANALYSIS?

ABC Analysis is a way to **classify inventory items** based on their **importance and value** to the company.
It helps managers focus more on the most valuable items instead of treating all inventory the same.

This method is based on the **Pareto Principle (80/20 Rule)**:

“A few items are very important (the critical few),
while many others are less important (the trivial many).”

So, not every item needs the same level of control or attention.

🧮 HOW ABC ANALYSIS WORKS

To classify items, calculate:

Annual Dollar Volume = (Annual Demand)×(Cost per Unit)

Then, sort all items from highest to lowest based on their total dollar volume.

🏷️ ABC ANALYSIS METHOD

📊 CLASSIFICATION OF INVENTORY

Class	% of Total Items	% of Total Value (Usage)	Characteristics	Control Level
🅰️ Class A	~15%	70% – 80%	High-value, critical items	Very tight control ✅
🅱️ Class B	~30%	15% – 25%	Moderate value, medium importance	Moderate control ⚙️
🅲 Class C	~55%	5%	Low-value, large quantity items	Simple control 🧾

🏷️ ABC ANALYSIS METHOD

🎯 PURPOSE OF ABC ANALYSIS

The goal is to use time, money, and effort wisely by focusing on the items that matter most.

🅰️ A Items – Need high attention
➤ Frequent monitoring, accurate records, secure storage
🅱️ B Items – Need moderate attention
➤ Periodic checks and standard storage
🅲 C Items – Need simple control
➤ Basic tracking, reorder in bulk when needed

🚀 BENEFITS OF ABC ANALYSIS

✅ Focuses on critical inventory that impacts cost the most.
✅ Improves forecast accuracy and inventory control.
✅ Reduces waste, storage costs, and stockouts.
✅ Helps plan better purchasing and supplier management.

🏷️ ABC ANALYSIS METHOD

⚙️ POLICIES BASED ON ABC ANALYSIS

Policy	Description
🏗️ **Purchasing Effort**	Spend more time and resources developing **reliable suppliers** for **A items**.
🔒 **Inventory Control**	Keep **A items** in secure areas and check their quantities **frequently**.
📈 **Forecasting**	Forecast **A items** more carefully since they have the biggest financial impact.

🏷️ ABC ANALYSIS METHOD

🧮 EXAMPLE: ABC ANALYSIS FOR A FURNITURE MANUFACTURER

Hatim Wood Sdn. Bhd. produces furniture such as tables, chairs, and cabinets. The operations manager wants to classify 8 inventory items using ABC analysis based on annual dollar usage.

🔢 Step 1: Gather Inventory Data

Item	Annual Demand (units)	Unit Cost (RM)	Annual Dollar Usage (RM)
Plywood Sheets	1,000	80	80,000
Wooden Legs	2,000	25	50,000
Table Tops	800	60	48,000
Chair Frames	1,200	35	42,000
Screws & Bolts	5,000	2	10,000
Paint & Finish	2,000	4	8,000
Glue	3,000	1	3,000
Cushion Foam	1,000	5	5,000

🏷️ ABC ANALYSIS METHOD

💰 **Step 2: Calculate Annual Dollar Usage**

Total Annual Usage = 80,000 + 50,000 + 48,000 + 42,000 + 10,000 + 8,000 + 3,000 + 5,000 = RM 246,000

📊 **Step 3: Rank Items by Annual Dollar Usage**

Rank	Item	Annual Usage (RM)	% of Total Value	Cumulative %	Class
1	Plywood Sheets	80,000	32.50%	32.50%	A
2	Wooden Legs	50,000	20.30%	52.80%	A
3	Table Tops	48,000	19.50%	72.30%	B
4	Chair Frames	42,000	17.10%	89.40%	B
5	Screws & Bolts	10,000	4.10%	93.50%	C
6	Paint & Finish	8,000	3.30%	96.80%	C
7	Cushion Foam	5,000	2.00%	98.80%	C
8	Glue	3,000	1.20%	100%	C

🏷️ ABC ANALYSIS METHOD

🎯 **Step 4: Classify Inventory**

- Class A: Top 70–80% of total value
  → Plywood Sheets, Wooden Legs
- Class B: Next 15–25% of total value
  → Table Tops, Chair Frames
- Class C: Remaining low-value items
  → Screws, Paint, Foam, Glue

✨ **Key Learning Point**
"A few items (A class) consume most of the money, while many items (C class) are cheap but numerous. Manage each class differently for best efficiency!"

💡 **Interpretation**

Class	% of Items	% of Total Value	Control Strategy
🅰 A	25% (2 items)	52.80%	Tight control, accurate records, frequent review
🅱 B	25% (2 items)	36.60%	Moderate control, periodic review
🅲 C	50% (4 items)	10.60%	Simple control, order in bulk

📦 ECONOMIC ORDER QUANTITY (EOQ)

💡 WHAT IS EOQ?

The **Economic Order Quantity (EOQ)** model helps a company decide **how much to order each time** so that the **total cost** of inventory (ordering + holding) is **as low as possible**.

🎯 **EOQ = the best order quantity that minimizes the total inventory cost.**

In simple words:

“Order too much, and you pay high storage costs.
Order too little, and you order too often.”
EOQ finds the sweet spot in between!

ECONOMIC ORDER QUANTITY (EOQ)

⚙ ASSUMPTIONS OF THE BASIC EOQ MODEL

To make EOQ calculations simple, we assume these six basic conditions:

No.	Assumption	Meaning (Simple)
	Constant Demand	The demand for the item is *known and steady* (e.g., 100 units per week).
	Known Lead Time	The time between placing and receiving an order is *fixed* (e.g., 2 days).
	Instant Delivery	The whole order arrives *at once* (not partially).
	No Discounts	The item's price *does not change* based on order size.
	Two Main Costs	Only *ordering cost* and *holding cost* are considered.
	No Shortages	Stockouts never happen if we reorder at the right time.

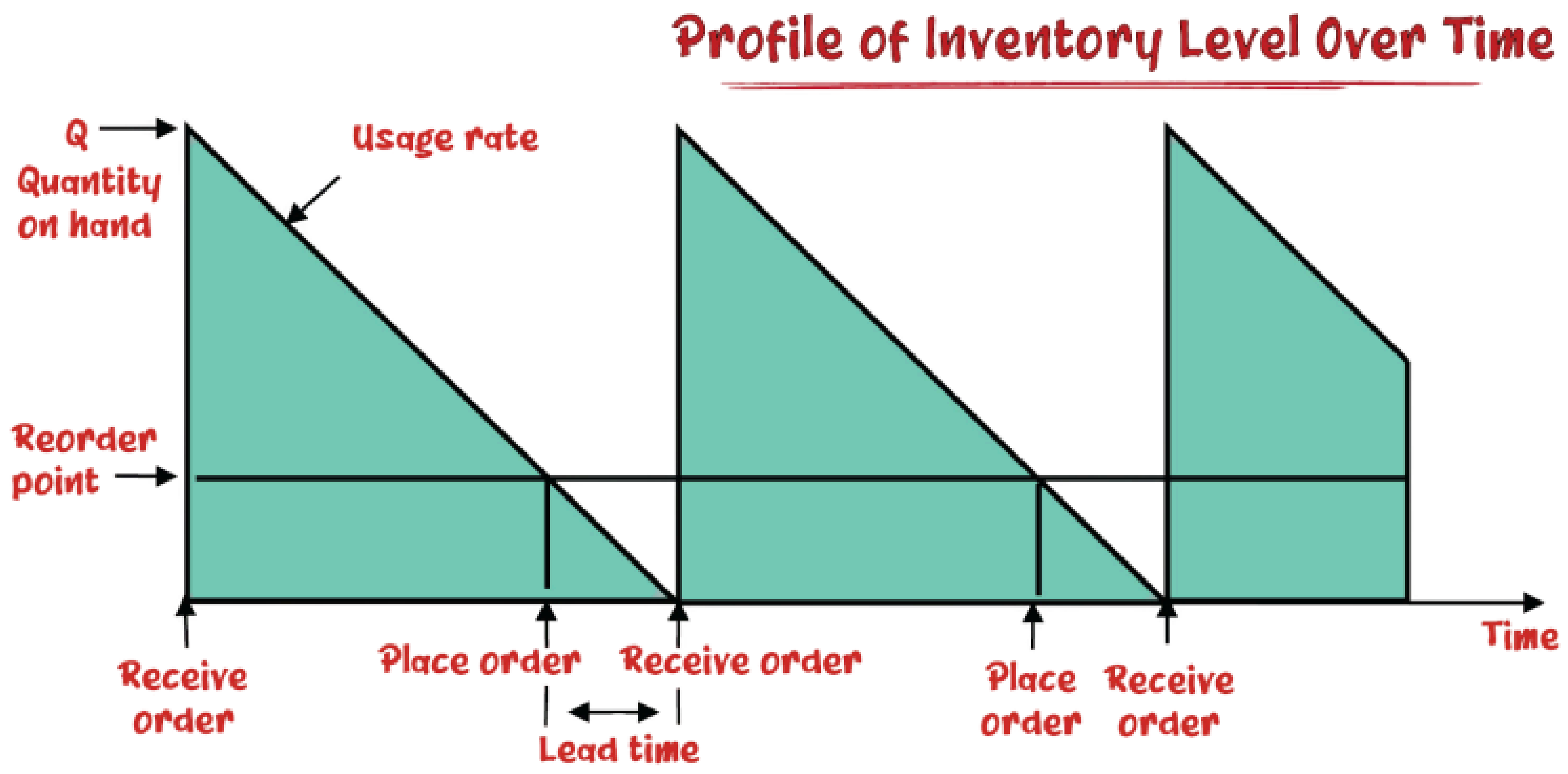
📦 ECONOMIC ORDER QUANTITY (EOQ)

📈 HOW EOQ WORKS (SIMPLE CONCEPT)

Imagine you're managing a store that sells 500 dresses per month.

- Every time you order new stock, the inventory jumps up (because new stock arrives).
- Then, as dresses are sold, the inventory decreases steadily.
- When it reaches zero, you place another order — and the process repeats.

This pattern looks like a sawtooth 🔺🔻 when drawn on a graph.



📦 ECONOMIC ORDER QUANTITY (EOQ)

💰 MAIN COSTS IN EOQ

Type of Cost	Meaning	Example
🧾 **Ordering Cost (S)**	The cost to place one order (paperwork, transport, setup)	RM 100 per order
🏗 **Holding Cost (H)**	The cost to store items in inventory (rent, insurance, spoilage)	RM 5 per item per year

💰 MAIN COSTS IN EOQ

$$EOQ = \sqrt{\frac{2DS}{H}}$$

Where:
D = Annual demand (units)
S = Cost per order
H = Holding cost per unit per year

📘 EXAMPLE 7.1 (FINDING THE OPTIMAL ORDER SIZE)

A workshop uses 2,400 bolts per year.
The cost of placing one order (S) = RM 60.
The holding cost per bolt per year (H) = RM 3.

Find the **Economic Order Quantity (EOQ)**:

$$EOQ = \sqrt{\frac{2DS}{H}} = \sqrt{\frac{2(2400)(60)}{3}} = \sqrt{96,000} = 310 \text{ units}$$

✅ Result:
Order 310 bolts each time to minimize total inventory cost.

📦 ECONOMIC ORDER QUANTITY (EOQ)

We can also determine the expected number of orders placed during the year (N) and the expected time between orders (T), as follows:

$$\text{Expected number of orders} = N = \frac{\text{Demand}}{\text{Order quantity}} = \frac{D}{Q^*}$$

$$\text{Expected time between orders} = T = \frac{\text{Number of working days per year}}{N}$$

📘 EXAMPLE 7.2 (COMPUTING NUMBER OF ORDERS AND TIME BETWEEN ORDERS)

(Refering to Example 7.1) has a 250-day working year and wants to find the number of orders (N) and the expected time between orders (T).

$$N = \frac{D}{EOQ}$$

$$N = \frac{2400}{310}$$

$$N \approx 7.74$$

$$T = \frac{\text{Working days per year}}{N}$$

$$T = \frac{250}{7.74}$$

$$T \approx 32.3 \text{ days}$$

✅ Number of orders per year ≈ 8 orders

✅ Expected time between orders ≈ 32 days

ECONOMIC ORDER QUANTITY (EOQ)

As mentioned earlier in this section, the total annual variable inventory cost is the sum of setup and holding costs:

Total annual cost = Setup (order) cost + Holding cost

In terms of the variables in the model, we can express the total cost TC as:

$$TC = \frac{D}{Q}S + \frac{Q}{2}H$$

EXAMPLE 7.3 (COMPUTING COMBINED COST OF ORDERING AND HOLDING)

(from Examples 7.1 and 7.2) wants to determine the combined annual ordering and holding costs.

- Step 1: Annual Ordering Cost

$$\text{Annual Ordering Cost} = \frac{D}{Q} \times S$$

$$= \frac{2400}{310} \times 60$$

$$= 7.74 \times 60$$

$$= RM464.40$$

- Step 2: Annual Holding Cost

$$\text{Annual Holding Cost} = \frac{Q}{2} \times H$$

$$= \frac{310}{2} \times 3$$

$$= 155 \times 3$$

$$= RM465$$

- Step 3: Combined Annual Ordering + Holding Cost

$$= 464.40 + 465$$

$$= RM929.40$$

ECONOMIC ORDER QUANTITY (EOQ)

After determining how much to order using the Economic Order Quantity (EOQ) model, the next important question is ***when to order***. This is determined by the **Reorder Point (ROP)**.

Reorder Point (ROP) is the inventory level at which a new order must be placed to avoid stockout during the lead time. ***Lead time*** refers to the time between placing an order and receiving it.

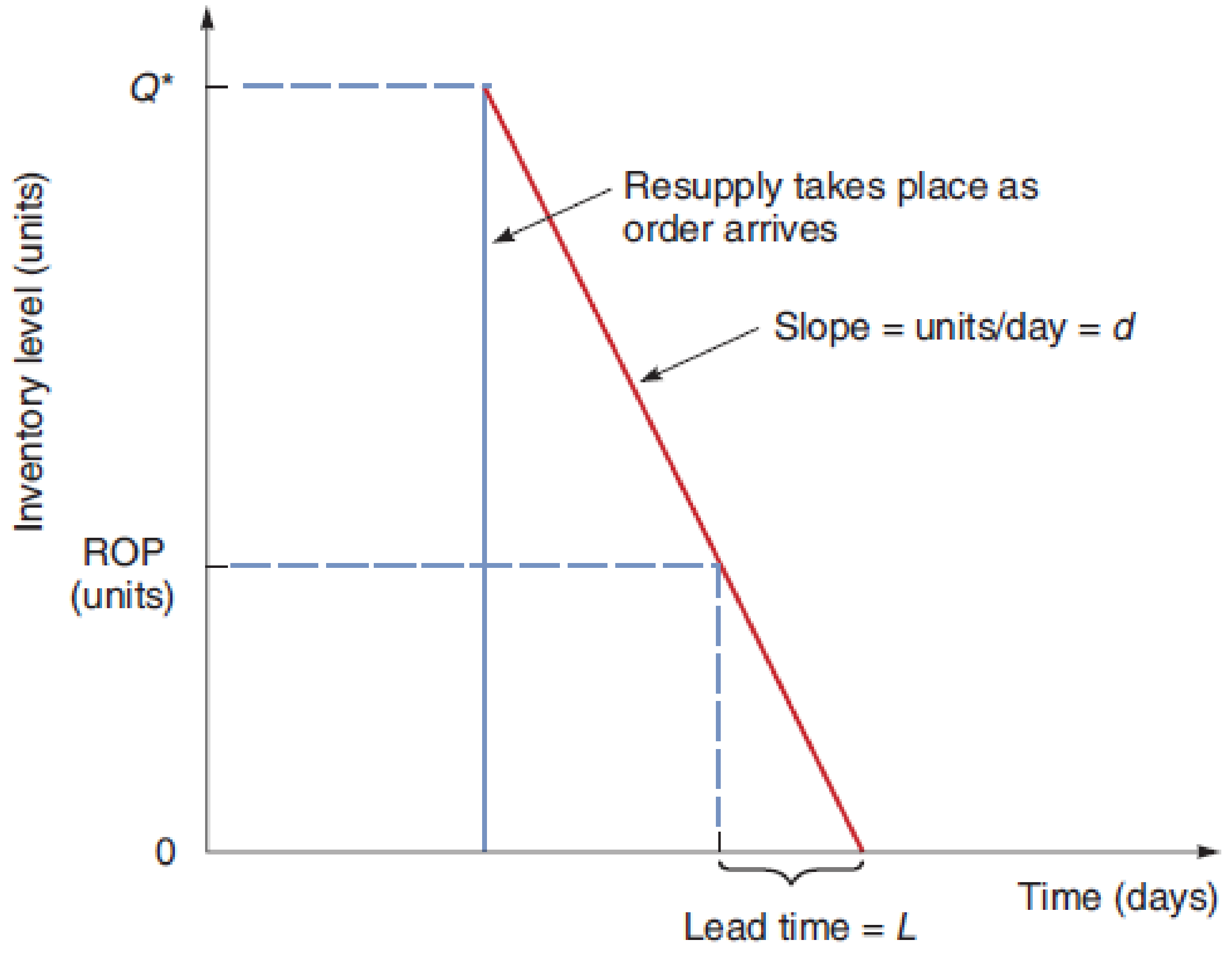
In a basic inventory model where demand and lead time are constant, ROP is calculated as:

$$ROP = d \times L$$

where:
d = daily demand
L = lead time (in days)

Daily demand is calculated as:

$$d = \frac{D}{\text{Number of working days per year}}$$



ECONOMIC ORDER QUANTITY (EOQ)

EXAMPLE 7.4 (COMPUTING REORDER POINTS (ROP))

(from Examples 7.1, 7.2 and 7.3) On average, delivery of an order takes 3 working days. The store wants to calculate the reorder point

- Step 1: Daily Demand

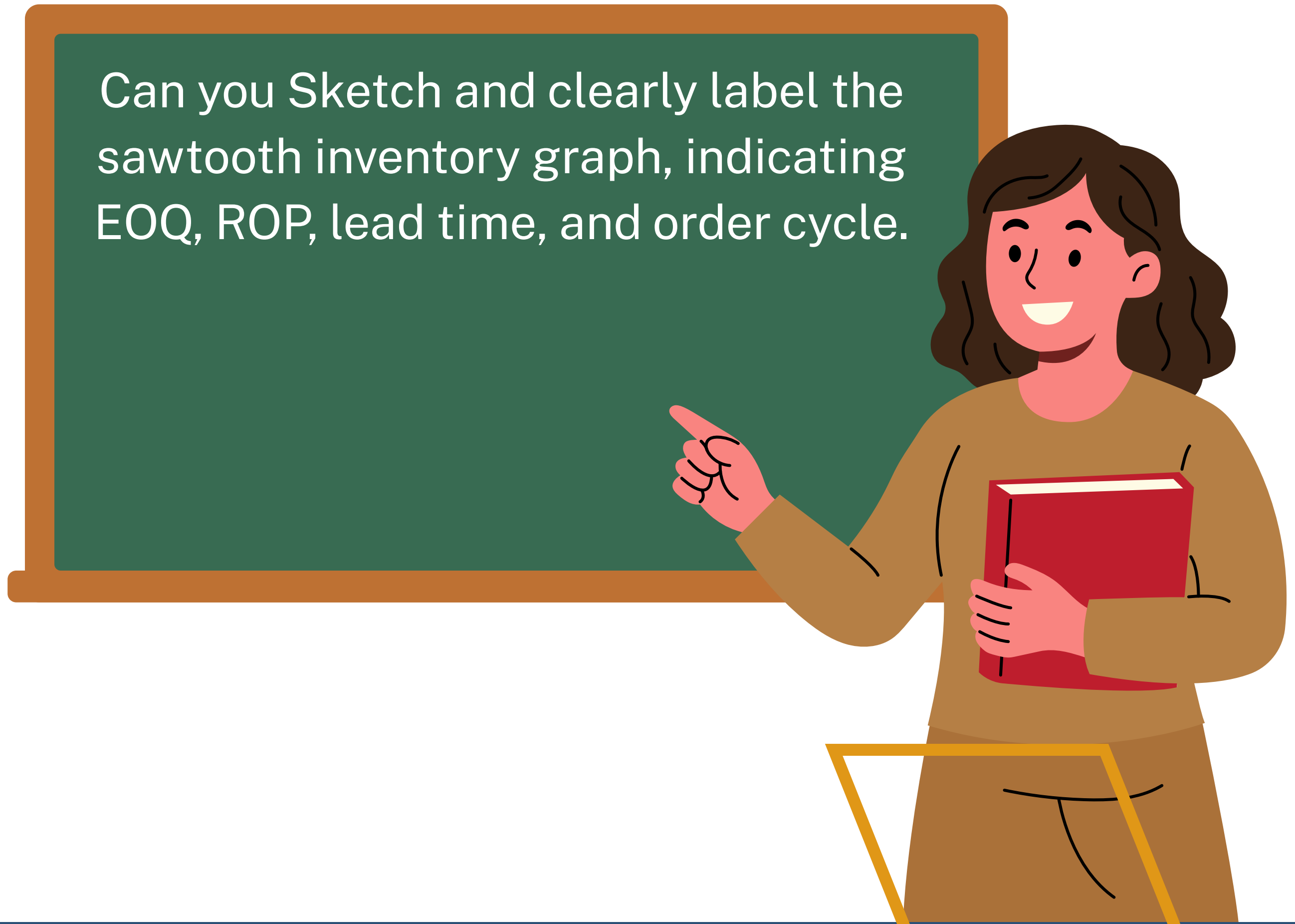
$$\text{Daily demand} = \frac{2400}{250}$$

$$= 9.6 \approx 10 \text{ units per day}$$

- Step 2: ROP

$$ROP = 9.6 \times 3$$

$$ROP = 28.8 \approx 29 \text{ units}$$



MATERIAL REQUIREMENT PLANNING (MRP)

Material Requirement Planning (MRP) is a systematic approach used to plan and control dependent demand inventory. It determines:

- **What materials are required**
- **How many units are needed**
- **When the materials are needed**

MRP ensures that materials are available for production while minimizing inventory levels and avoiding stockouts.
MRP is mainly used in manufacturing environments where products are made from multiple components.

📦 MATERIAL REQUIREMENT PLANNING (MRP)

📈 TREE PRODUCT STRUCTURE

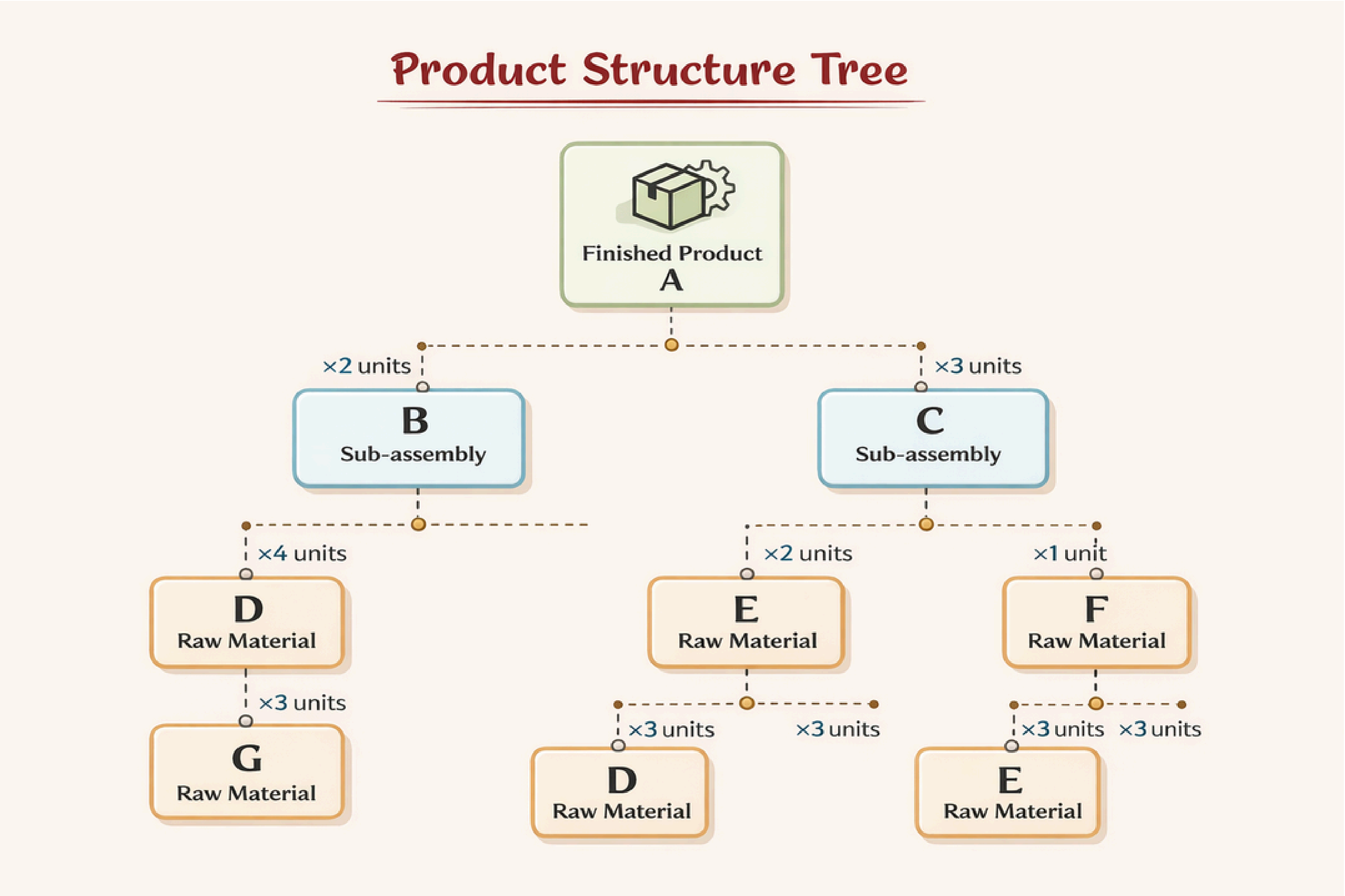
A Tree Product Structure (also known as Product Structure Tree) is a graphical representation that shows the hierarchical relationship between a finished product and its components.

It illustrates:

- Parent items (finished product)
- Child items (sub-assemblies)
- Raw materials
- Quantity required at each level

Structure Levels:

- Level 0 → Finished product
- Level 1 → Major sub-assemblies
- Level 2 and below → Components and raw materials



📦 MATERIAL REQUIREMENT PLANNING (MRP)

📈 TIME-PHASE STRUCTURE CONSTRUCTION

A Time-Phase Structure **shows when each component must be ordered or produced based on lead time**.
It considers:

- Production schedule (Master Production Schedule – MPS)
- Lead time for each component
- Order release timing

The time-phase structure works backward from the required completion date of the finished product.
Key Concept:

If Product A must be completed in Week 6:

- Components with 1-week lead time must be ordered in Week 5.
- Components with 2-week lead time must be ordered in Week 4.

This ensures materials arrive exactly when needed.

📦 MATERIAL REQUIREMENT PLANNING (MRP)

📈 BILL OF MATERIALS (BOM)

A Bill of Materials (BOM) is a detailed list of all materials, components, and sub-assemblies required to produce a finished product.
It contains:

- Item number
- Description
- Quantity required per unit
- Unit of measure
- Level code

BOM acts as the database for MRP calculations.

Types of BOM:
1. Single-level BOM – shows only immediate components.
2. Multi-level BOM – shows full hierarchical structure.

Without an accurate BOM, MRP results will be incorrect.

📦 MATERIAL REQUIREMENT PLANNING (MRP)

📈 MATERIAL REQUIREMENT PLANNING (MRP) TABLE

The MRP table is used to calculate material requirements over time.

A typical MRP table contains:

1. Gross Requirements
2. Scheduled Receipts
3. Projected Available Balance
4. Net Requirements
5. Planned Order Receipts
6. Planned Order Releases

📦 MATERIAL REQUIREMENT PLANNING (MRP)

📈 EXCERCISE

Product: Portable Bluetooth Speaker (Item: P)
A company manufactures a Portable Bluetooth Speaker. The structure of the product is described below:

Product Description

- Each P requires:
  - 2 units of H (Housing Assembly)
  - 1 unit of E (Electronics Module)
- Each H requires:
  - 1 unit of C (Casing)
  - 2 units of S (Screws)
- Each E requires:
  - 1 unit of B (Battery Pack)
  - 1 unit of M (Mainboard Assembly)
- Each M requires:
  - 2 units of W (Wiring Set)
  - 1 unit of L (LED Indicator)

Lead Time (LT) for Each Item & on-hand inventory

item	Lead Time (Week)	On-hand inventory
P	1	0
H	1	5
E	2	5
C	3	15
S	1	10
B	2	0
M	1	0
W	1	10
L	1	20

Customer Order
The company must deliver 80 units of P in Week 8.

Assume:

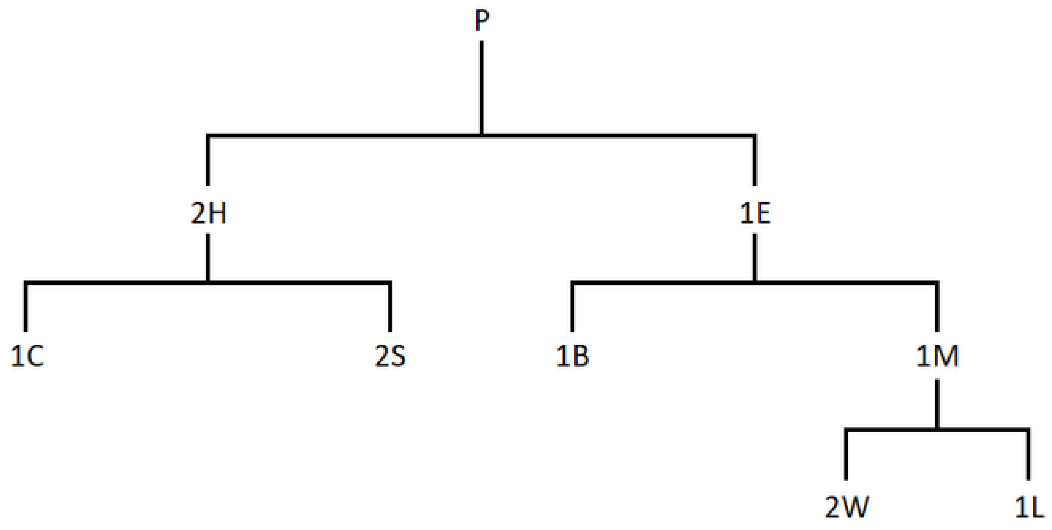
- No beginning inventory
- Lot-for-lot (L4L) ordering
- No scheduled receipts

📘 **Required:**
(i) Construct the product tree structure for item P.
(ii) Construct the time-phased product structure based on lead times.
(iii) Prepare the Bill of Materials (BOM)
(iv) Structure the MRP tables

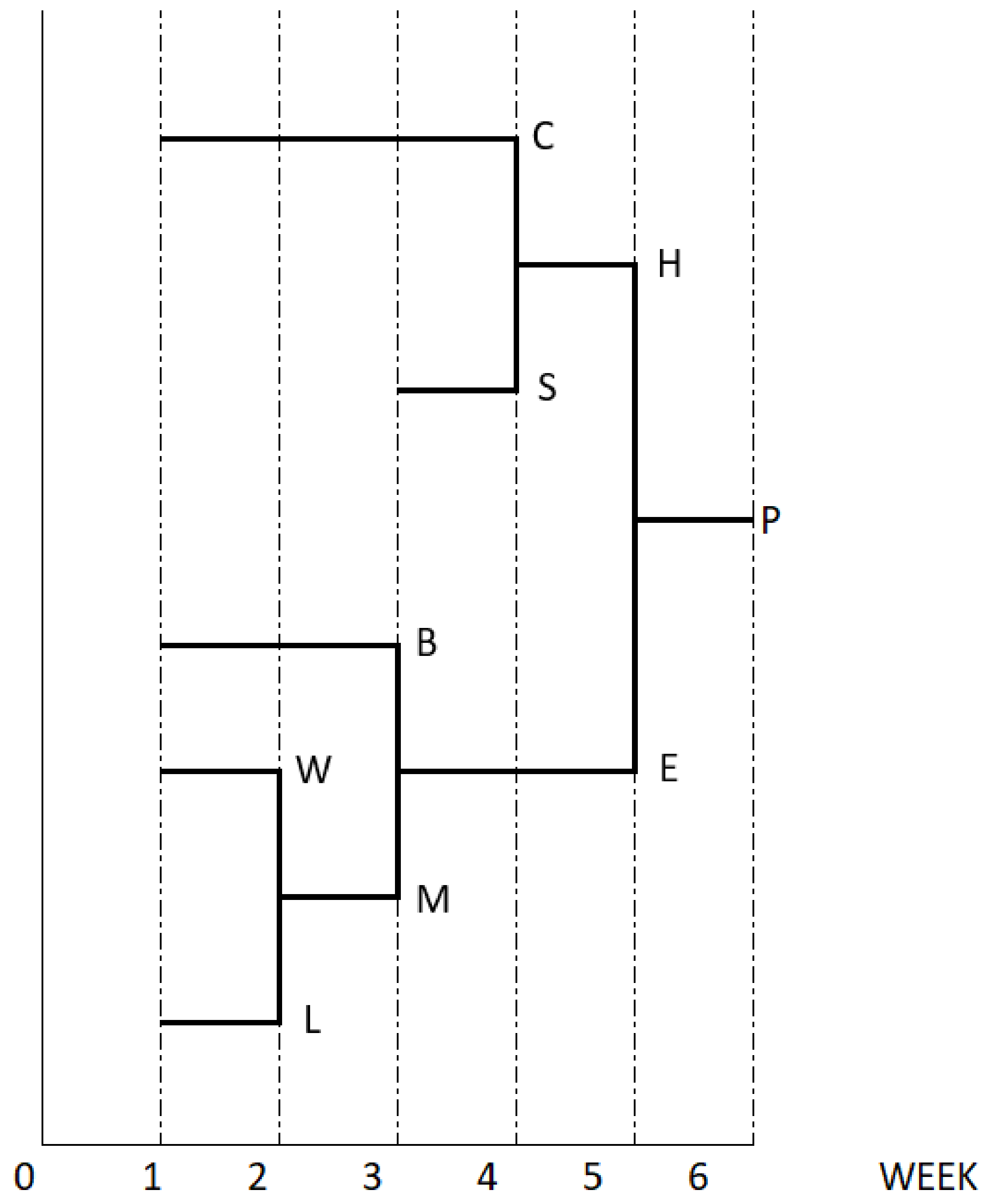
MATERIAL REQUIREMENT PLANNING (MRP)

SOLUTION

Product tree structure for item P



Time-phased product structure



Bill of Materials (BOM)

item	Quantities
P	80
H	2 x 80 = 160
E	1 x 80 = 80
C	1 x 2 x 80 = 160
S	2 x 2 x 80 = 320
B	1 x 1 x 80 = 80
M	1 x 1 x 80 = 80
W	2 x 1 x 1 x 80 = 160
L	1 x 1 x 1 x 80 = 80

MATERIAL REQUIREMENT PLANNING (MRP)

SOLUTION

MRP tables

ITEM: P (Portable Bluetooth Speaker)	Week							LEAD TIME
	1	2	3	4	5	6	7	
Gross requirements						80		1
Projected on-hand inventory: 0						0		
Planned receipts						80		
Planned order releases					80			

MATERIAL REQUIREMENT PLANNING (MRP)

ITEM: H (Housing Assembly)	Week							LEAD TIME
	1	2	3	4	5	6	7	
Gross requirements					2 X 80 = 160			1
Projected on-hand inventory: 5					5			
Planned receipts					155			
Planned order releases				155				

ITEM: E (Electronics Module)	Week							LEAD TIME
	1	2	3	4	5	6	7	
Gross requirements					80			2
Projected on-hand inventory: 5					5			
Planned receipts					75			
Planned order releases			75					

MATERIAL REQUIREMENT PLANNING (MRP)

ITEM: C (Casing)	Week							LEAD TIME
	1	2	3	4	5	6	7	
Gross requirements				155				3
Projected on-hand inventory: 15				15				
Planned receipts				140				
Planned order releases	140							

ITEM: S (Screws)	Week							LEAD TIME
	1	2	3	4	5	6	7	
Gross requirements				2 X 155 = 310				1
Projected on-hand inventory:10				10				
Planned receipts				300				
Planned order releases			300					

MATERIAL REQUIREMENT PLANNING (MRP)

ITEM: B (Battery Pack)	Week							LEAD TIME
	1	2	3	4	5	6	7	
Gross requirements			75					2
Projected on-hand inventory: 0			0					
Planned receipts			75					
Planned order releases	75							

ITEM: M (Mainboard Assembly)	Week							LEAD TIME
	1	2	3	4	5	6	7	
Gross requirements			75					1
Projected on-hand inventory: 0			0					
Planned receipts			75					
Planned order releases		75						

MATERIAL REQUIREMENT PLANNING (MRP)

ITEM: W (Wiring Set)	Week							LEAD TIME
	1	2	3	4	5	6	7	
Gross requirements		2 X 75 =150						1
Projected on-hand inventory: 10		10						
Planned receipts		140						
Planned order releases	140							
ITEM: L (LED Indicator)	Week							LEAD TIME
	1	2	3	4	5	6	7	
Gross requirements		75						1
Projected on-hand inventory: 20		20						
Planned receipts		55						
Planned order releases	55							

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