FLEXIBLE MANUFACTURING SYSTEM

ME655

Syllabus

- Definition and classification of manufacturing system, automation and automation strategies.
- Flexible manufacturing systems: Introduction, Needs, Industrial Relevance. Problems of conventional batch manufacturing systems.
- Overview of multi model and mixed model flexible lines, Types of flexibility in FMS, flexible and dynamic manufacturing systems, various FMS configurations
- Typical FMS operation, decision support systems, computer simulation, process control strategies.
- Group technology, role of integrated and automated material handling systems, robotics and its peripherals,.

References:

- Automation, Production Systems, and Computer-Integrated Manufacturing by Mikell Groover, Prentice-Hall of India Pvt. Ltd.
- CAD/CAM: Computer-Aided Design and Manufacturing, Mikell Groover, Emory W. Zimmers, JR., Prentice-Hall of India Pvt. Ltd.
- Robotics, by Appu Kuttan K.K., I.K.International Publishing House Pvt.Ltd.

DEFINITION AND CLASSIFICATION OF MANUFACTURING SYSTEMS

Manufacturing

a definition………...

The full cycle of industrial activity from understanding markets through design, production and service.

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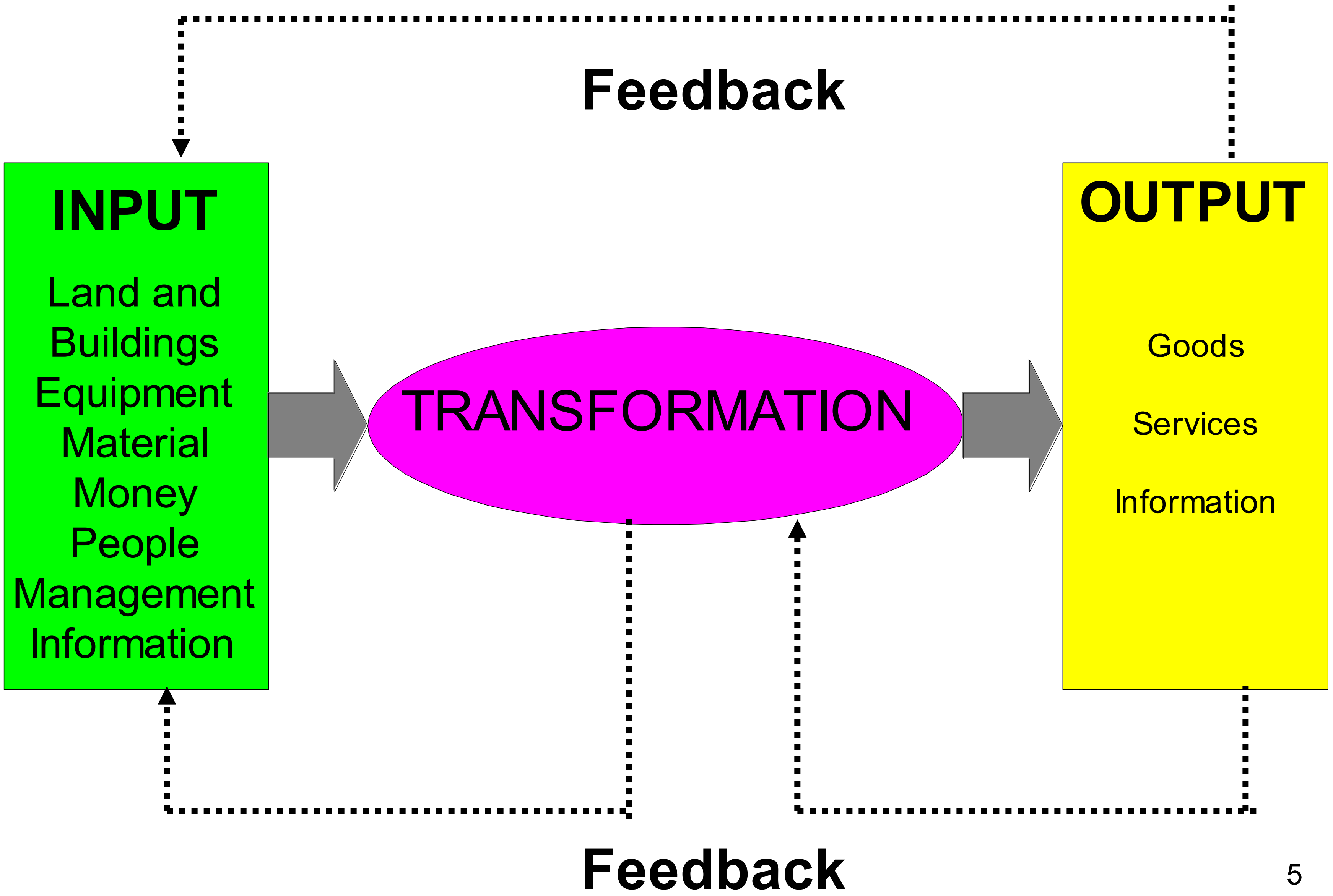
Manufacturing: A Transformation Process



Manufacturing System

A collection of integrated equipment and human resources, whose function is to perform one or more processing and/or assembly operations on a starting raw material, part, or set of parts.

Manufacturing Systems

Examples:

- Single-station cells
- Machine clusters
- Manual assembly lines
- Automated transfer lines
- Automated assembly systems
- Machine cells (cellular manufacturing)
- Computer integrated manufacturing systems
- Flexible manufacturing systems

Manufacturing System

Components:

1. Production machines
2. Material handling system
3. Computer system
4. Human workers

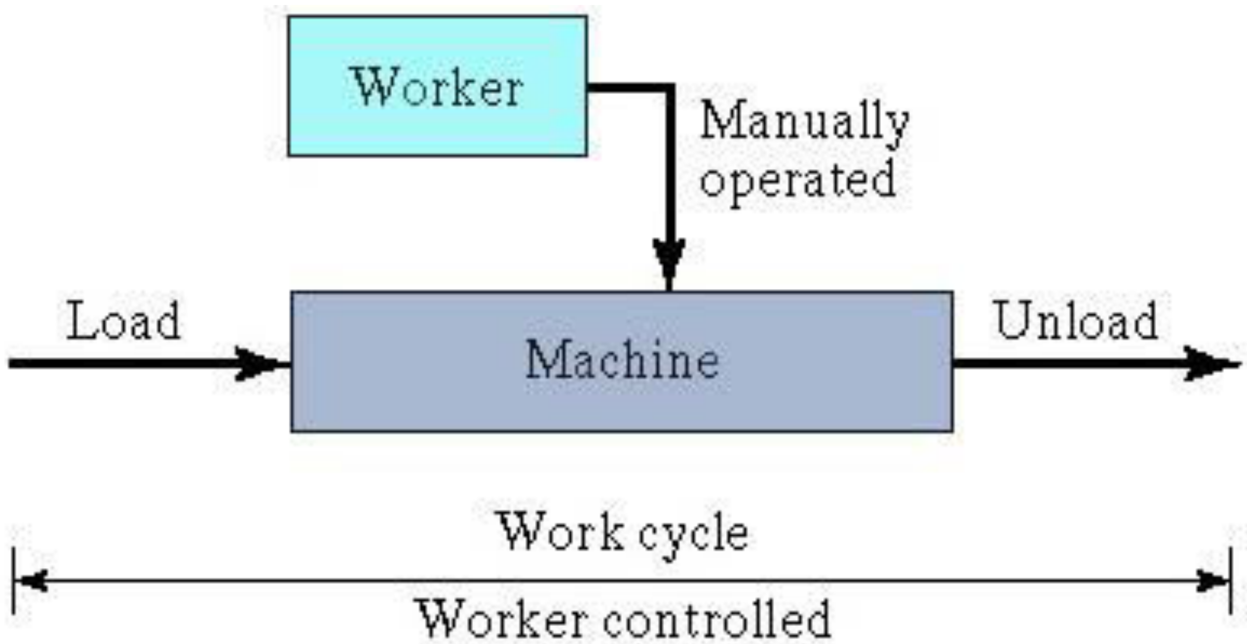
Manufacturing Systems: 1. Production Machines

In virtually all modern manufacturing systems, most of the actual processing or assembly work is accomplished by machines or with the aid of tools.

Classification:

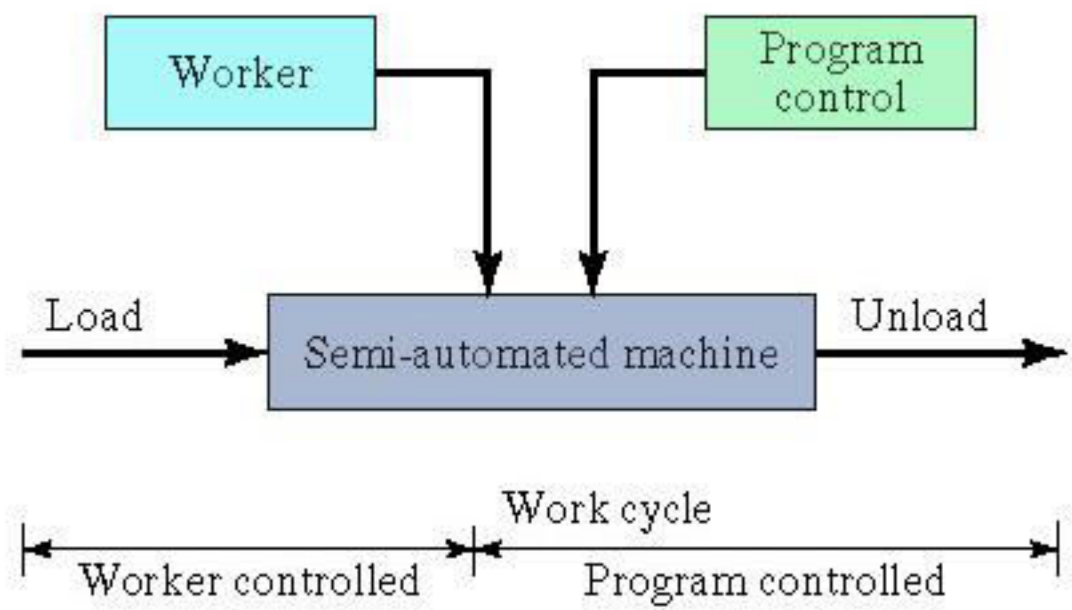
i. Manually operated machines.
ii. Semi-automated machines.
iii. Fully automated machines.

Production Machines: i. Manually Operated Machines



- Controlled or supervised by a human worker.
- The machine provides the power for the operation and the worker provides the control.
- The entire work cycle is operator controlled.

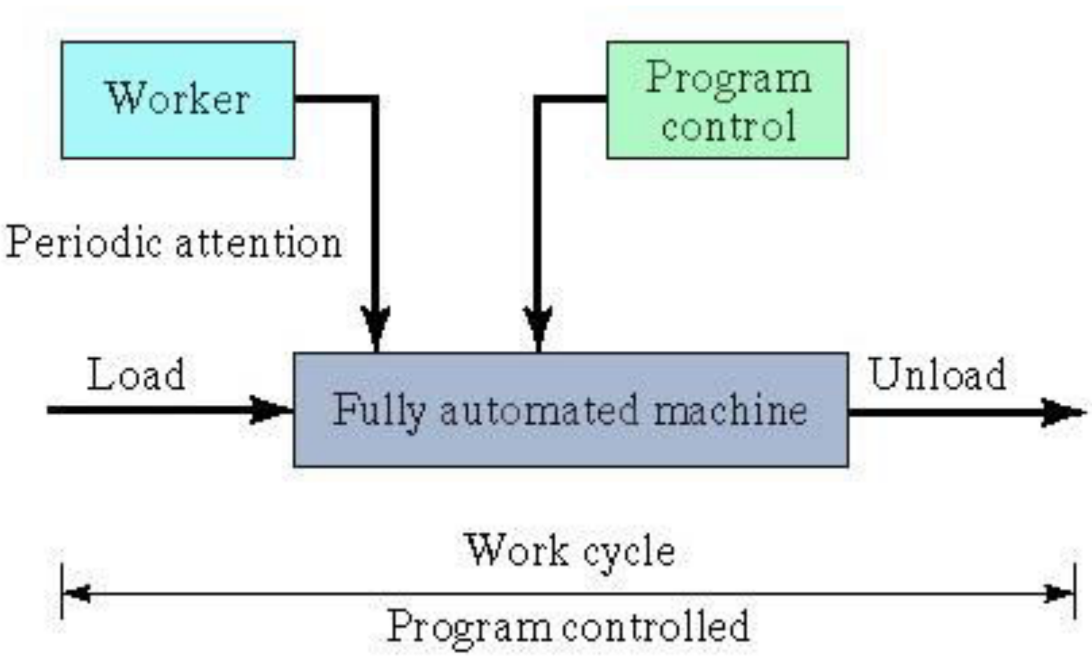
Production Machines: ii. Semi-Automated Machines



- A semi-automated machines performs a portion of the work cycle under some form of program control, and a worker tends to the machine for the remainder of the cycle.

- Typical worker tasks include loading and unloading parts.

Production Machines: iii. Fully-Automated Machines



Machine operates for extended periods (longer than one work cycle) without worker attention.

Manufacturing Systems: 2. Material Handling System

Functions:

- Loading work units at each station.
- Positioning work units at each station.
- Unloading work units at each station.
- Transporting work units between stations in multi-station systems.
- Temporary storage of work units.

Manufacturing Systems: 3. Computer Control System

Functions:

- Communicate instructions to workers
- Download part programs to computer-controlled machines
- Control material handling system
- Schedule production
- Failure diagnosis
- Safety monitoring
- Quality control
- Operations management (manage overall operations)

Manufacturing Systems: 4. Human Resource

Functions:

- Maintenance
- Part Programming
- Monitoring
- Reporting the status of manufacturing systems

Classification of Manufacturing Systems

- Factors that distinguish manufacturing systems are:

    - Types of operations performed
    - Types of transformation processes
    - Volume of production
    - Number of workstations
    - System layout
    - Automation and manning level
    - Part or product variety

Types of Operations Performed

- Processing operations on work units versus assembly operations to combine individual parts into assembled entities
- Type(s) of materials processed
- Size and weight of work units
- Part or product complexity
  - For assembled products, number of components per product
  - For individual parts, number of distinct operations to complete processing
- Part geometry
  - For machined parts, rotational vs. non-rotational

Types of Transformation Processes

1. Continuous type: Chemical, oil, electricity, food industries;

2. Discrete type: Electronics, computer and goods industries.

Volume of Production

1. Mass manufacturing systems (cars, engine blocks etc.) quantities in the range of 10000 to million of parts per year

2. Batch manufacturing systems (paints, books, machine parts etc.). quantities in the range of 100 to 10000 units per year.

3. Job shop production (planes, ships etc.). quantities in the range of 1 to 100 units per year.

Number of Workstations

- Convenient measure of the size of the system
  - Let n = number of workstations
  - Individual workstations can be identified by subscript i, where $i = 1, 2, \ldots, n$
- Affects performance factors such as workload capacity, production rate, and reliability
  - As n increases, this usually means greater workload capacity and higher production rate
  - There must be a synergistic effect that derives from n multiple stations working together vs. n single stations

System Layout

- Applies mainly to multi-station systems
- Fixed routing vs. variable routing
  - In systems with fixed routing, workstations are usually arranged linearly
  - In systems with variable routing, a variety of layouts are possible
- System layout is an important factor in determining the most appropriate type of material handling system.

Automation and Manning Levels

- Level of workstation automation
  - Manually operated
  - Semi-automated
  - Fully automated
- Manning level M_i = proportion of time worker is in attendance at station i
  - $M_i = 1$ means that one worker must be at the station continuously
  - $M_i \geq 1$ indicates manual operations
  - $M_i < 1$ usually denotes some form of automation

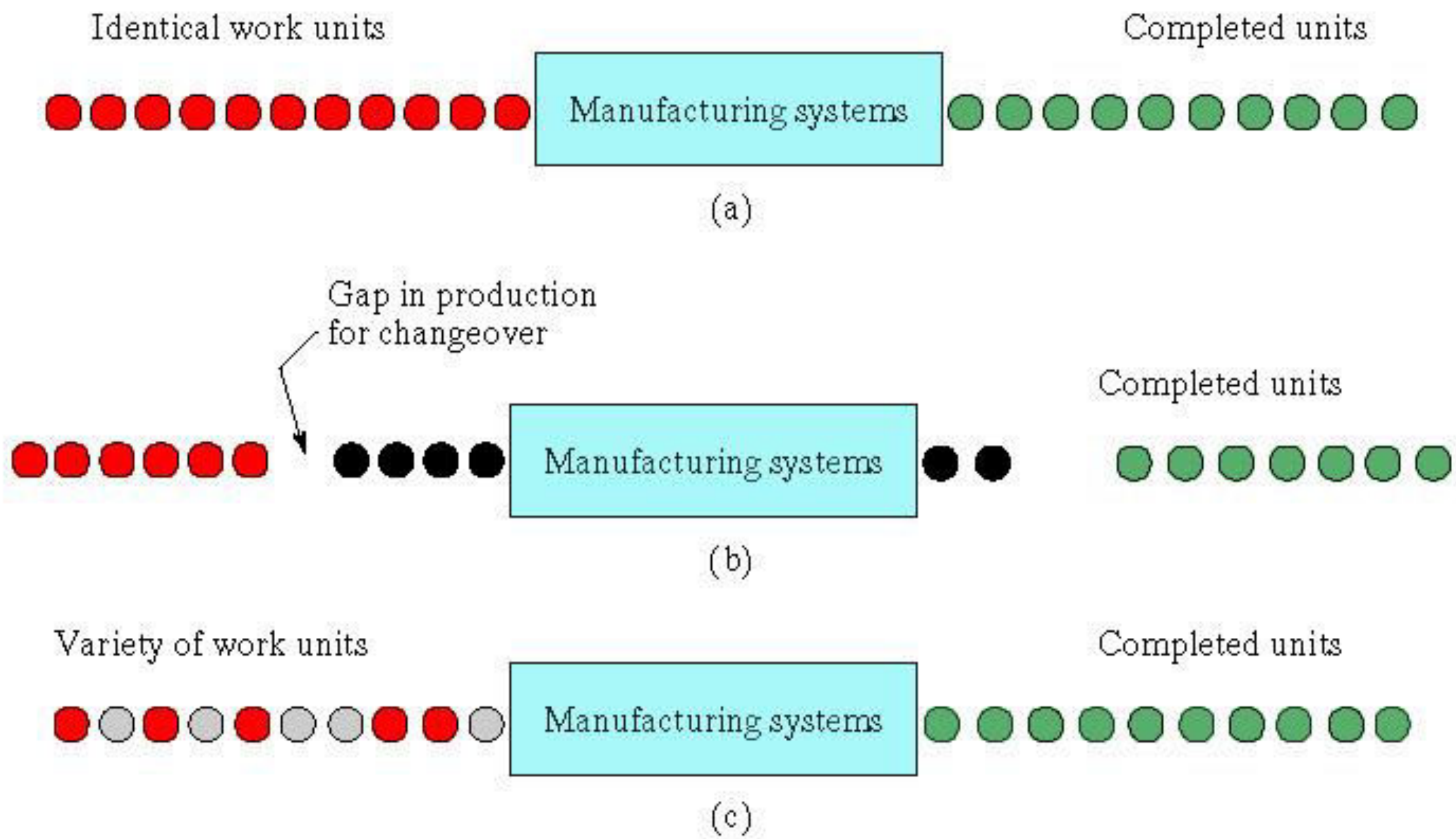
Part or Product Variety: Flexibility

The degree to which the system is capable of dealing with variations in the parts or products it produces.

Three cases:

1. Single-model case - all parts or products are identical (sufficient demand/fixed automation)
2. Batch-model case - different parts or products are produced by the system, but they are produced in batches because changeovers are required (hard product variety)
3. Mixed-model case - different parts or products are produced by the system, but the system can handle the differences without the need for time-consuming changes in setup (soft product variety)

Three Cases of Product Variety in Manufacturing Systems



(a) Single-model case, (b) batch model case, and (c) mixed-model case

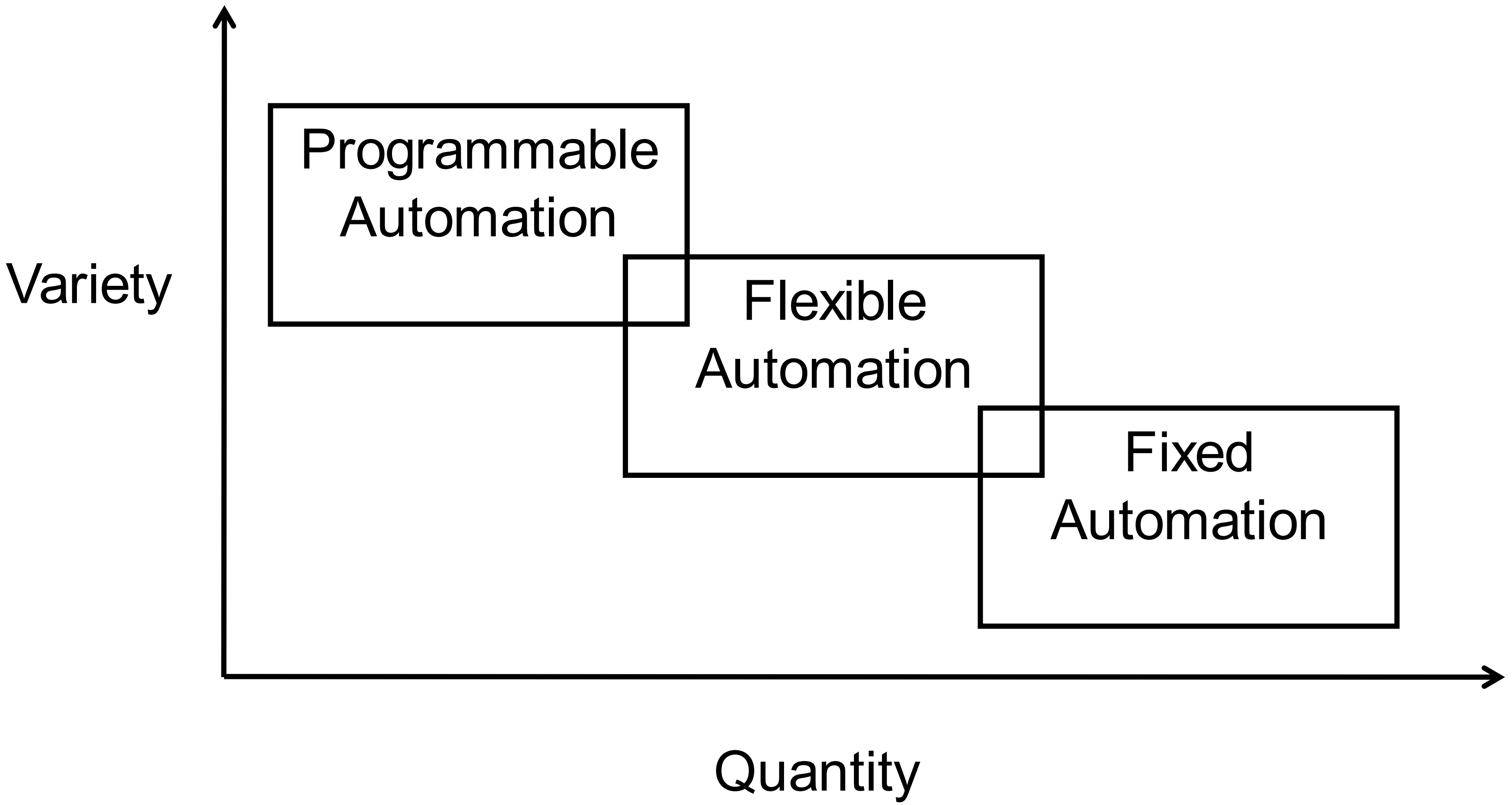
AUTOMATION

a definition

- Automation can be defined as a **technology** concerned with the application of **mechanical, electronics**, and **computer** based systems to operate and control production.

- In the past, automation meant the replacement of **human effort** with **machine effort**, to save **labor costs**.
- Today, **automation** means integrating a full range of advanced information and engineering discoveries into operations processes for strategic purposes.
- Today, **automation** is applied not only for labor cost savings, but also for:
  - Improved quality
  - Faster production and delivery of products/services
  - Increased flexibility

Three Automation Types



Fixed Automation

- **Fixed automation** is a system in which the sequence of processing operations is fixed by the equipment configuration.

    - Typical features:

  – High initial investment for custom-engineered equipment
  – High production rate
  – Relatively inflexible in accommodating product variety.

- The economic justification for the fixed automation is found in products that are produced in very **large quantities** and at **high production rates.**

- The **high initial cost** of the equipment can be spread over a very large number of units, thus making the **unit cost attractive** compared with alternate methods of production.

Example:

Transfer lines, automated assembly lines

Programmable Automation

- Capability to change the sequence of operations through **reprogramming** to accommodate different product configurations.

  - Typical Features:

  – High investment in general purpose equipment.
  – Lower production rate than fixed automation.
  – Flexibility to deal with variations and changes in product configuration.
  – Most suitable in batch production.

Programmable automation production systems are used in **low and medium volume** production. The parts are typically made in batches.

Examples:

– Numerical machine tools (NC)
– Industrial Robots
– Programmable logic controllers.

Flexible Automation

- A **flexible automated** system is capable of producing a **variety of parts** with virtually no time is lost over changeovers from one part style to the next.

- There is no lost production time while reprogramming the system and altering the physical set up.

- What makes flexible automation possible is that the difference between the parts processed by the system are not significant **(soft variety).**

- Typical Features:

  - High investment for a custom engineered system.
  - Continuous production of variable mixture of parts.
  - Medium production rates.
  - Flexibility to deal with product design variations.
  - Ability to adapt to engineering changes in parts.
  - Increase in number of similar parts produced on the system.
  - Ability to accommodate routing changes.
  - Ability to rapidly change production set up.

Example:

FLEXIBLE MANUFACTURING SYSTEM

Automation in action…

- CAD/CAM
- CNC
- Rapid Prototyping
- Inspection
- CMM
- Robots
- Conveyors
- Process Controls
- FMS
- Data Collection
- Manufacturing Planning and Control
- EDI
- Accounting Systems
- Material handling
- Sales Force Automation

Reasons for Automating

1. To increase labor productivity
2. To reduce labor cost
3. To mitigate the effects of labor shortages
4. To reduce or remove routine manual and clerical tasks
5. To improve worker safety
6. To improve product quality
7. To reduce manufacturing lead time
8. To accomplish what cannot be done manually
9. To avoid the high cost of not automating

Automation Principle and Strategies

- A certain caution and respect must be observed in applying automation technologies.

- There are 3 approaches for dealing with automation projects.

1. USA: Principle

1. **Understand** the existing process
   - Input/output analysis
   - Value chain analysis
   - Charting techniques and mathematical modeling
2. **Simplify** the process **(Value Stream Mapping)**
   - Reduce unnecessary steps and moves
3. **Automate** the process
   - Ten strategies for automation and production systems
   - Automation migration strategy

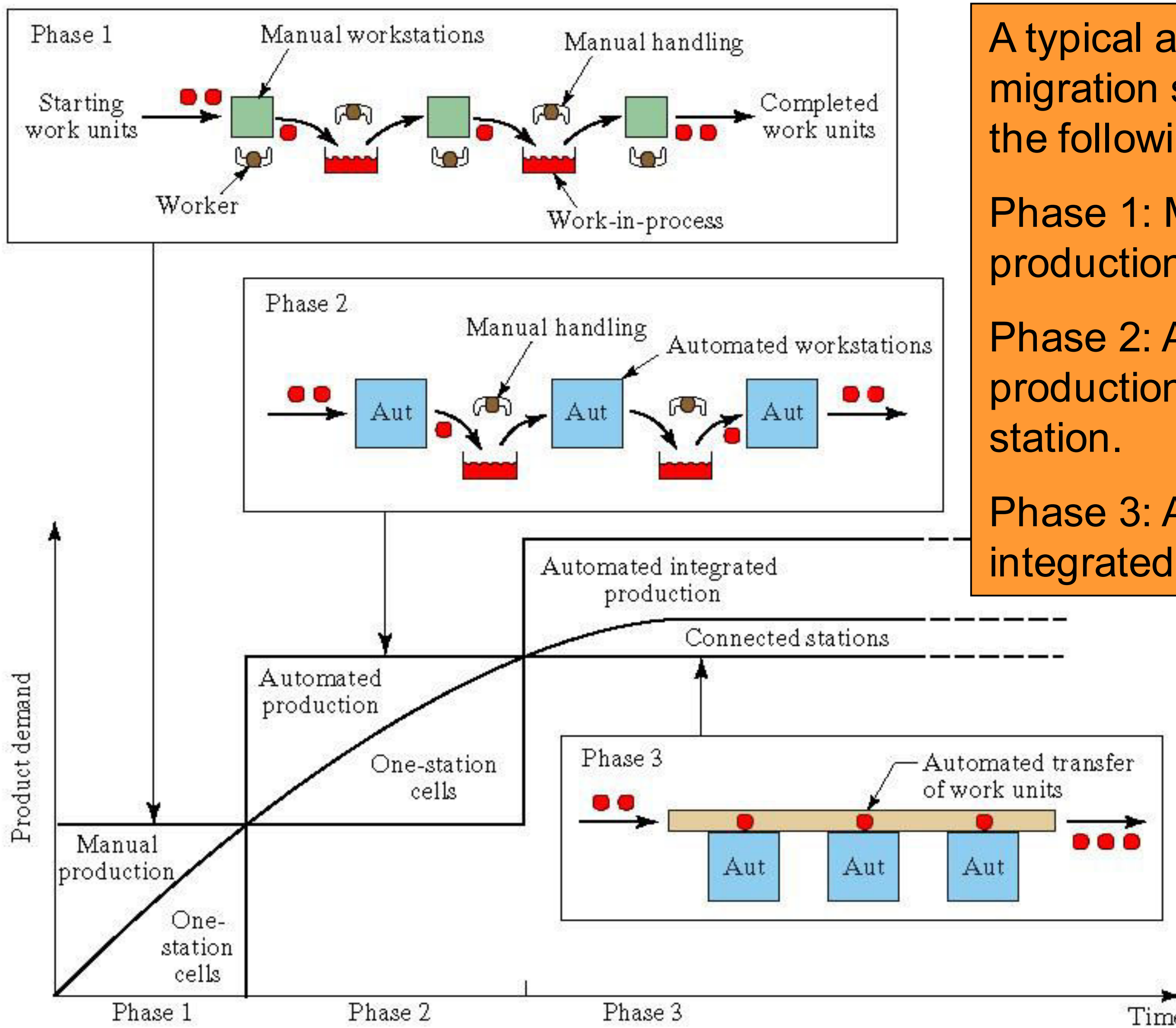
2. 10 Strategies for Automation

1. Specialization of operations
2. Combined operations
3. Simultaneous operations
4. Integration of operations
5. Increased flexibility
6. Improved material handling and storage
7. On-line inspection
8. Process control and optimization
9. Plant operations control
10. Computer-Integrated manufacturing

3. Automation Migration Strategy

- Owing to competitive pressure in the market place, a company often needs to introduce a new product in the shortest possible time.
- If the product turns out to be successful, and higher future demand is anticipated, then it makes sense for the company to automate production.
- The improvements are often carried out in phases.
- Many companies have an automation migration strategy.
- It is a formalized plan for evolving the manufacturing systems used to produce new products as demand grows.

Automation Migration Strategy



A typical automation migration strategy is the following:

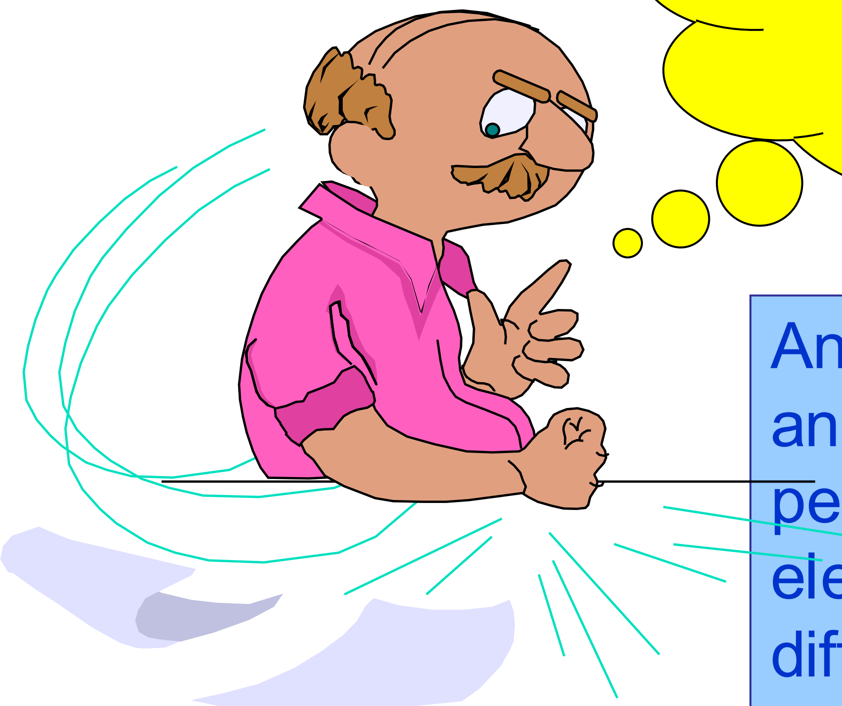
Phase 1: Manual production

Phase 2: Automation production with single station.

Phase 3: Automated integrated system

COMPUTER INTEGRATED MANUFACTURING SYSTEM (CIMS)

What is Computer Integrated Manufacturing System?



An attempt to define CIM is analogous to a group of blind persons trying to describe an elephant by touching it; each has a different description depending upon the body part touched.

What is CIM?

Computer Integrated Manufacturing, known as CIM, is the phrase used to describe the complete automation of a manufacturing plant, with all processes functioning under computer control and digital information tying them together.

Salient Features of CIMS

- CIMS involves the use of computers to automate, control and document manufacturing activity through the entire manufacturing process.
- Keeps track of Inventory so proper materials & tools are supplied on continuous basis.
- Coordinates different programs needed to produce parts
- Can change from one item to another quickly.
- CIMS work because of Common Computer Network where information can flow between machines.
- Optimize the use of *Information*
- *Integration* is the key word.

CIMS

CIM Can be found at several levels:

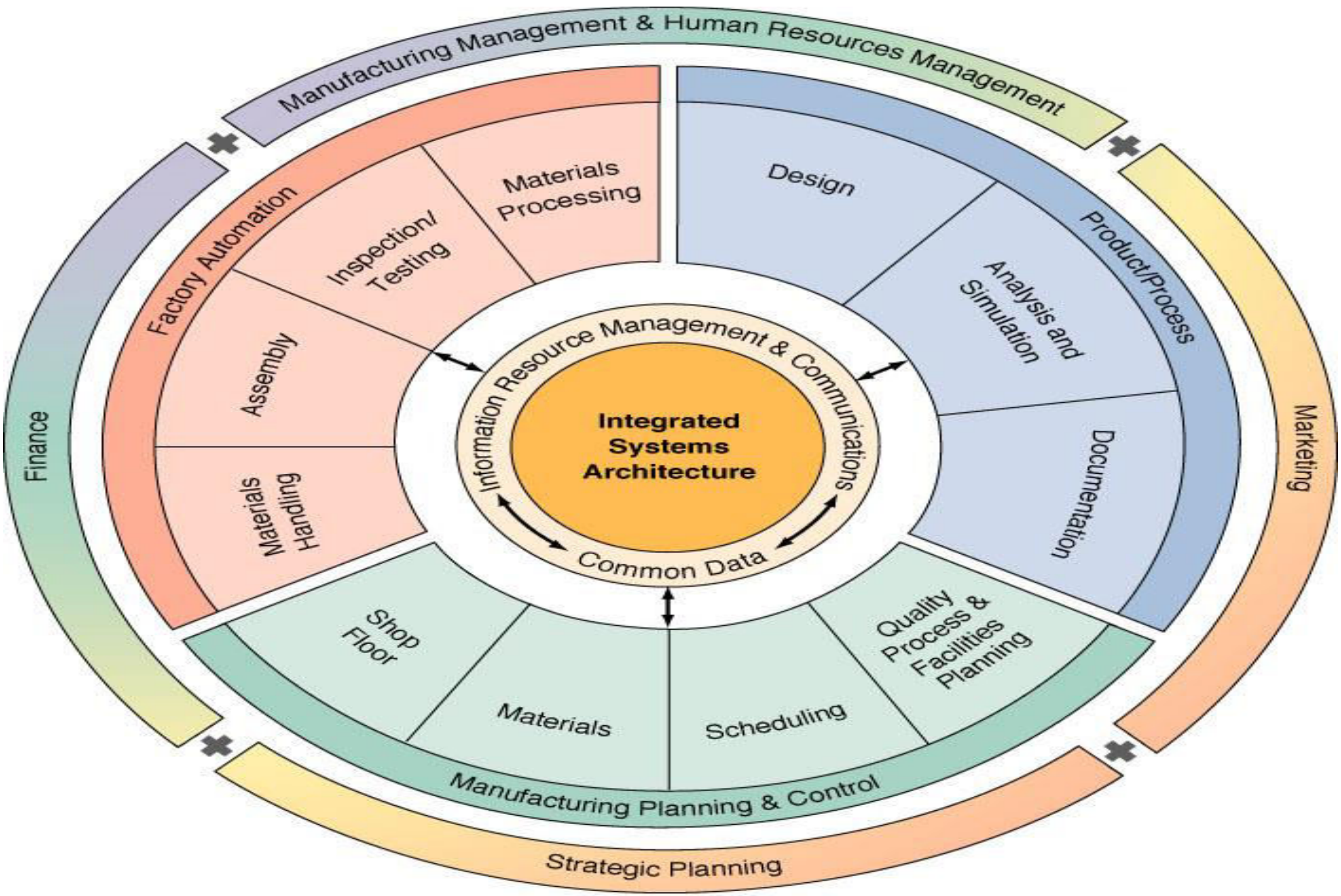
- Shop floor automation / work cell
  - "islands of automation"
- Manufacturing Operations
  - "islands" are linked together
- Information systems integration
  - Information shared across functional boundaries
- Strategic or "Supply Chain" level
  - Integration extends up to customers and down to the suppliers

Low

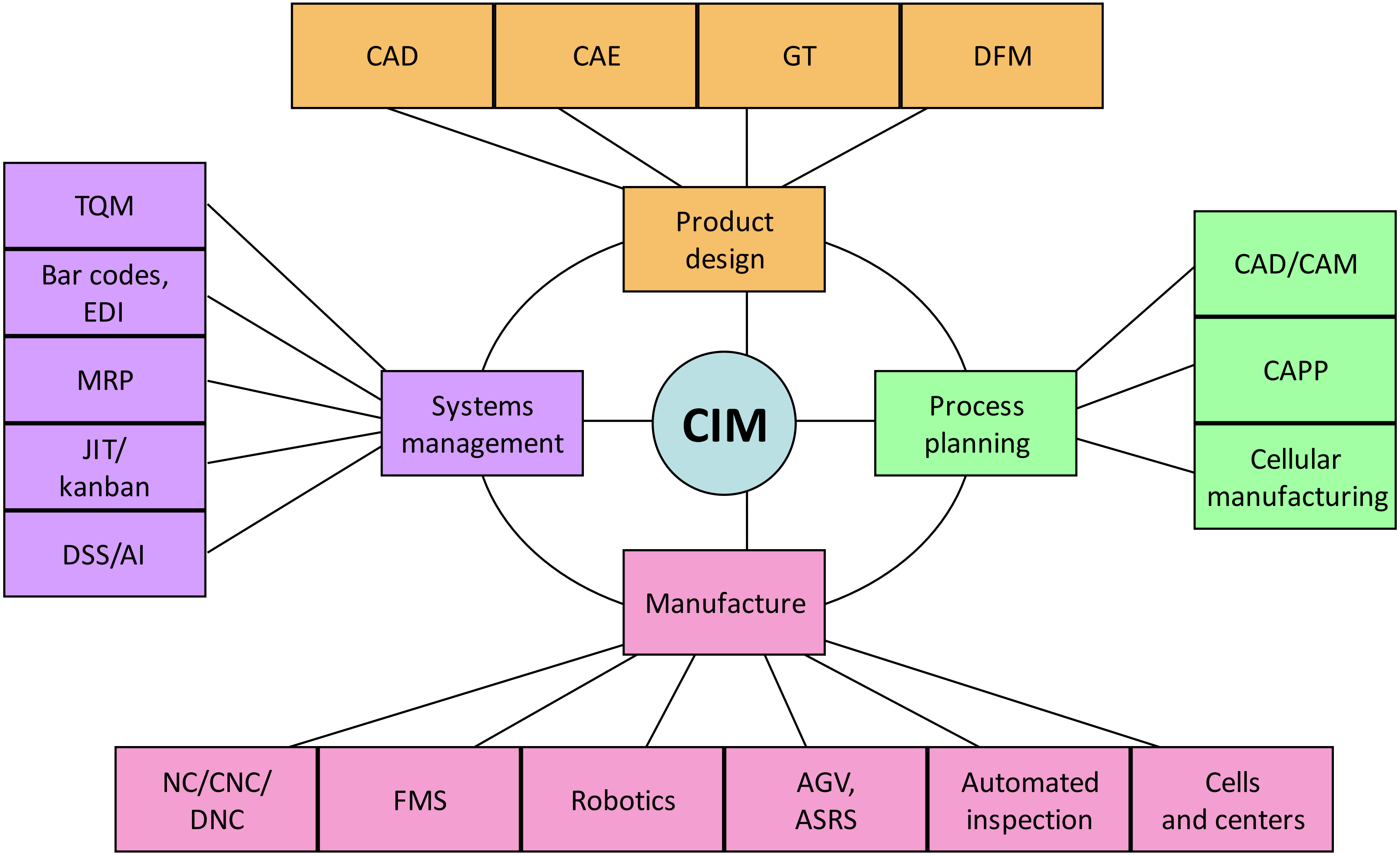
↓

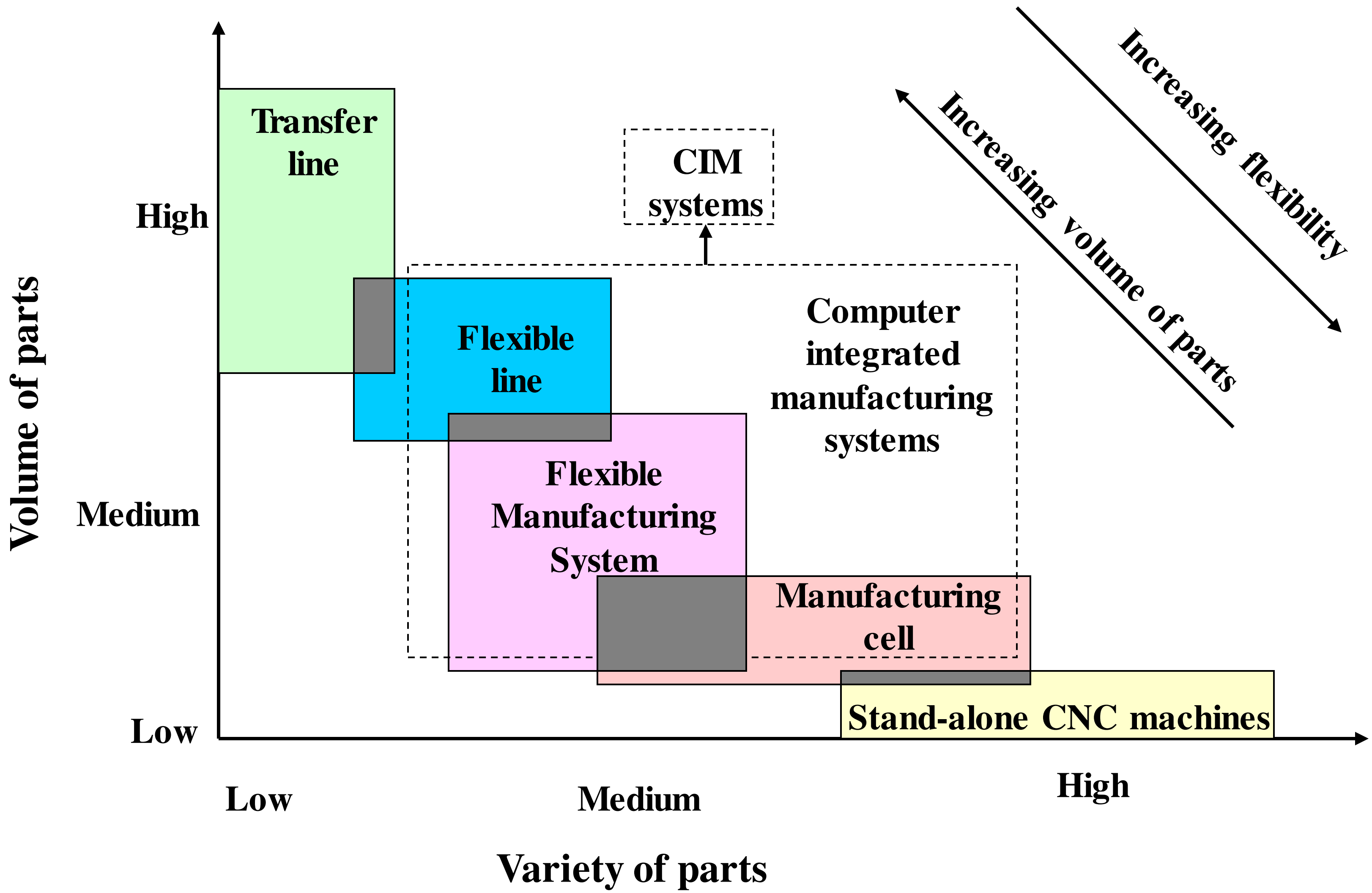
High

CIM Wheel


Manufacturing Management & Human Resources Management
Finance
Marketing
Strategic Planning
Factory Automation
Materials Processing
Inspection/ Testing
Assembly
Materials Handling
Product/Process
Design
Analysis and Simulation
Documentation
Manufacturing Planning & Control
Shop Floor
Materials
Scheduling
Quality Process & Facilities Planning
Information Resource Management & Communications
Common Data
Integrated Systems Architecture

Components of CIM




Transfer line
CIM systems
Increasing flexibility
Increasing volume of parts
High
Flexible line
Computer integrated manufacturing systems
Volume of parts
Medium
Flexible Manufacturing System
Manufacturing cell
Stand-alone CNC machines
Low
Low
Medium
High
Variety of parts

Benefit from CIM

Integration of technologies brings following benefits:

1. Creation of a truly **interactive system** that enables manufacturing functions to communicate easily with other relevant functional units.

2. Accurate **data transferability** among manufacturing plant or subcontracting facilities at implant or diverse locations.

3. Faster responses to **data-changes** for manufacturing flexibility.

4. **Increased flexibility** towards introduction of new products.

5. Improved **accuracy** and **quality** in the manufacturing process.

Benefit from CIM

6. **Improved quality** of the products.

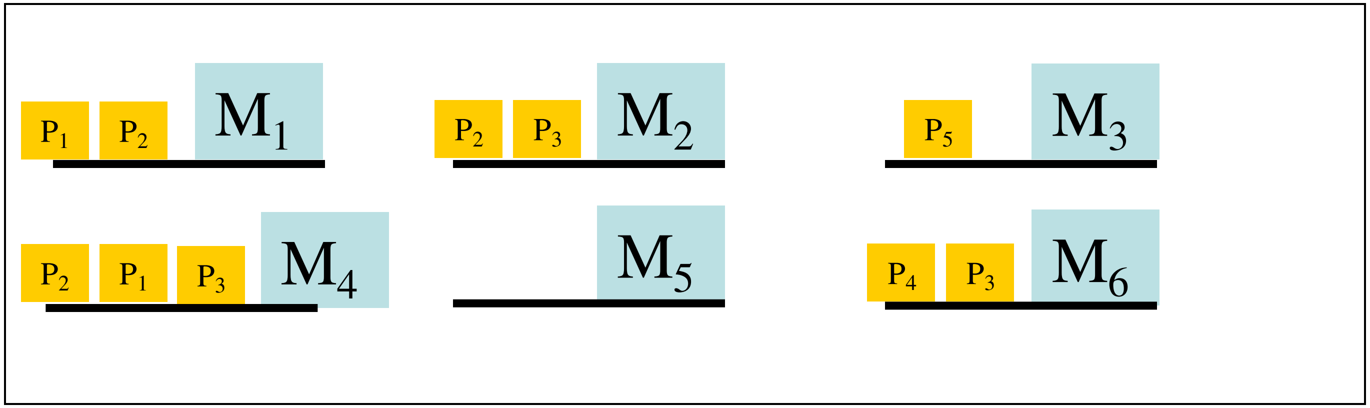
7. Control of **data-flow** among various units and maintenance of user-library for system-wide data.

8. Reduction of **lead times** which generates a competitive advantage.

9. **Streamlined** manufacturing flow from order to delivery.

10. Easier **training and re-training** facilities.

Problems of Conventional Batch Manufacturing Systems



PROBLEMS:

- High Lead Times, High WIP
- Utilization Losses, Quality problems
- Delivery problems, Poor Management

- Poor Machine Flexibility, Setup time ≃ 100 times Operation Time
- No Dynamic Use of Routing Flexibility, Lack of Status Monitoring

Two Basic Approaches

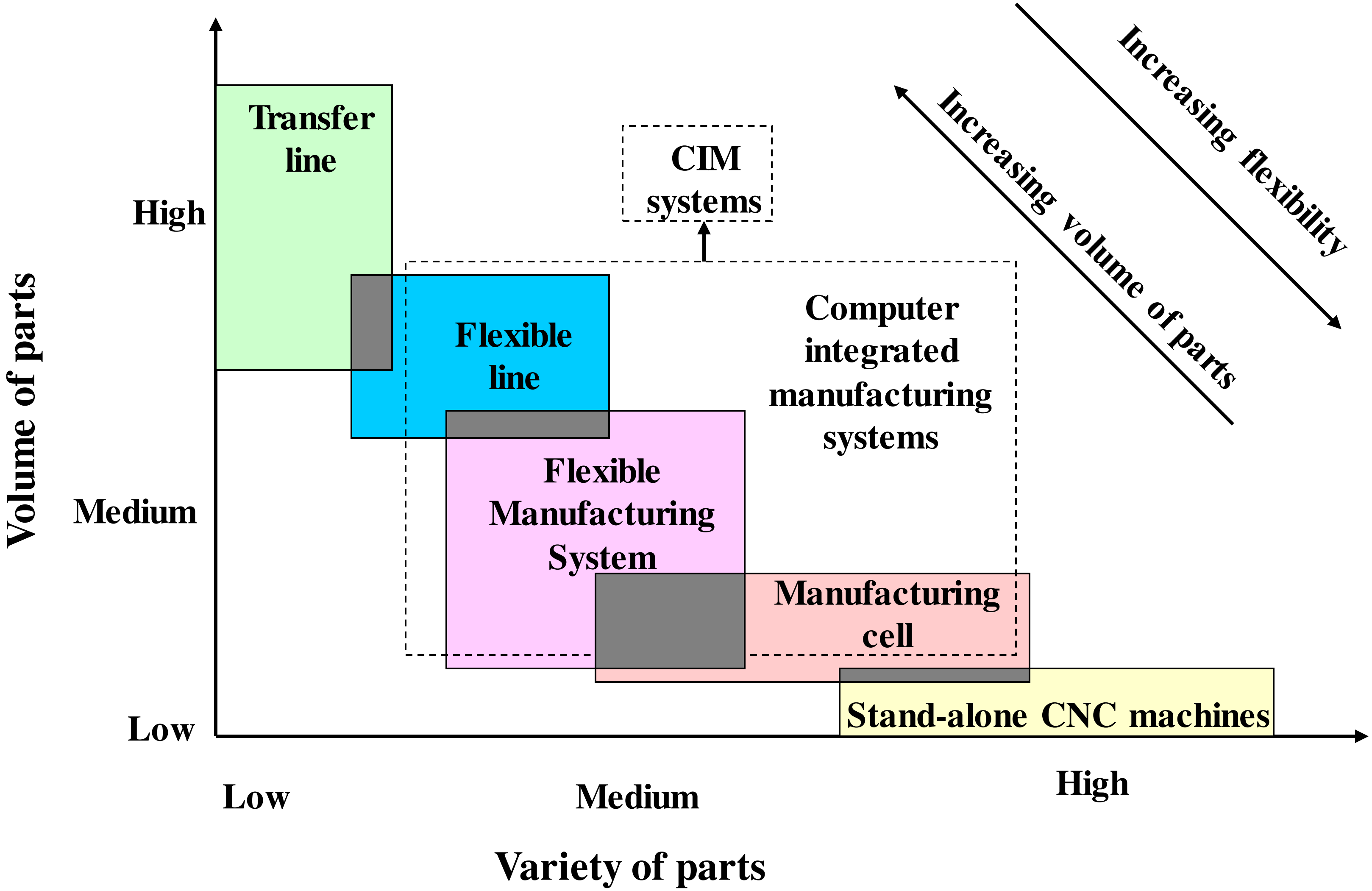
- More than 50% of all manufacturing industry is facing the BMS scenario problems.
- Hence Need for greater Focus on CIMS

Two Basic Approaches

1. IT Driven System Approach: FMS
2. An Organizational Approach: GT

Ideal : Use FMS with GT Ideas For More Benefits

FLEXIBLE MANUFACTURING SYSTEM (FMS)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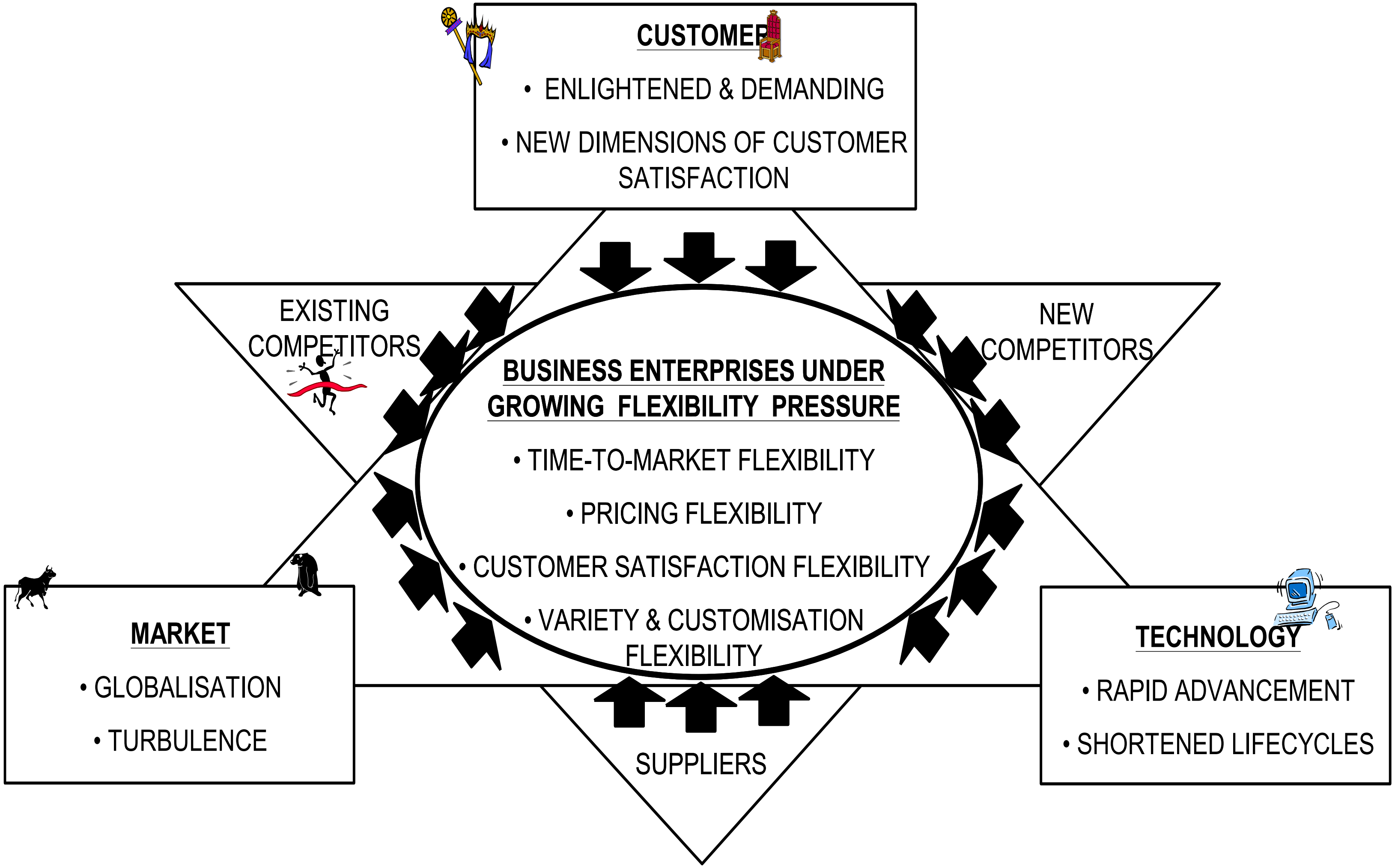
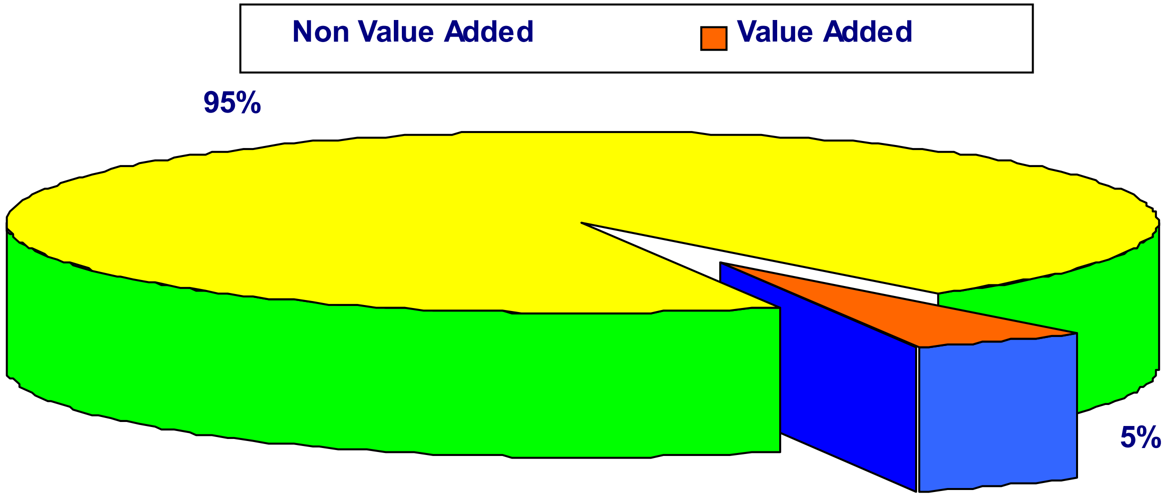


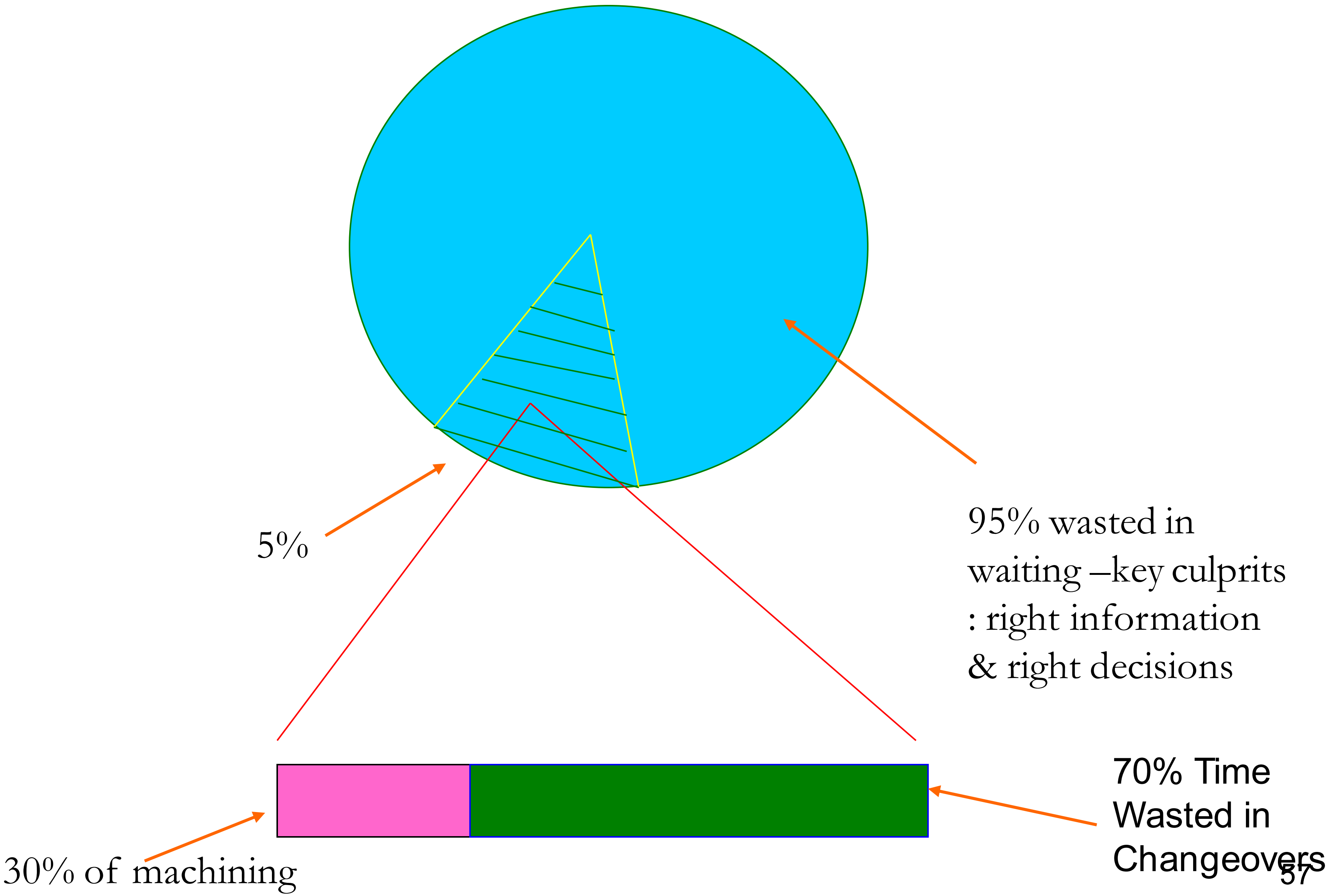
Evolving Flexibility Environment



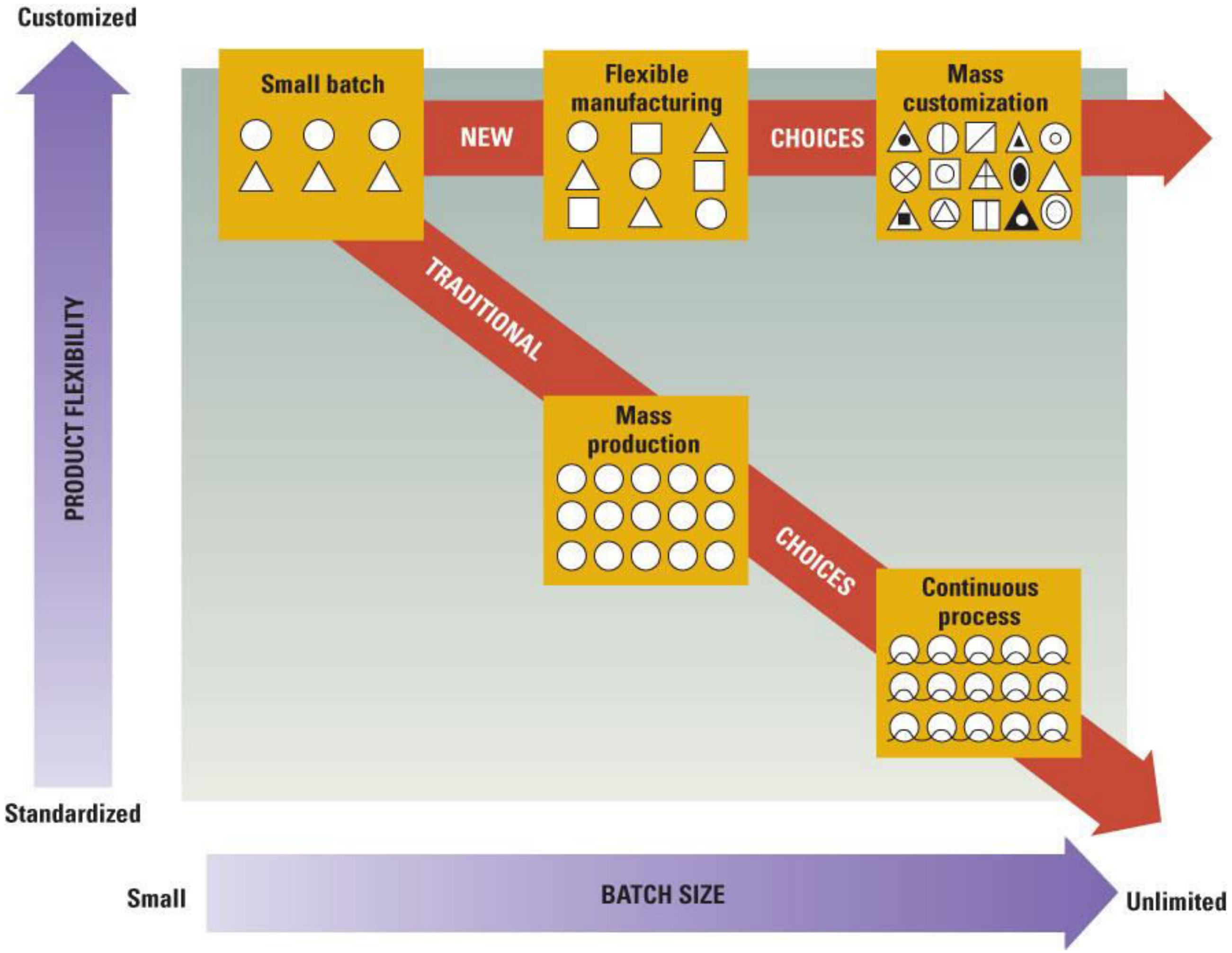
Analysis of Lead Time

Non Value Added Time vs. Value Added Time

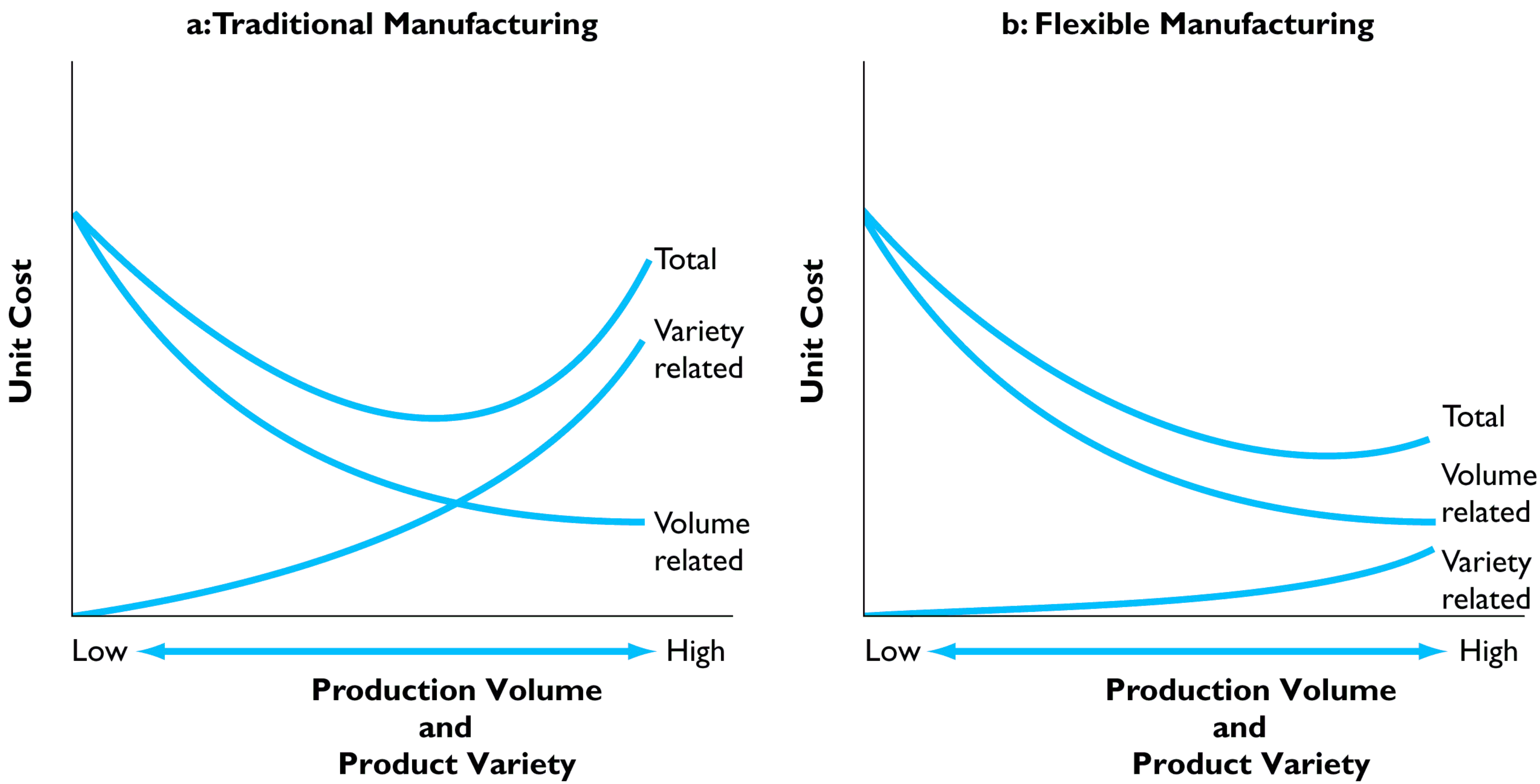
Time Based Competitiveness and Flexibility



Flexible Manufacturing Technology vs. Traditional Technologies



Production and Efficiency: Flexible Manufacturing



- The tradeoff between costs and product variety

History of FMS

- FMS first proposed in England in 1960’s
- “System 24” operates 24 hours a day
- Automation is main purpose in beginning

Definition of FMS

A Flexible Manufacturing System (FMS) is a set of **numerically controlled machine** tools and supporting **workstations** connected by an automated **material handling system** and controlled by a **central computer.**

FMS

- An FMS is a **"reprogrammable"** manufacturing system capable of producing a **variety of products** automatically.
- Conventional manufacturing systems have been marked by one of two distinct features:
  - The capability of producing a variety of different product types, but at a high cost (e.g., job shops).
  - The capability of producing large volumes of a product at a lower cost, but very inflexible in terms of the product types which can be produced (e.g., transfer lines).
- An FMS is designed to provide both of these features.

- A Flexible Manufacturing System (FMS) is a highly automated **GT** motivated system, consisting of a group of CNC machine tools, interconnected by an **automated and integrated material handling** and **storage system**, and controlled by a **distributed computer system.**
- The reason the FMS is called flexible is that it is capable of processing a **variety of different part styles** and **quantities of production** can be adjusted in response to changing demand patterns.

Components of Flexible Manufacturing Systems

- **FMS Consists of two subsystems**
  - ***Physical subsystems***
    - Workstations
      - NC ,CNC,DNC Machines and tools
    - Storage-retrieval systems
    - Material-handling systems
    - Automated Inspection
    - Cells and Centers
    - Robotics
    - AGV
    - ASRS

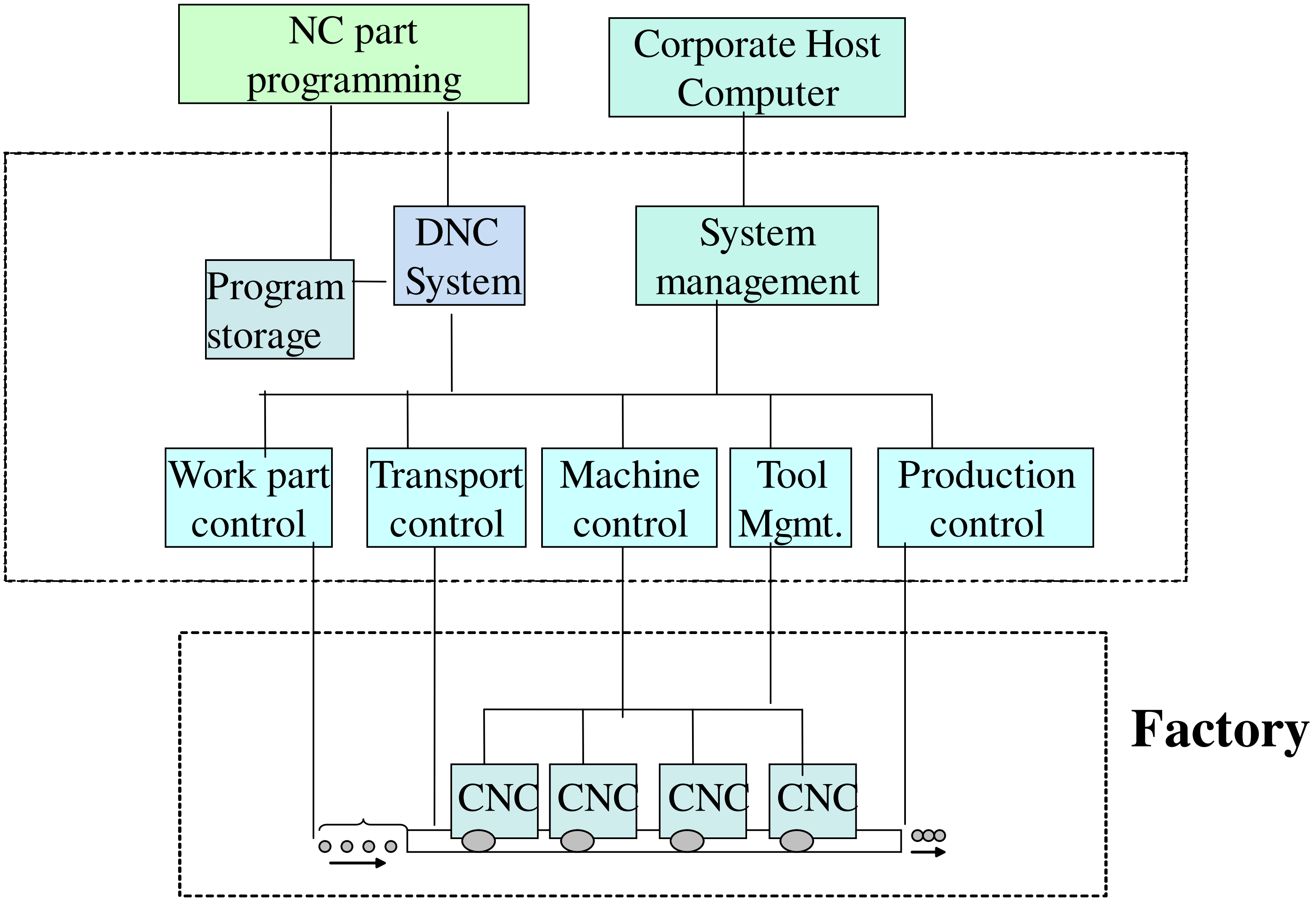
– ***Control subsystems***

- Control hardware
  - Mini and micro computers
  - Programmable logic controllers
  - Communication network
  - Sensors, switches etc.

- ***Control Software***
  - Files and programs used to control physical sub-systems

FMS computer control system

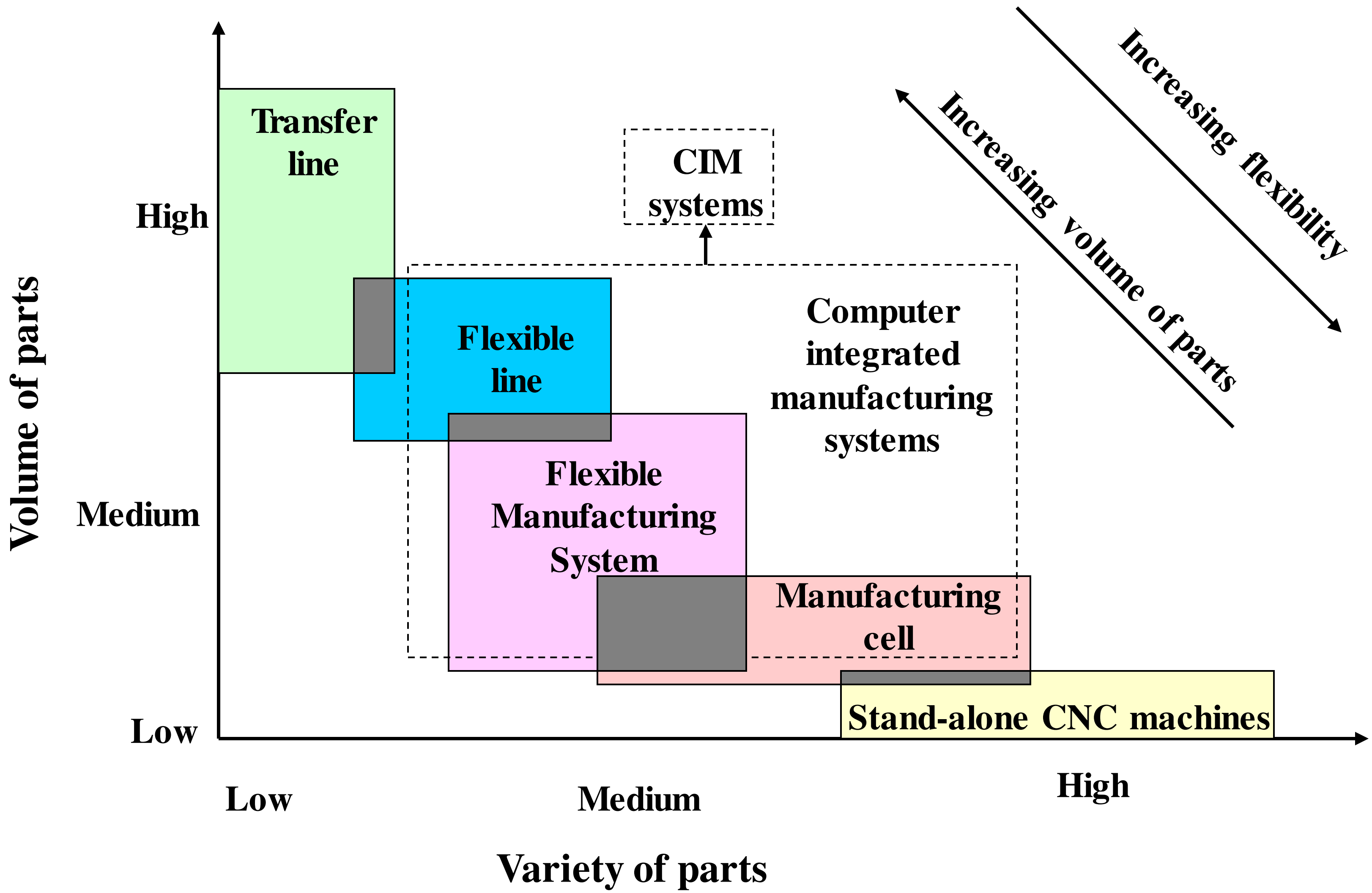
1. Workstation control
2. Supervisory control among workstations
3. Production control (part rate and mix)
4. Traffic control (manage part delivery systems)
5. Shuttle control (part handling between machine and primary handling system)
6. Workpiece monitoring (status of various systems)
7. Tool control (location and tool life)
8. Performance monitoring and reporting
9. Diagnostics (identify sources of error, preventive maintenance)



FMS: COMPUTER CONTROL SYSTEM

CNC =Computer Numerical Control, DNC: Distributed Numerical Control

Structure of A Typical FMS Computer Configuration



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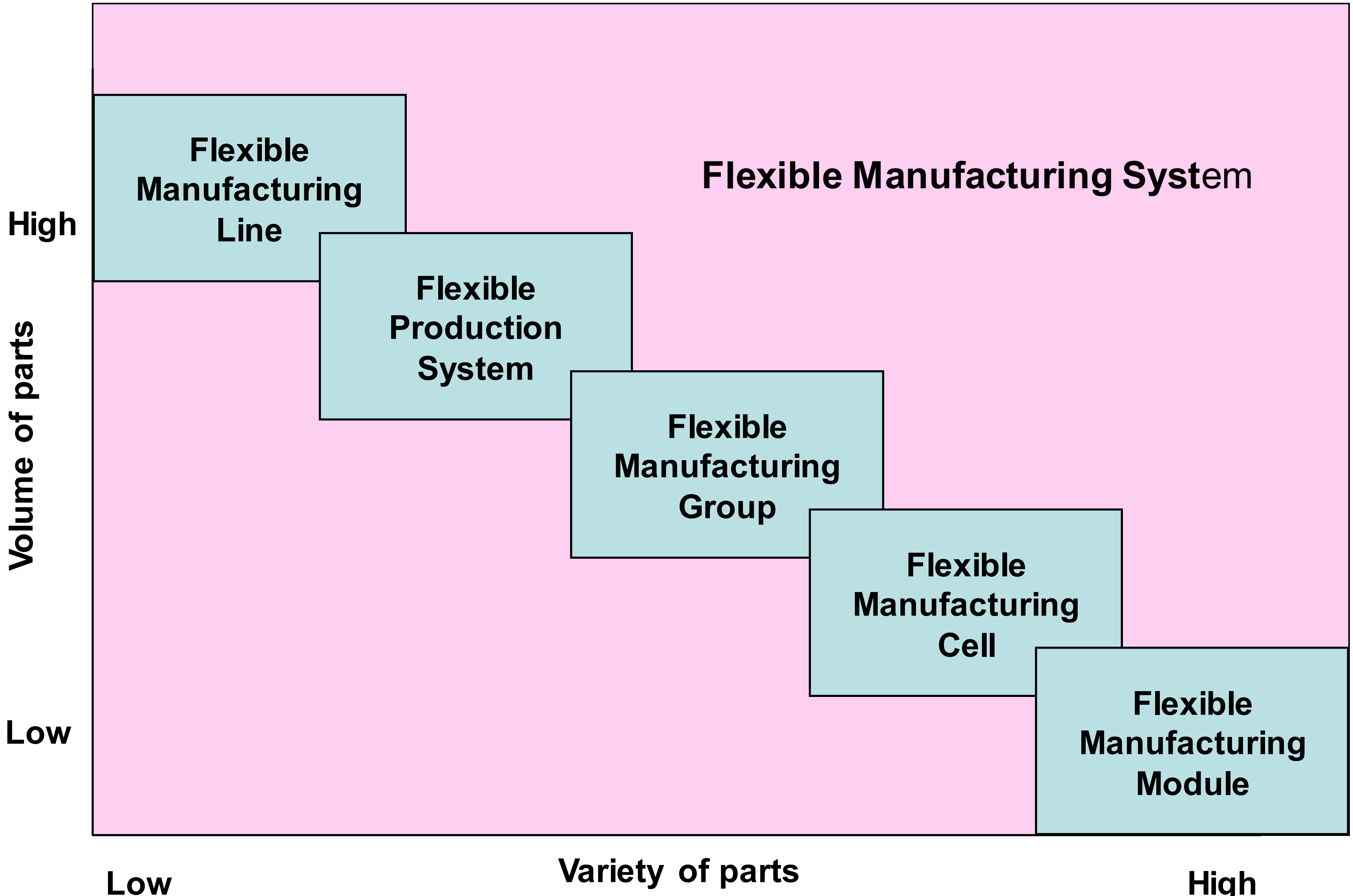
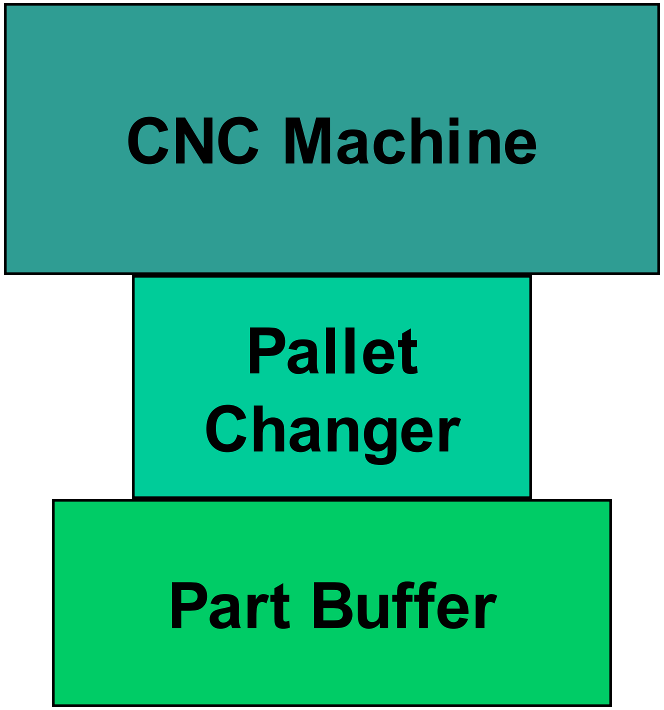
FMS ALTERNATIVE APPROACHES



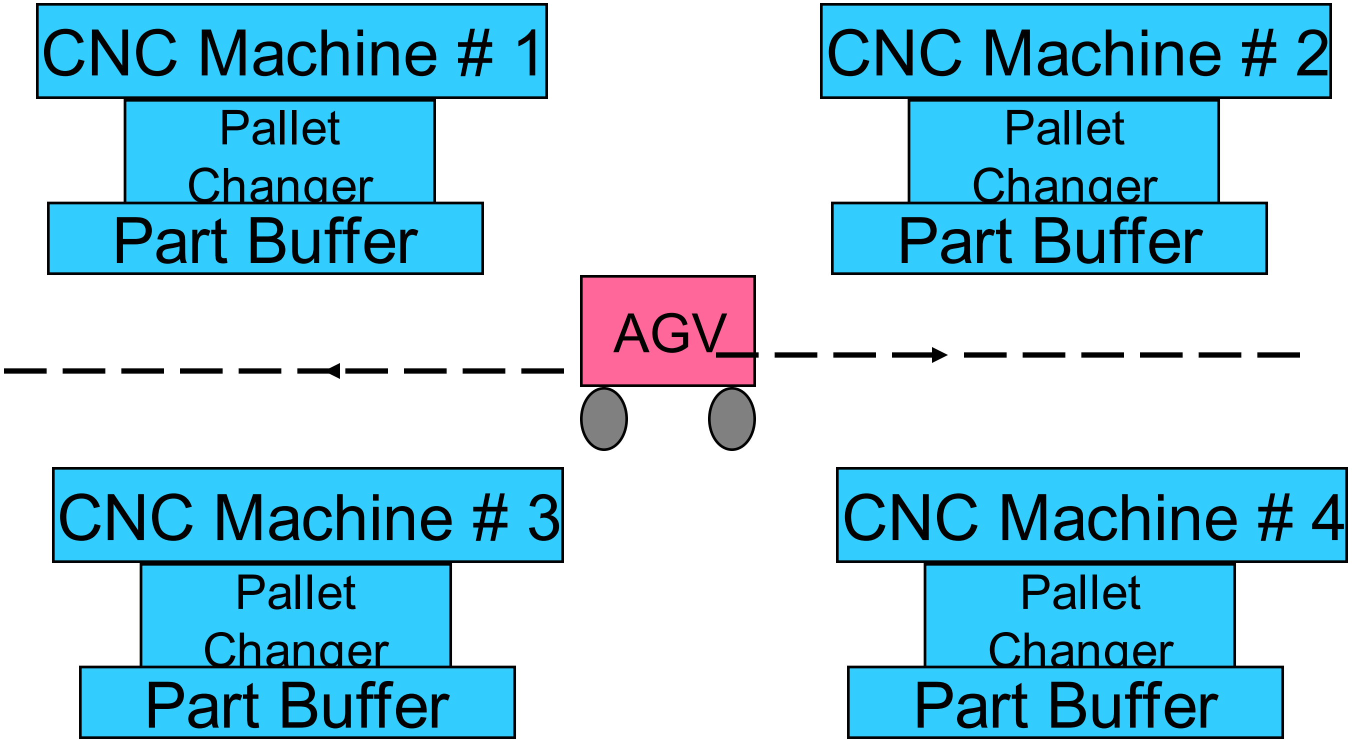
Flexible Manufacturing Module

A Numerically Controlled Machine Supported With a Parts Inventory, a Tool Change, and A Pallet Changer



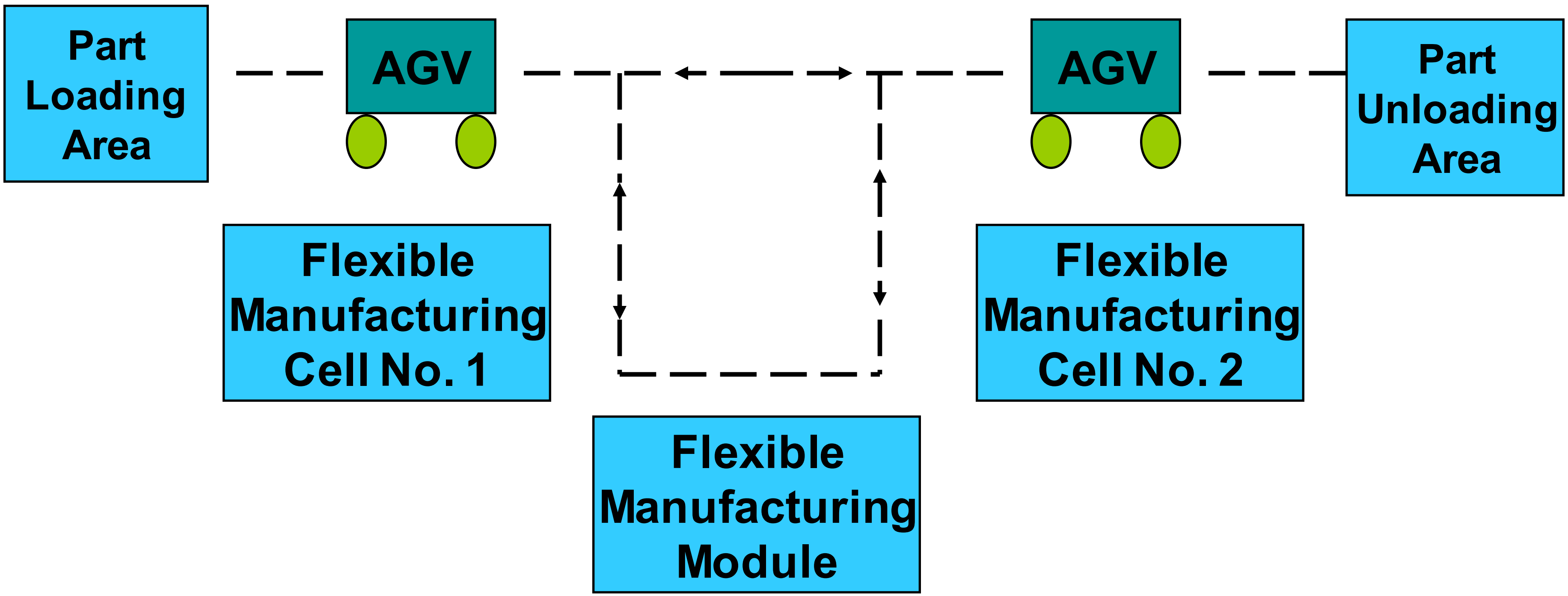
Flexible Manufacturing Cell

Several Flexible Manufacturing Modules Organized According to a Particular Product's Requirements



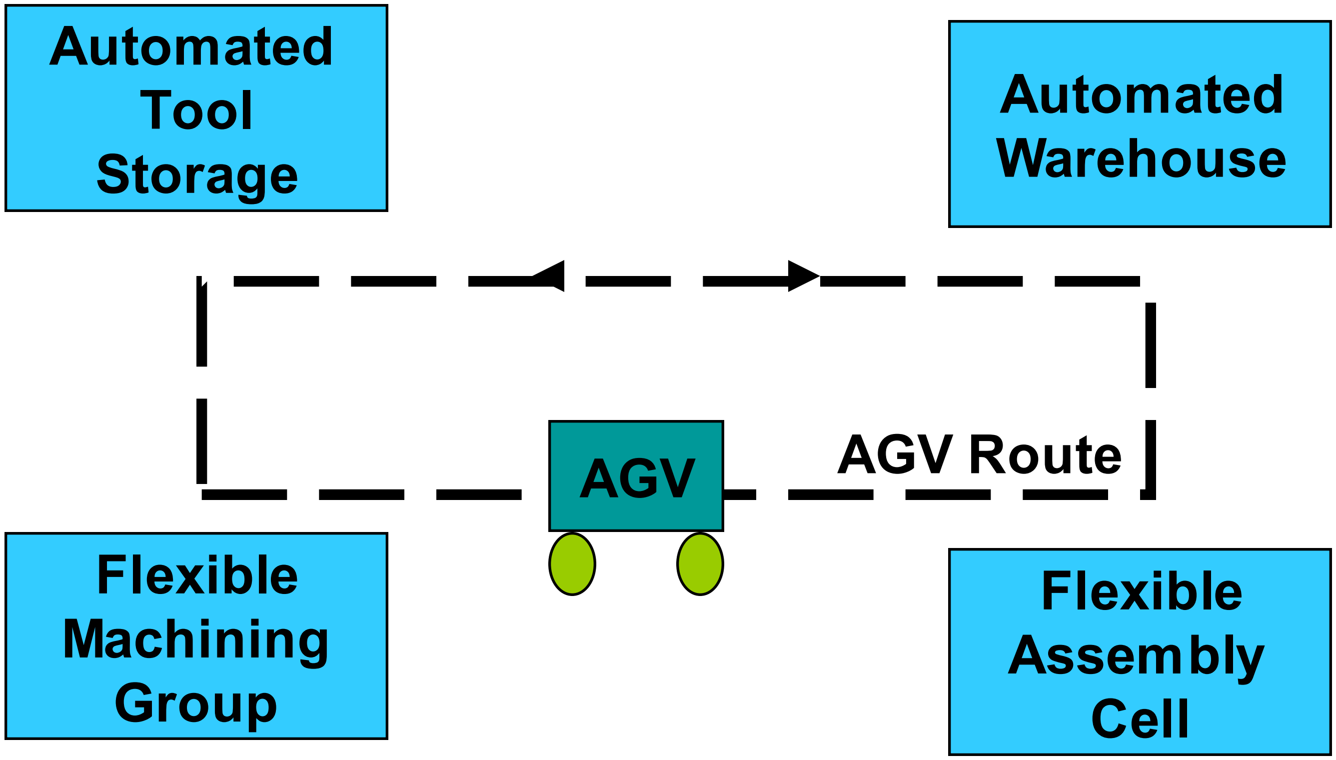
Flexible Manufacturing Group

A Combination of Flexible Manufacturing Modules and Cells Located in the Same Area and joined by a Material Handling System



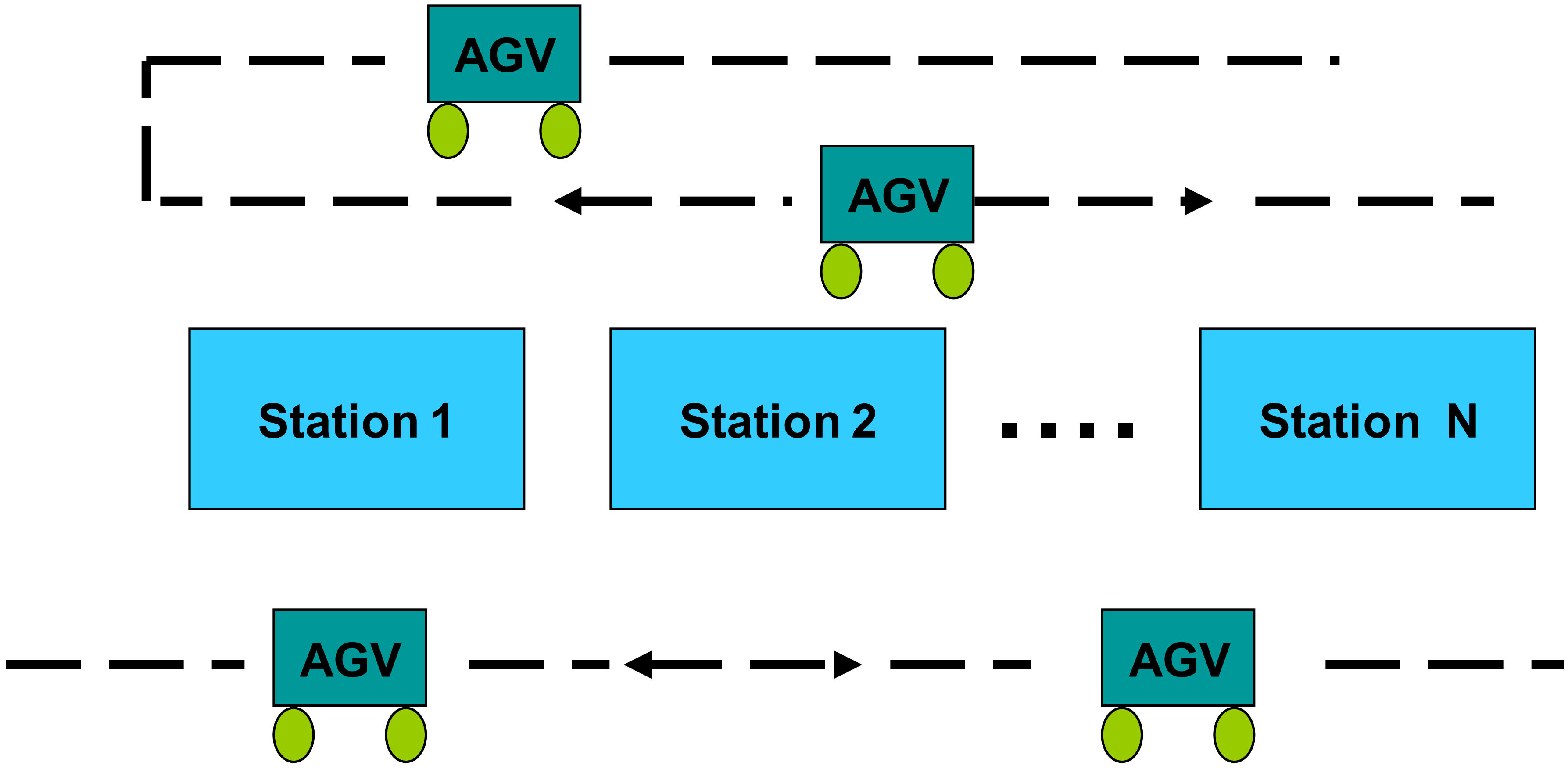
Flexible Production System

Flexible Manufacturing Groups that Connect Manufacturing Areas



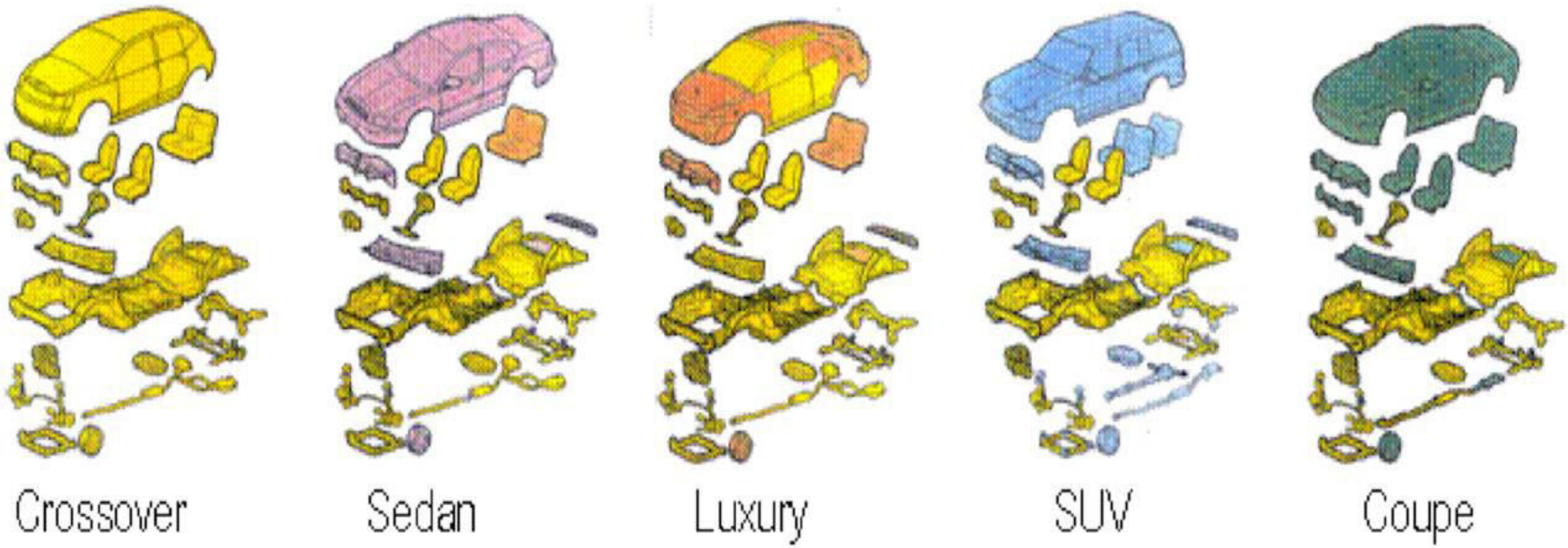
Flexible Manufacturing Lines

A Series of Dedicated Machines connected by AGV's, robots, or conveyors



FMS Example

One Design + One Assembly Process = Multiple Models



When different models are designed to be assembled in the same sequence they can be built in the same plant.
This maximizes efficiency and allows the company to respond quickly to changing customer

FMS: Implementations

- About 300 FMS installations by 1985
- 20-25% of those were located in the US
- Emphasis on smaller, less expensive Flexible Manufacturing Cells (FMC)
- Parts for Automobiles, Aircraft etc.
- More for Prismatic than Rotational Parts
- Horizontal Machining Centers popular

First FMS (Conceptual)

- First conceptualized for machining.
- Required NC.
- Credited to David Williamson, a British engineer employed by Molins.
- The original concept included:
  - Computer control of the NC machines
  - A variety of parts being produced
  - Tool magazines capable of handling various tools for different machining operations.

First FMS (in the US)

- One of the first FMS to be installed in US was a machining system at Ingersoll-Rand Company in Roanoke, Virginia in late 1960s by Sundstrand.

- Other systems in the US
  - Kearny and Trecker FMS at Caterpillar Tractor
  - Cincinnati Milacron "Variable Mission System"

First FMS (Other Places)

- Germany
  - Developed by Heidleberger Druckmaschinen in cooperation with the University of Stuttgart in the year 1969.
- Russia (Former U.S.S.R.)
  - Demonstrated at the Stanki Exhibition in Moscow in 1972.
- Japan
  - Installed by Fuji Xerox in the year 1972.

FMS benefits

- Increased machine utilization
  - 24 hr/day operation
  - Automatic tool changing at machine tools
  - Automatic pallet changing at workstations
  - Queues of parts at stations
  - Dynamic scheduling of production that account irregularities from normal operations

It is possible to approach 80-90% asset utilization by implementing FMS technology.

- Fewer machines required
- Reduction in factory floor space required
- Greater responsiveness to change
  - FMS Improves response capability to:
    - Part design changes
    - Introduction of new parts
    - Changes in production schedule and product mix
    - Machine breakdowns
    - Cutting tool failures
  - Adjustments could be made to respond to rush orders and special customer requests.

- Reduced inventory requirements (estimated reduction of 60-80%)
  - WIP is less than in a batch production mode because different parts are processed together
  - Starting and finished parts inventory also reduces
- Lower manufacturing lead times
- Reduced direct labour requirements and higher labour productivity (estimated labour savings of 30-50%)
- Oppourtunity for unattended production
  - No need of human attention for long hours

Manufacturing Flexibility

Manufacturing Flexibility

What is "Flexibility"?

Ability to "change" towards a desired goal

The change may be:

- Certain /Uncertain
- Internal/External
- Local/Global
- In product/process
- In machine/cell
- In competition factors
- Product mix/volume

Flexibility is EXPENSIVE: Use the right type and level of flexibility

Flexibility: A definition

- Flexibility can be viewed as control on flow of entities through the system (Wadhwa and Browne, 1989).

- Flexibility is the ability to change with little penalty in time, effort, cost or performance (Upton, 1995).

- Flexibility is the ability to respond to changes either in the environment or in the system itself (Chowdary, 2001).

Manufacturing Flexibility

- **Basic**
  - ***machine*** (variety of operations)
  - ***material handling*** (part mobility and placement)
  - ***operation*** (variety of operations producing same part features)

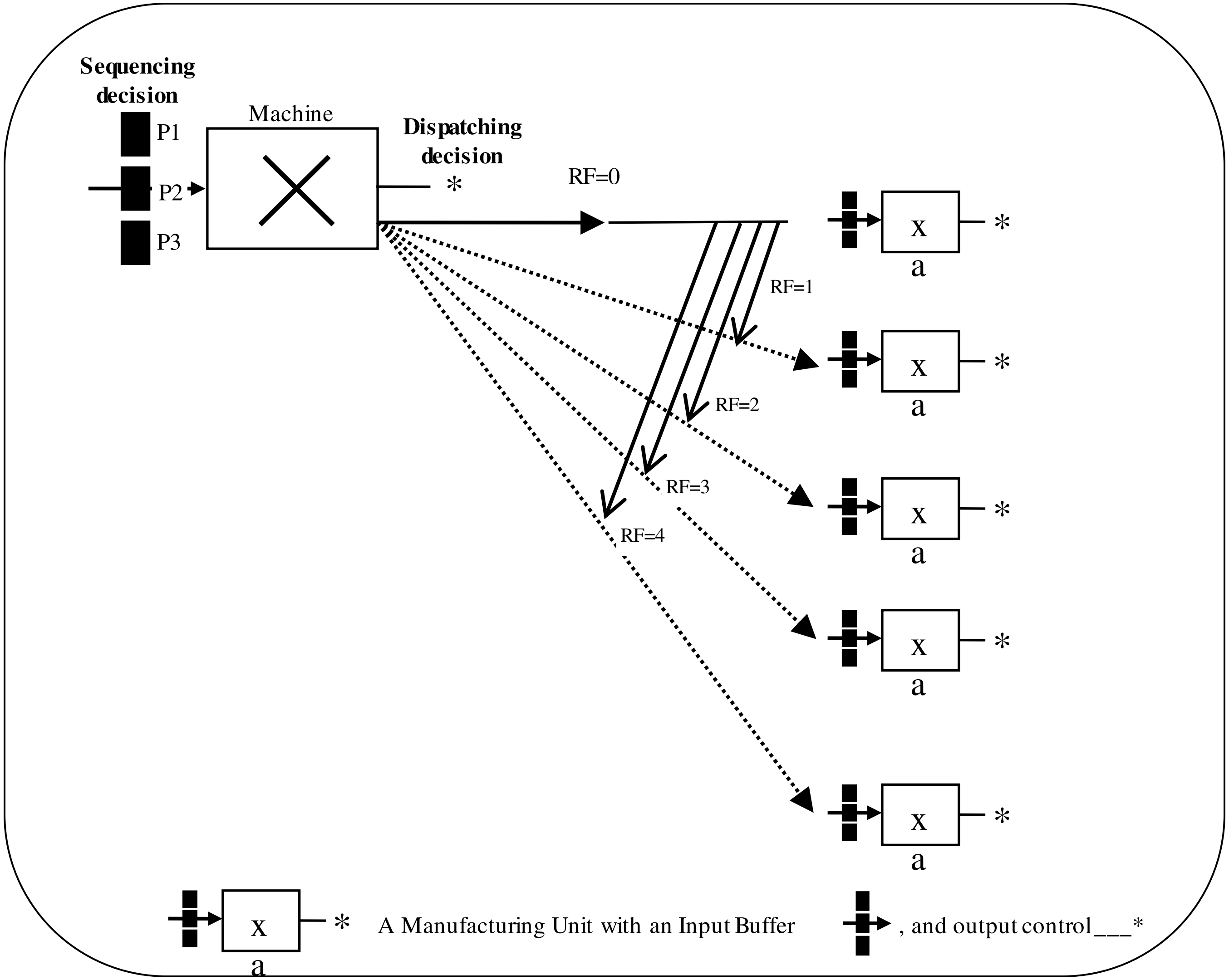
Manufacturing Flexibility

- **System**
  - ***process*** (variety of parts producible with same setup)
  - ***routing*** (ability to use different machines under same setup)
  - ***product*** (changeover)
  - ***volume*** (production level)
  - ***expansion*** (added capacity)

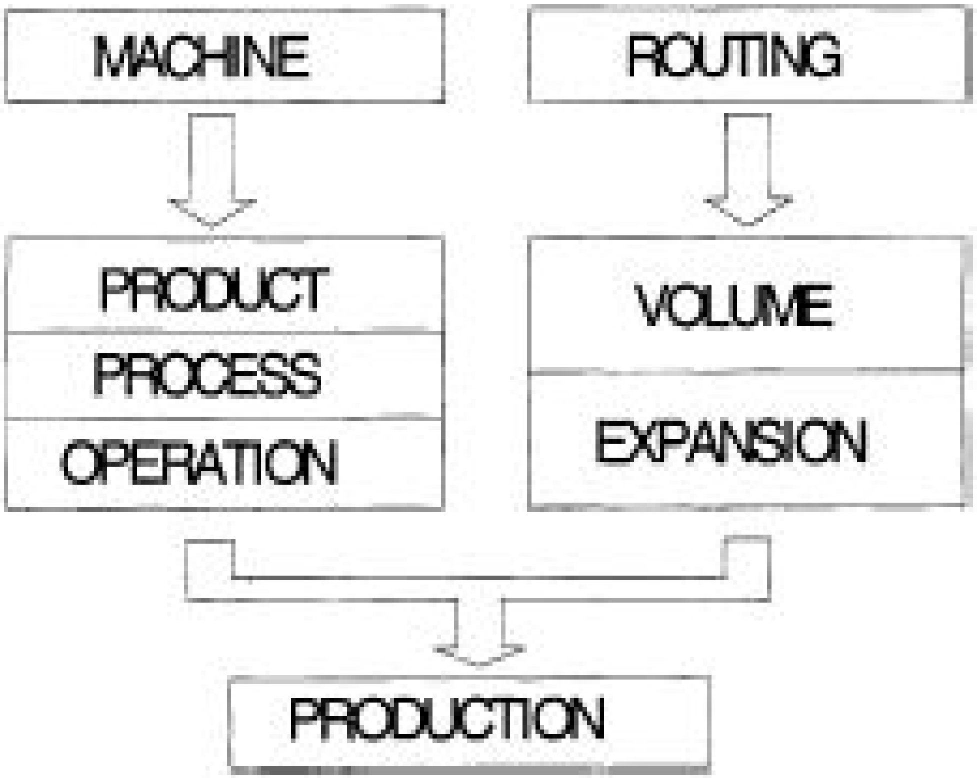
Manufacturing Flexibility

- **Aggregated**
  - ***program*** (unattended running)
  - ***production*** (ranges of parts, products, processes, volume, expansion)
  - ***market*** (combination of product, process, volume and expansion)

Flexibility Concept



Relationships



The emerging needs for manufacturing flexibility

- Slack (1989) stated that the first order objectives of a flexible system should be to have the following three abilities, namely availability, reliability and productivity.
- The first order objectives proposed by Slack (1989) are associated with the things which customers are really concerned about.
- Customers demand the availability of new products, different product-mixes and volumes, reliable delivery, on time delivery, and low cost to produce the products.
- However, customers do not expect to spend money to pay for the flexibility of a system.

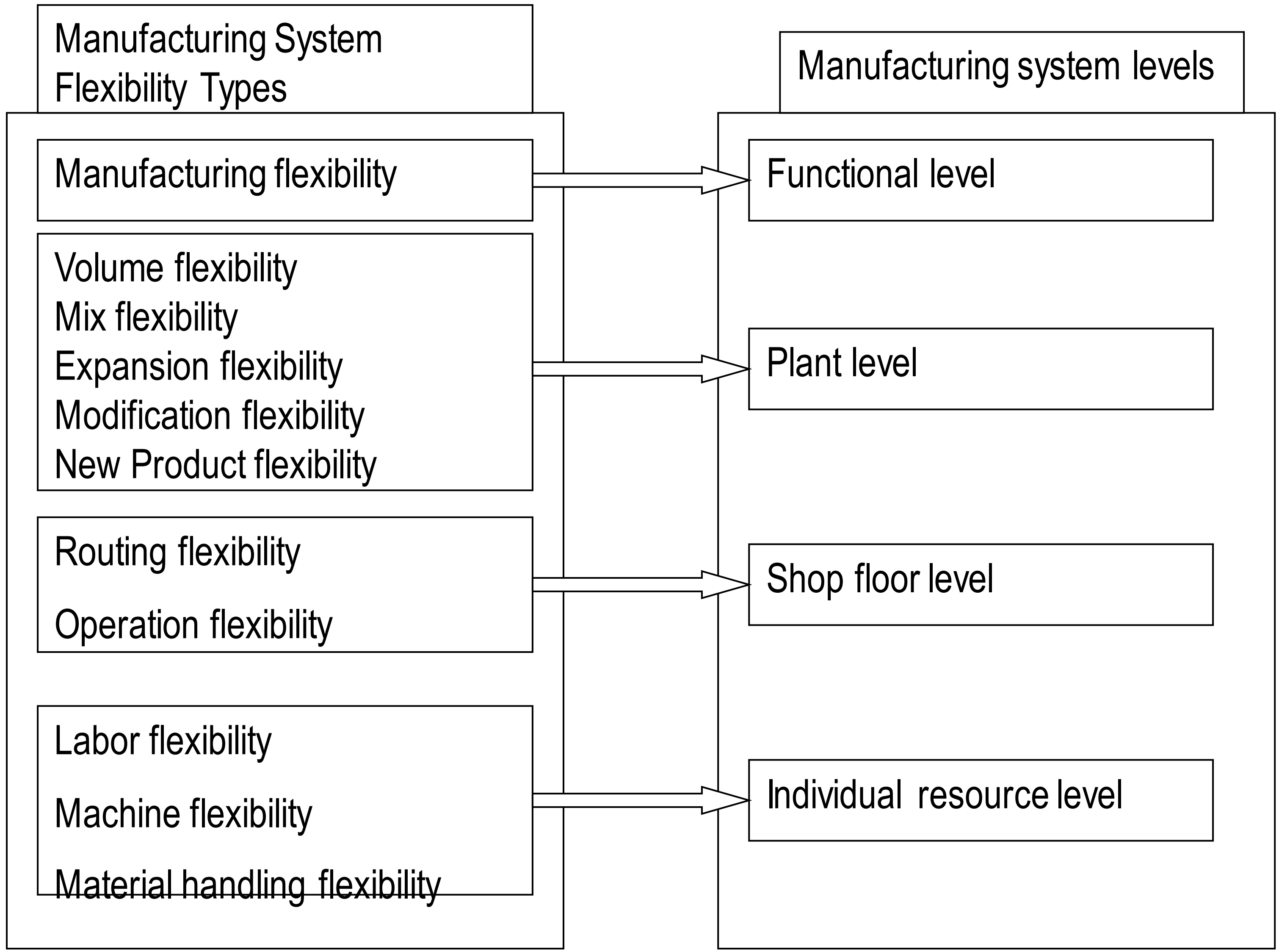
- Therefore, Slack (1989) pointed out that flexibility is a second order objective, which means it is for supporting the first objectives.

- The competitive value of manufacturing flexibility lies in its controllability in the face of uncertain demand.

- Wadhwa et al. 2002 suggests that flexibility can resolve conflicts between organizational objectives. They emphasized that some of the organizational objectives like faster delivery at lower cost, lower cost with greater variety, greater variety with higher quality, faster delivery and higher quality, lower cost and higher quality can be resolved by providing flexibility in the organization.

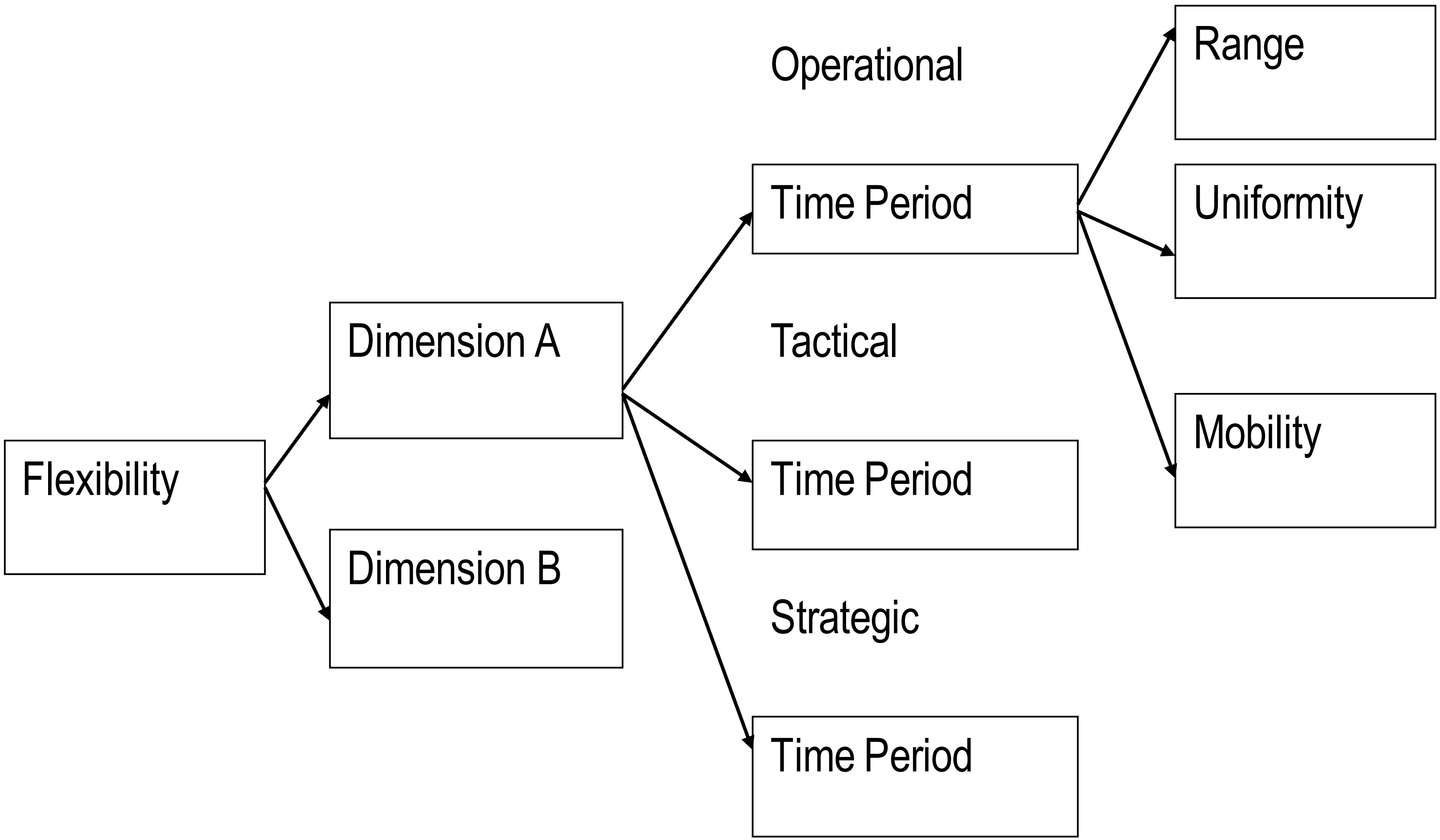
Flexibility and its elements

Elements	Indicators
Range	Number of options (operations, tasks, products)
Mobility	Transition penalties (time, cost and effort of transition)
Uniformity	Similarities of performance, outcomes (quality, cost, time), minimize deterioration.
Speed	Time of transition
Change	Time to respond quickly
Uncertainty	Product requirements, operational sequence,
Diversity	Variability, variety, complexity
Stimuli	Unplanned change

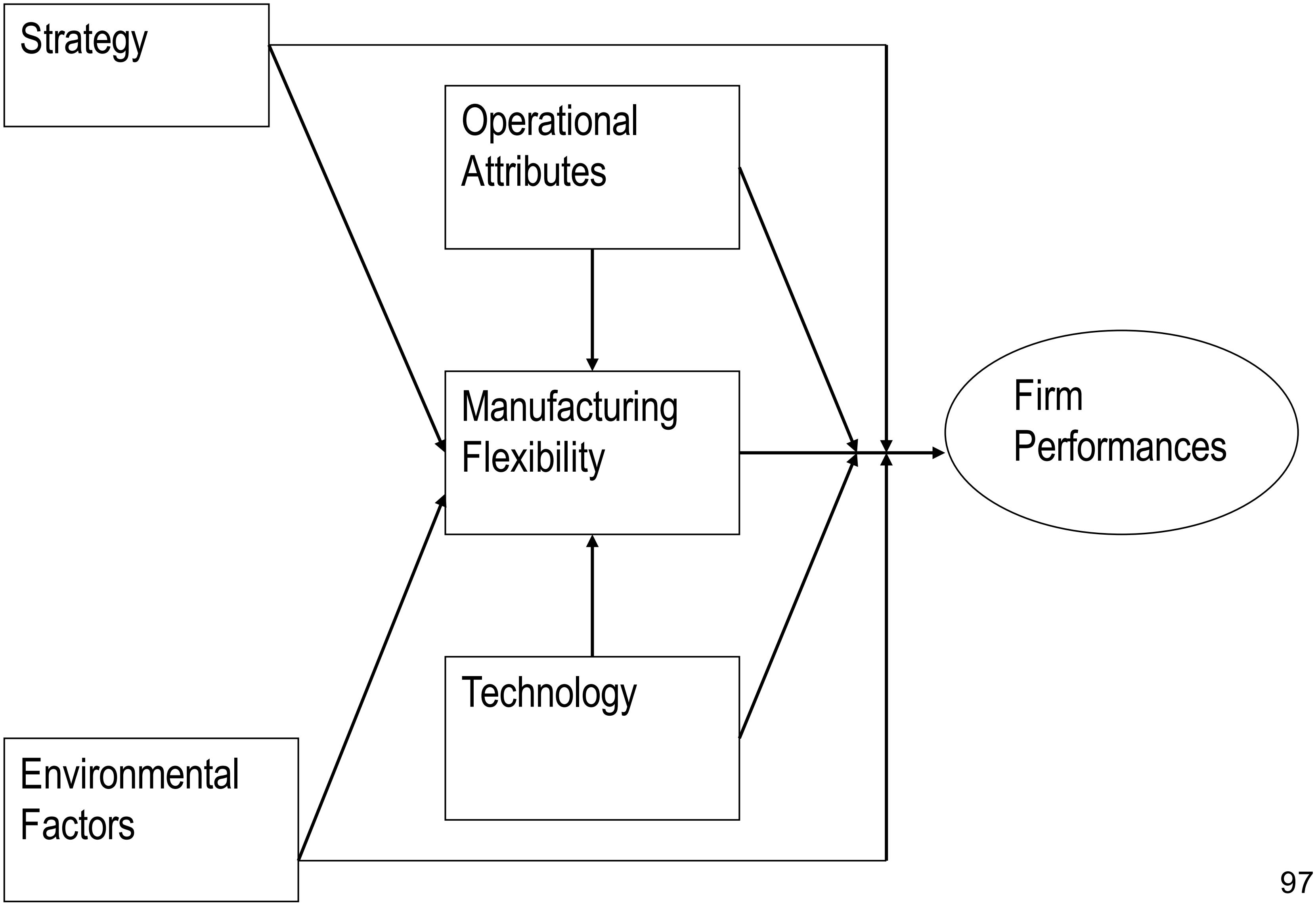


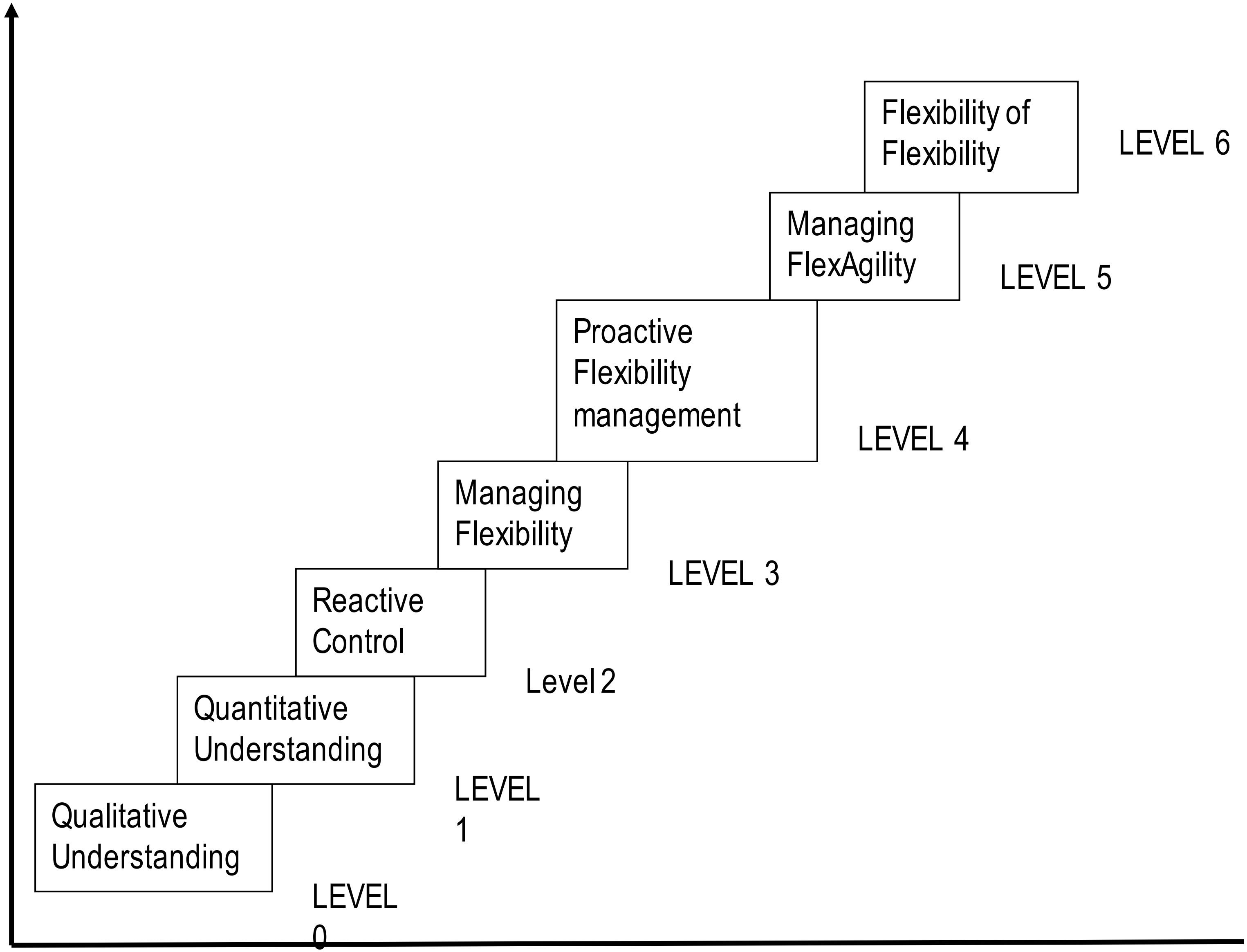
Manufacturing system levels and hierarchy of manufacturing flexibility types. Koste and Malhorta (1999)

Flexibility frameworks



Manufacturing flexibility's Conceptual framework





Flexibility Maturity Model Framework - Levels View

Levels	Explanation
Level 0 Qualitative Understanding	A state of being aware of the nature of flexibility and its relationship with systems' performance and changes in systems' environments
Level 1 Quantitative Understanding	A state of being able to identify and measure flexibility types & levels already available in the system and estimate their potential impact on systems performance.
Level 2 Reactive Control	A state of being able to exploit available flexibility in a reactive manner to sustain the systems performance.
Level 3 Managing Flexibility	A state of being able to plan and control the available flexibility to sustain systems performance.
Level 4 Proactive Flexibility Management	A state of being able to impact the flexibility requirement and its synchronization with available and exploited flexibility.
Level 5 Managing Flex Agility	This emphasizes the proactive management of flexibility towards agility.

FMS DESIGN AND OPERATIONAL ISSUES

FMS DESIGN ISSUES

1. **Workstation types**
2. **Variations in process routings and FMS layout (increasing product variety move you from in-line layouts to open field layouts)**
3. **Material handling system**
4. **Work in process (WIP) and storage capacity (FMS storage capacity must be compatible with WIP)**
5. **Tooling (numbers and types of tools at each station, tool duplication)**
6. **Workpiece monitoring (status of various systems)**
7. **Pallet fixtures (numbers in system, flexibility)**

FMS OPERATIONALISSUES

1. Scheduling (master production schedule) and dispatching (launching of parts into the system)
2. Machine loading
3. Part routing
4. Part grouping
5. Tool management
6. Pallet and fixture allocation

QUANTITATIVE ANALYSIS OF FLEXIBLE MANUFACTURING SYSTEM

Most of the design and operational problems can be addressed using quantitative analysis techniques.

FMS analysis techniques can be classified as follows:

- Deterministic models
- Queuing models
- Discrete event simulation
- Heuristics

To obtain starting estimates of system performance, **deterministic models** can be used.

Queuing models can be used to describe some of the dynamics not accounted for in deterministic approaches. These models are based on the mathematical theory of queues.

Discrete event simulations probably offer the most accurate method for modeling the specific aspects of a given FMS.

Bottleneck Model

Important aspects of FMS performance can be mathematically described by a deterministic model called bottleneck model.

It can be used to provide starting estimates of FMS design parameters such as production rate and number of workstations.

Features/terms and symbols for the bottleneck model

Part-Mix

The mix of the various part on product styles produced by the system is defined by $p_{j.}$

p_j is the function of the total system output that is of style j.

The sub-script j=1, 2, 3,…,p, where p = total number of different part of styles made in the FMS during the time period of interest. The value of p_j must sum to 1.

That is:

$$\sum_{j=1}^{p} p_j = 1 \qquad (1)$$

Workstations and servers

- FMS has number of different workstations **n**. each workstations may have more than one server, which simply means that it is possible to have two or more machine capable of performing the same operation.

- Let S_i = the number of servers at workstations i, where i=1,2,3,…,n.

- Load/Unload stations can be combined as one of the stations in FMS.

Process routing

Process routing defines the sequence of operations, the work stations at which they are performed, and the associated processing time.

Let

t_{ijk} = the processing time

i= refers to the station

j= part or product

k= sequence of operations in the process routing

FMS Operation parameters

Average workload

Average workload for a given station is defined as the mean total time spent at the station per part.

$$WL_i = \sum_i \sum_j \sum_k f_{ijk} \, t_{ijk} \, p_j \qquad (2)$$

WL_i = average workload for station i (min)

t_{ijk} = processing time for operation k in process plan j at station i (min)

f_{ijk} = operation frequency for operation k in part j at station i.

p_j = part mix fraction for part j.

The average number of transport is equal to the mean number of operations in the process routing minus one. That is

$$n_t = \sum_i \sum_j \sum_k f_{ijk}\, p_j \quad - 1 \qquad (3)$$

n_t = mean number of transport

The workload of the handling system is the mean transport time multiplied by the average number of transports required to complete the processing of a work part.

We are now in a position to compute the workload of the handling system

$$WL_{n+1} = n_t\, t_{n+1} \qquad (4)$$

WL_{n+1} = workload of the handling system

n_t = mean number of transporters

t_{n+1} = mean transport time per move

System Performance Measures

Important measures for assessing the performance of an FMS include:

1) Production rate of all parts
2) Production rate of each part style
3) Utilization of the different workstations
4) The number of busy servers at workstation

These measures can be calculated under the assumption that the FMS is producing at its maximum possible rate.

This rate is constrained by the bottleneck stations in the system, which is the station with the highest workload per server.

The workload per server is simply the ratio WL_i / S_I for each station.

Thus the bottleneck is identified by finding the maximum value of the ratio among all stations.

The comparison must include the handling systems, since it might be bottleneck in the system.

Let

WL^* , S^* and t^* equal the workload, number of servers, and processing time respectively, for the bottleneck station.

1.Maximum production rate of all parts

$$R_p^* = S^* / WL^* \qquad (5)$$

R_p^* = maximum production rate of all parts styles produced by the system, which is determined by the capacity by the bottleneck station (pc/min)

S^* = number of servers at the bottleneck stations

WL^* = workload at the bottleneck station (min/pc)

2. Part production rates

$$R_{pj}^{*} = p_j \left(R_p^{*}\right) \qquad (6)$$

$R_p^{*} = S^{*} / WL^{*}$

R_{pj}^{*} = maximum production rate of part style (pc/min)

p_j = part mix fraction for part j.

3. Utilization

The mean utilization of each workstation is the proportion of the time that the servers at the station are working and not idle. This can be computed as:

$$U_i = (WL_i / S_i)(R_p^*)$$
$$= (WL_i / S_i)(S^* / WL^*) \qquad (7)$$

U_i = Utilization of station i

WL_i = workload of station i (min/pc)

S_i = number of servers at station i

R_p^* = overall production rate (pc/min)

The Utilization of the bottleneck station is 100% at R_p^*.

4. Average station utilization

One simply computes average value for all stations, including the transport system. This can be calculated as follows:

$$U^* = \sum_{i=1}^{n+1} u_i \qquad (8)$$

U^* = an unweighted average of the workstation utilization

5. Overall FMS Utilization

This can be obtained using weighted average, where weighing is based on the number of servers at each station for the n regular stations in the system, and the transport system is omitted from the average. The overall FMS Utilization is calculated as follows:

$$U_s^* = \sum_{i=1}^{n} s_i U_i \Big/ \sum_{i=1}^{n} s_i \qquad (9)$$

U_s^* = overall FMS Utilization

S_i = number of servers at station i

U_i = Utilization of station i

6. Number of busy servers

All of the servers at the bottleneck station are busy at the maximum production rate, but the servers at the other stations are idle some of the time. The values can be calculated as follows:

$$BS_I = WL_I\,(R_P^*) \qquad (10)$$

BS_i = number of busy server on average at station i

WL_i = workload at station i

R_P^* = overall production rate (pc/min)

Problem 1

Consider a manufacturing system with two stations: (1) a load/unload station and (2) a machining station. There is just one part to processed through the production system, part A, so the part mix is fraction $p_{A.}$ The frequency of all operations is $f_{ijk} = 1$. The parts are loaded at station 1, routed to station 2 for machining, and then sent back to station 1 for unloading (three operations in the routing).

- Using equation $n_t = \sum_i \sum_j \sum_k f_{ijk} p_j - 1$

$n_t = 1(1.0) + 1(1.0) + 1(1.0) – 1 = 3-1=2$

Looking at it another way, the process routing is (1) $\longrightarrow$ (2) $\longrightarrow$ (1)

Counting the number of arrows gives us the number of transporters $n_t = 2$

Problem 2

- A flexible manufacturing system consists of two machining workstations and a load/unload station.
- Station 1 is the load/unload station.
- Station 2 performs milling operation and consists of two servers.
- Station 3 has one server that performs drilling operation.
- The stations are connected by a part handling system that has four work carriers. The mean transport time is 3 min.
- The FMS produces parts A and B.
- The part mix fractions and process routing for the two parts are presented in the given table.
- The operation frequency f_{ijk} = 1 for all operations.

Determine:

1. Maximum production rate of FMS.
2. Corresponding production rates of each product.
3. Utilization of each station.
4. Number of busy servers at each station.

Part j	Part Mix p_j	Operation k	Description	Station i	Processing time t_{ijk} (min)
A	0.4	1	Load	1	4
		2	Mill	2	30
		3	Drill	3	10
		4	Unload	1	2
B	0.6	1	Load	1	4
		2	Mill	2	40
		3	Drill	3	15
		4	Unload	1	2

(a) To compute the FMS production rate, we first need to compute workloads at each station so that the bottleneck station can be identified.

Using Equation $WL_i = \sum_i \sum_j \sum_k f_{ijk} t_{ijk} p_j$

WL1 = (1.0)(4+2)(0.4) + (1.0)(4+2)(0.6) = 6 min.
WL2 = (1.0) 30(0.4) + (1.0) 40 (0.6) = 36.0 min.
WL3 = (1.0) 10 (0.4) + (1.0) 15 (0.6) = 13 min.

Number of transports needed

Station 1 = 0.4x1+0.6x1=1
Station 2 = 0.4x1+0.6x1=1
Station 3 = 0.4x1+0.6x1=1
Station 4 = 0.4x1+0.6x1=1

$$n_t = \sum_i \sum_j \sum_k f_{ijk} p_j - 1$$

= 4-1=3

The station routing for both parts is the same

$1 \longrightarrow 2 \longrightarrow 3 \longrightarrow 1$

There are three moves,
Therefore nt = 3

$WL_{n+1} = n_t \, t_{n+1}$

WL4 = 3 (3.0) = 9 min.

The bottleneck station is identified by finding the largest WL_i / S_i ratio.

For station 1, $WL_1 / S_1 = 6.0/1 = 6.0$ min.

For station 2, $WL_2 / S_2 = 36.0/ 2 = 18.0$ min.

For station 3, $WL_3 / S_3 = 13.0/1 = 13.0$ min.

For station 4, the part handling system WL_4/S_4

$= 9.0/4 = 2.25$ min.

The maximum ratio occurs at station 2, so it is the bottleneck station that determines the maximum production rate of all parts made by the system.

$R^*_p = S^*/WL^* = 2/36.0 = 0.05555$ pc/min $= 3.333$ pc/hr

(b) To determine production rate of each product multiply R^*p by its respective part mix fraction.

- R^*_{pA} = 3.333 (0.40) = 1.333 pc/hr
- R^*_{pB} = 3.333 (0.60) = 2.00 pc/hr

(c) The utilization of each station can be computed by using equation 7.

$U_i = (WL_i / S_i)(R_p^*) = (WL_i / S_i)(S^* / WL^*)$

$U_1 = (6.0/1)(0.05555) = 0.333$ (33.3%)

$U_2 = (36.0/2)(0.05555) = 1.0$ (100%)

$U_3 = (13.0/1)(0.05555) = 0.722$ (72.2%)

$U_4 = (9.0/4)(0.05555) = 0.125$ (12.5%)

(d) Mean number of busy servers at each station is determined using equation 10.

$BS_I = WL_I\,(R_P^*)$

$BS_1 = 6.0\ (0.05555) = 0.333$

$BS_2 = 36.0\ (0.05555) = 2.0$

$BS_3 = 13.0\ (0.05555) = 0.722$

$BS_4 = 9.0\ (0.05555) = 0.50$

Problem 3:

An FMS consists of four stations. Station 1 is load/unload station with one server. Station 2 performs turning operations with three servers (three identical CNC turning machines). Station 3 performs drilling operations with two servers (two identical CNC drilling machines). Station 4 is an inspection station with one server that performs inspections on a sampling of parts. The stations are connected by part handling system that has two work carriers and whose mean transport time = 4.0 minutes. The FMS produces four parts A, B, C, and D.

The part mix fractions and process routings of the four parts are presented in the table below. The operation frequency at the inspection station (f_{4jk}) is less than 1 to account for the fact that only a fraction of the parts are inspected.

Determine:

(a) maximum production rate of the FMS,

(b) corresponding production rate of each part,

(c) utilization of each station in the system, and

(d) the overall FMS utilization.

Part j	Part Mix p_i	Operation k	Description	Station i	Process Time t_{ijk} (min)	Frequency f_{ijk}
A	0.1	1	Load	1	4	1.0
		2	Turn	2	20	1.0
		3	Drill	3	15	1.0
		4	Inspect	4	10	0.8
		5	Unload	1	2	1.0
B	0.2	1	Load	1	4	1.0
		2	Drill	3	20	1.0
		3	Turn	2	30	1.0
		4	Drill	3	08	1.0
		5	Inspect	4	5	0.4
		6	Unload	1	2	1.0
C	0.3	1	Load	1	4	1.0
		2	Drill	3	16	1.0
		3	Inspect	4	8	0.5
		4	Unload	1	2	1.0
D	0.4	1	Load	1	4	1.0
		2	Turn	2	15	1.0
		3	Inspect	4	12	0.5
		4	Unload	1	2	1.0

EXTENDED BOTTLENECK MODEL

- The bottleneck model assumes that the bottleneck station is utilized 100% and that there are no delays in the system due to queue.
- This implies on one hand there are a sufficient number of parts in the system to avoid starving of workstations and on the other hand that there will be no delay due to queuing.
- The extended bottleneck model assumes a close queuing network in which there are always a certain number of workparts in the FMS.
- Let **N**= the number of parts in the system
- When one part is completed and exits the FMS, a new raw workpart immediately enter the system, so that **N** remains constant.

1. If **N** is small (say much smaller than the number of workstations), then some of the stations will be idle due to starving, sometimes even the bottleneck station. In this case, the production rate of the FMS will be less than

$$R_p^* = S^* / WL^*$$

2. If **N** is large (say much larger than the number of workstations), then the system will be fully loaded, with the queues of parts waiting in front of the stations. In this case, R_p^* will provide a good estimates of the production capacity. However, **WIP** will be high , and manufacturing lead time **(MLT)** will be long.

- In effect, WIP corresponds to N, and MLT is the sum of processing times at all workstations, transport times between stations, and any waiting time experienced by the parts in the system.

$$MLT = \sum_{i=1}^{n} WL_i + WL_{n+1} + T_w \qquad (11)$$

Where

WL_i = summation of average workloads overall stations in the FMS (min)

WL_{n+1} = workload of the part handling system (min)

T_w = mean waiting time by a part due to queues at the station (min)

- **WIP** (that is **N**) and **MLT** are correlated.
  - If **N** is small, then **MLT** will take on its smallest possible value because waiting time will be short (zero),
  - If **N** is large, then **MLT** will be long and there will be waiting time in the system.
- Thus we have two alternative cases that must be distinguished and adjustment must be made in the bottleneck model to account for them.
- **LITTLE'S FORMULA** for queuing theory can take care of the above two cases.
- Little's formula can be expressed as follows:

$$N = R_P\,(MLT) \qquad (12)$$

Where N= number of parts in the system

R_P = production rate of the system (pc/min)

MLT= manufacturing lead time

Now let us examine the two cases:

Case 1: When N is small, production rate is less than in the bottleneck case because the bottleneck station is not fully utilized. In this case, the waiting time T of a unit is (theoretically) zero, and equation (11) reduces to

$$MLT_1 = \sum_{i=1}^{n} WL_i + WL_{n+1} \qquad (13)$$

Production rate can be estimated by using Little's formula

$$R_p = N / MLT_1 \qquad (14)$$

and production rates of individual parts are given by

$$R_{pj} = p_j R_p \qquad (15)$$

As indicated waiting time is assumed to be zero, $T_w = 0$ (16)

Case 2: When N is large, the estimate of maximum production rate provided by equation 5 should be valid. It is restated here: $R_p^* = S^* / WL^*$ **(5)**

The production rate of the individual products are given by

$$R_{pj}^* = p_j R_p^* \qquad (17)$$

In this case, average manufacturing lead time is evaluated using Little's formula $MLT_2 = N/R_p^*$ **(18)**

The mean waiting time a part spends in the system can be estimated by rearranging equation (11) to solve for T_w

$$T_w = MLT_2 - \left(\sum_{i=1}^{n} WL_i + WL_{n+1}\right) \qquad (19)$$

The decision whether to use Case 1 or Case 2 depends on the value of N. The dividing line between Case 1 and Case 2 is determined by whether N is greater than or less than critical value given by the following:

$$N^* = R_p^* \left(\sum_{i=1}^{n} WL_i + WL_{n+1}\right) \qquad (20)$$

$$N^* = R_p^* (MLT_1) \qquad (21)$$

Where **N^*** = critical value of N, the dividing line between the bottleneck and non-bottleneck cases.

If **$N < N^*$** , then Case 1 applies.

If **$N > N^*$** , then Case 2 applies.

For previous example compute production rate, manufacturing lead time, and waiting time for three values of N.

a) N=2; b) N=3; and c) N= 4

From previous example

R^*p = 0.05555 pc/min = 3.333 pc/hr

$$\mathbf{MLT_1 = \sum_{i=1}^{n} WL_i + WL_{n+1}}$$

$$= WL_1 + WL_2 + WL_3 + WL_4$$

$$= 6+36+13+9 = 64 \text{ min}$$

Critical value on N is given by equation (20)

$N^* = R_p{}^* (MLT_1)$

$= 0.5555 * 64 = 3.584 = 4$

a) N=2 is less than the critical value, so we apply the equation of case 1.

i) Production rate $R_p = N / MLT_1 = 2/64 = 0.03125$ pc/min

$= 1.875$ pc/hr

ii) $MLT_1 =$ 64 min

iii) $T_w = 0$

b) N=3 is again less than the critical value, so we apply the equation of case 1.

i) Production rate R_p = N/ MLT_1 = 3/64 = 0.0469 pc/min

= 2.813 pc/hr

ii) MLT_1 = 64 min

iii) T_w = 0

c) N=4, Case 2 applies since $N > N^*$.

i) Production rate $R_p^* = S^* / WL^*$ = 0.5555 pc/min

= 3.33 pc/hr

ii) $MLT_2 = N / R_p^* = 4/0.5555 = 72$ min

iii) $T_w = MLT_2 - MLT_1 = 72 - 64 = 8$ min

Sizing the FMS

- The bottleneck model can be used to calculate the number of servers required at each workstation to achieve a specified production rate.
- Such calculations would be useful during the initial stages of FMS design in determining the size (number of workstation and servers) of the system.
- The starting information needed to make the computation consists of part mix, process routing, and processing time so that workloads can be calculated for each of the stations to be included in the FMS.
- Given the workloads, the number of servers at each station "i" is determined as follows:

S_i = minimum integer >= R_p (WL_i)   (22)

Where

S_i = number of servers at station "i"

R_p = specified production rate of all parts to be produced by the system

WL_i = workload at station "i" (min)

Determine how many servers at each station “i” will be required to achieve annual production rate of 60000 parts/year. FMS will operate 24hr/day, 5 days/week, 50 week/year. Anticipated availability of the system is 95%.

Suppose:

WL_1 = 6 min; WL_2 = 19 min; WL_3 = 14.4 min; WL_4 = 4 min; WL_5 = 10.06 min.

The number of hours of FMS operation will be

24*5*50=6000 hr/year

Taking into account the anticipated system availability, the average hourly production can be given by:

R_p^* = 60000/(6000 * 0.95) = 10.526 pc/hr

= 0.1754 pc/min

Now:

S_1 = 0.1754 * 6= 1.053= 2 servers

S_2 = 0.1754 * 19 = 3.333= 4 servers

S_3 = 0.1754 * 14.4 = 2.523 = 3 servers

S_4 = 0.1754 * 4 = 0.702 = 1 server

S_5 = 0.1754 * 10.96 = 1.765 = 2 servers

Because the number of servers at each workstations must be an integer, station utilization may be less than 100% for most if not all of the stations.

- The bottleneck station in the system is identified as the station with the highest utilization, and if that utilization is less than 100%, the maximum production rate of the system can be increased until U^* = 1.0.
- For this example determine a) the utilization for each station and b) the maximum possible production rate at each station if the utilization of the bottleneck station were increased to 100%.
- a) The utilization at each workstation is determined as the calculate value of S_i divide by the resulting integer value >= S_i.
- U_1 = 1.053/2 = 0.426 = 42.6%
- U_2 = 3.333/4= 0.833 = 83.3%

- U_3 = 2.526/3 = 0.842 = 84.2%
- U_4 = 0.702/1 = 0.702 = 70.2%
- U_5 = 1.765/2 = 0.883 = 88.3%

- The maximum value is at station 5, the work transport system. This is the bottleneck station.
- b) The maximum production rate of the FMS, as limited by the bottleneck station is

$R^*p = Rp / U_5$ = (10.526 pc/hr)/ 0.883= 11.93 pc/hr

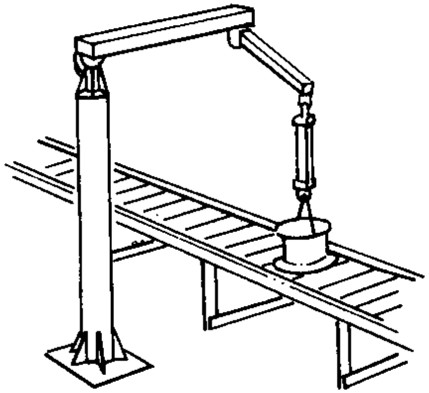
= 0.1988 pc/min

The corresponding utilization is $U^* = U_5$

$= (WL_5 / S_5)\, R_p^*)$

= 0.1988 * (10.06/2) = 100%

MATERIAL HANDLING SYSTEM



Material Handling

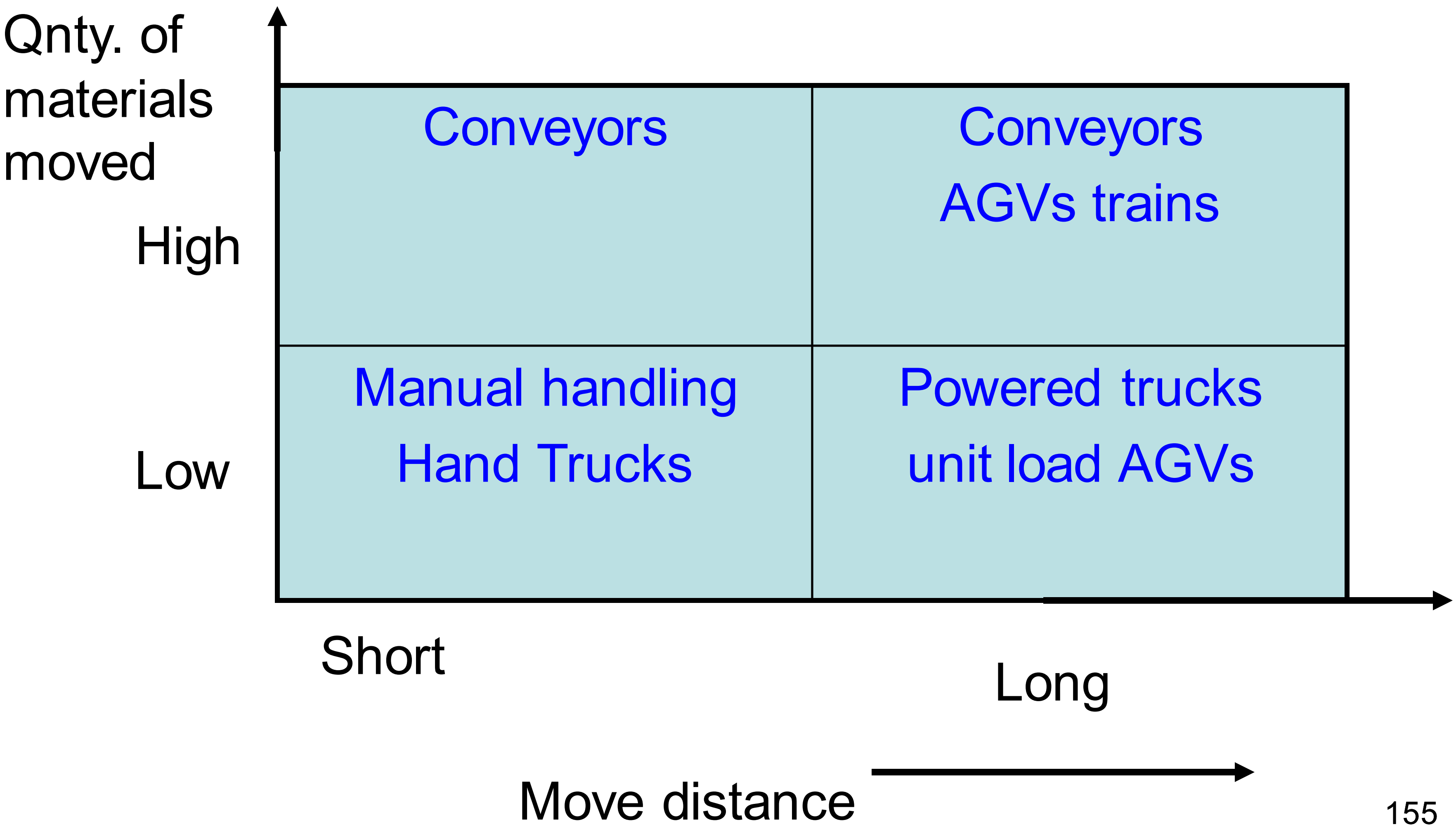
Material handling is defined as the movement storage, protection and control of materials throughout the manufacturing and distribution process including their consumption and disposal.

- Material handling equipment include:
  - i) Transport equipment
  - ii) Storage system
  - iii) Unitizing equipment
  - iv) Identification and tracking systems

i) Material Transport Equipment

- a) Industrial trucks
- b) Automated guided vehicles
- c) Monorails and other guided vehicles
- d) Conveyors
- e) Cranes and hoists

General types of material transport equipment as a function of material quantity and distance moved



Features and application of five categories of MH equipment

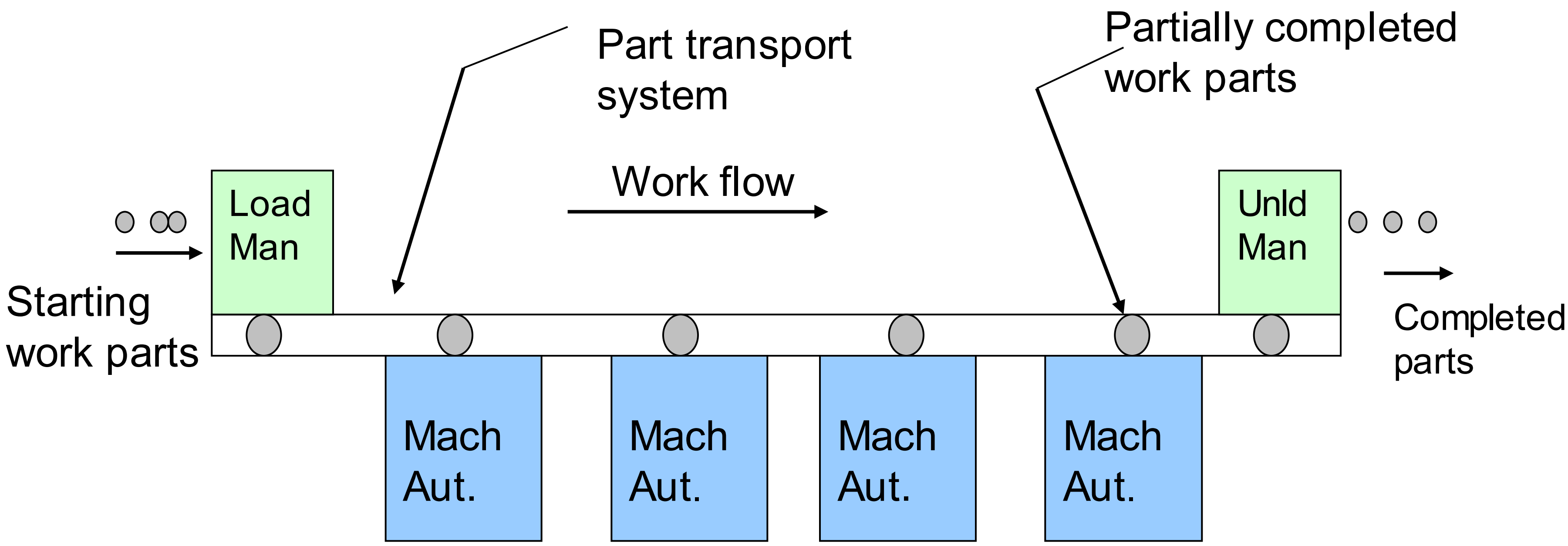
MH equipment	Features	Applications
Industrial trucks, manual/ powered	Low cost/medium cost, low rate of deliveries/hr	Moving light loads in the factiry
AGVs system	High cost, battery powered vehicles, flexible routing, non obstructive pathways	Moving pallets loads in the factory, moving WIP along variable routes in low and medium production
Monorails and otter guided vehicles	High cost, flexible routing, on the flow or over head types	Moving single assemblies, products or pallets loading along variable routes in factory or warehouse, moving large quantities of items over fixed routes etc.

MH equipment	Features	Applications
Conveyors	Greater variety of equipment, in-floor, on-floor or overhead. Mechanical power to move loads , reside in the pathway	Moving products along a manual assembly line
Cranes and hoists	Lift capacities ranging up to more than 100 tons	Moving large heavy items, in factories etc.

Material Handling Systems (MHS) in FMS

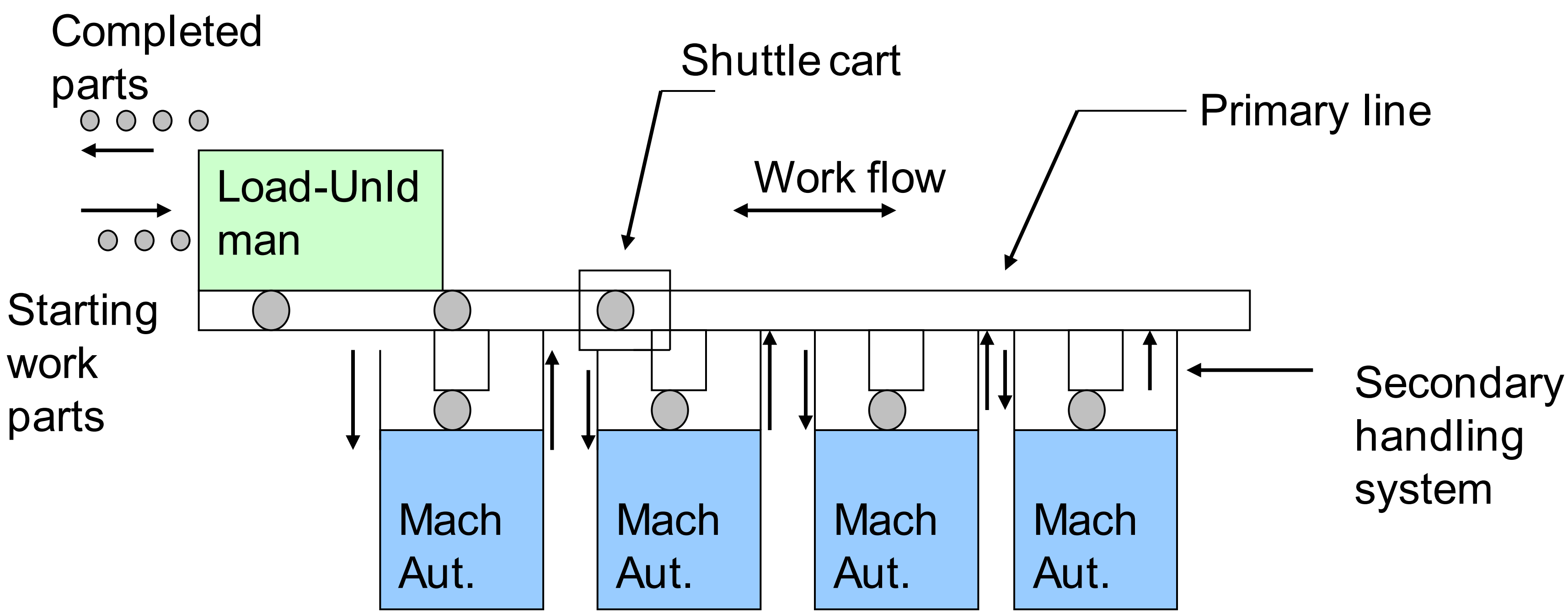
- Allow Dynamic Routing under Computer Control
- Operate in various configurations (In Line, Off Line)
- Integration with Storage Systems (Buffers, AS/RS)
- Convenient Access for Loading/Unloading of Parts
- Integration of primary and secondary MHS
- Examples (FMS): AGV, Conveyor, Robots etc
- Various Types of FMS Layouts Are Used.

Various Types of FMS Layouts



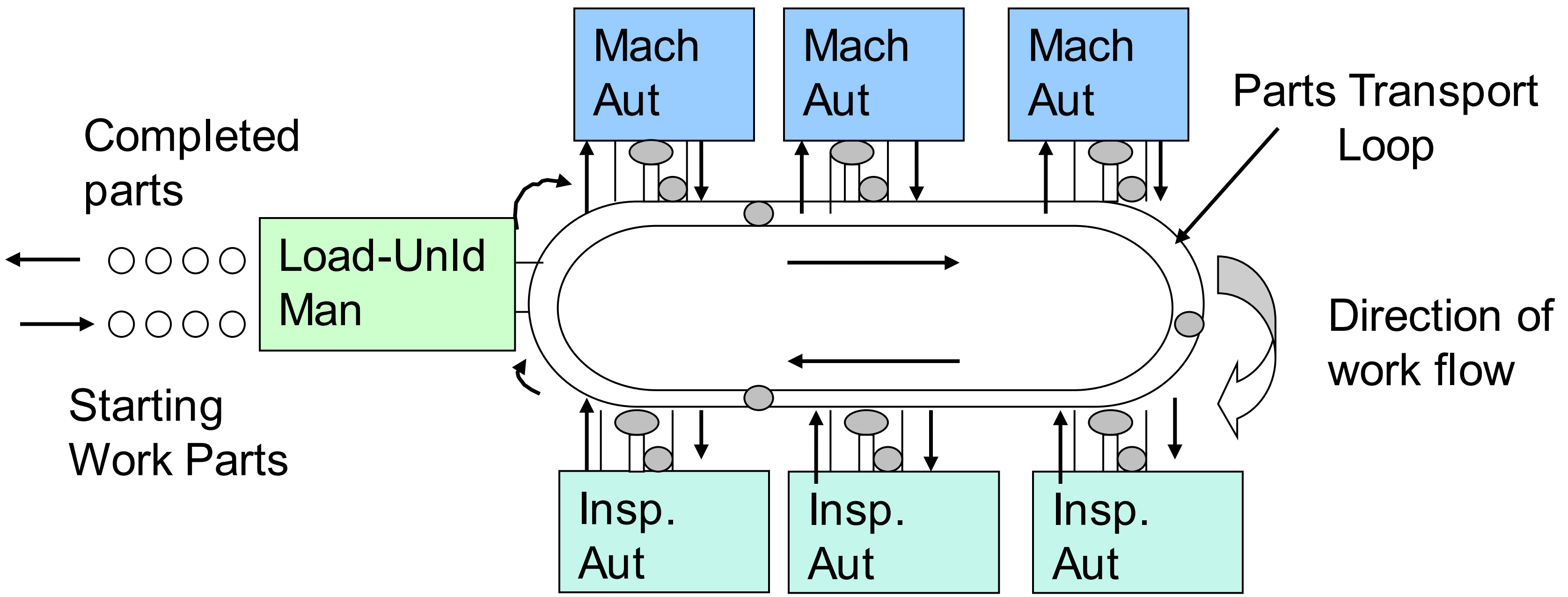
In-line FMS layouts: one directional flow similar to a transfer line.

Key: Load =parts loading station, UnLd =parts unloading station, Mach= maching station ,Man=manual station, Aut = automated station.

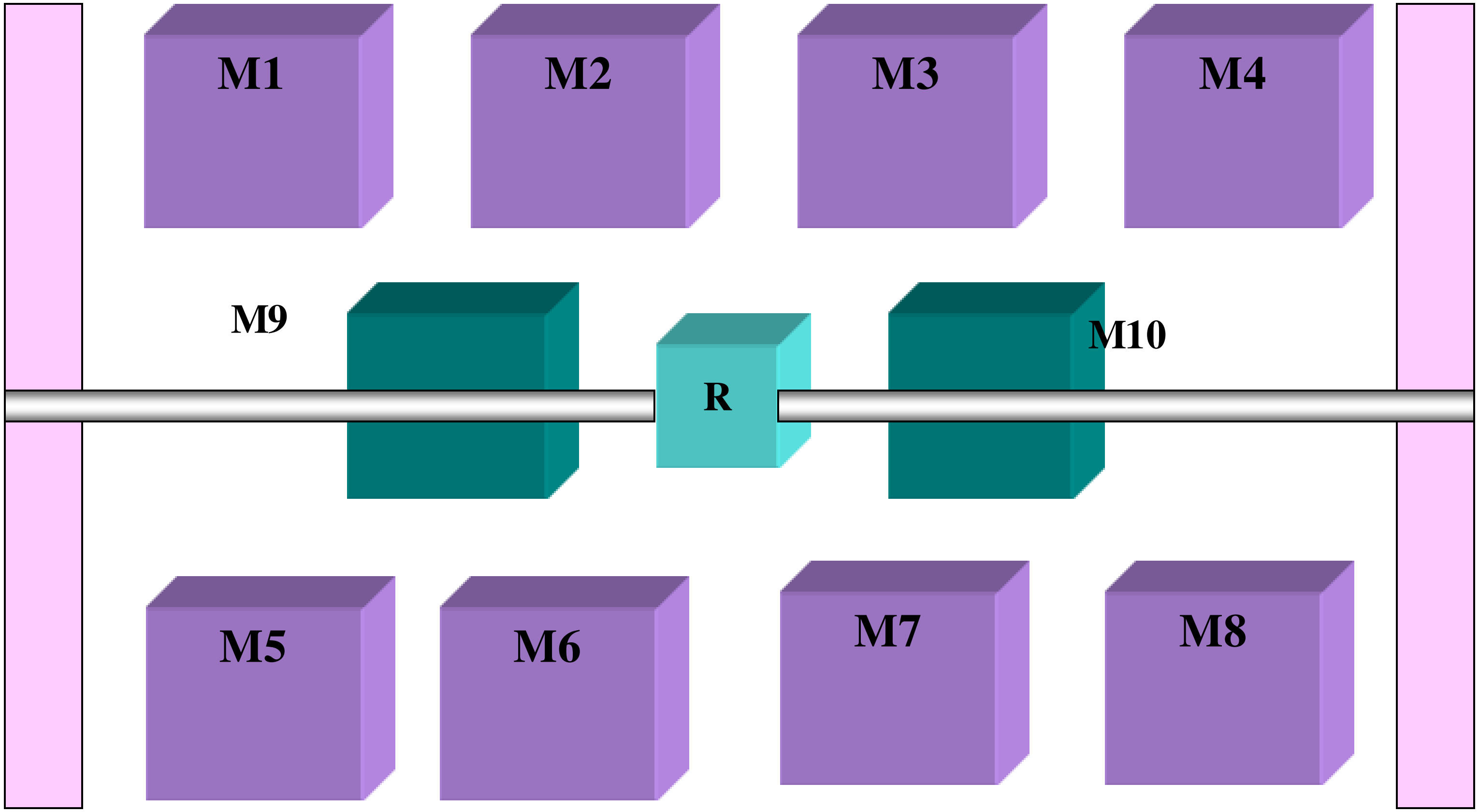


In-line FMS layouts: Each station to facilitate flow in two directions .

Key: Load =parts loading station, UnLd =parts unloading station, Mach= machining station ,Man=manual station, Aut = automated station.



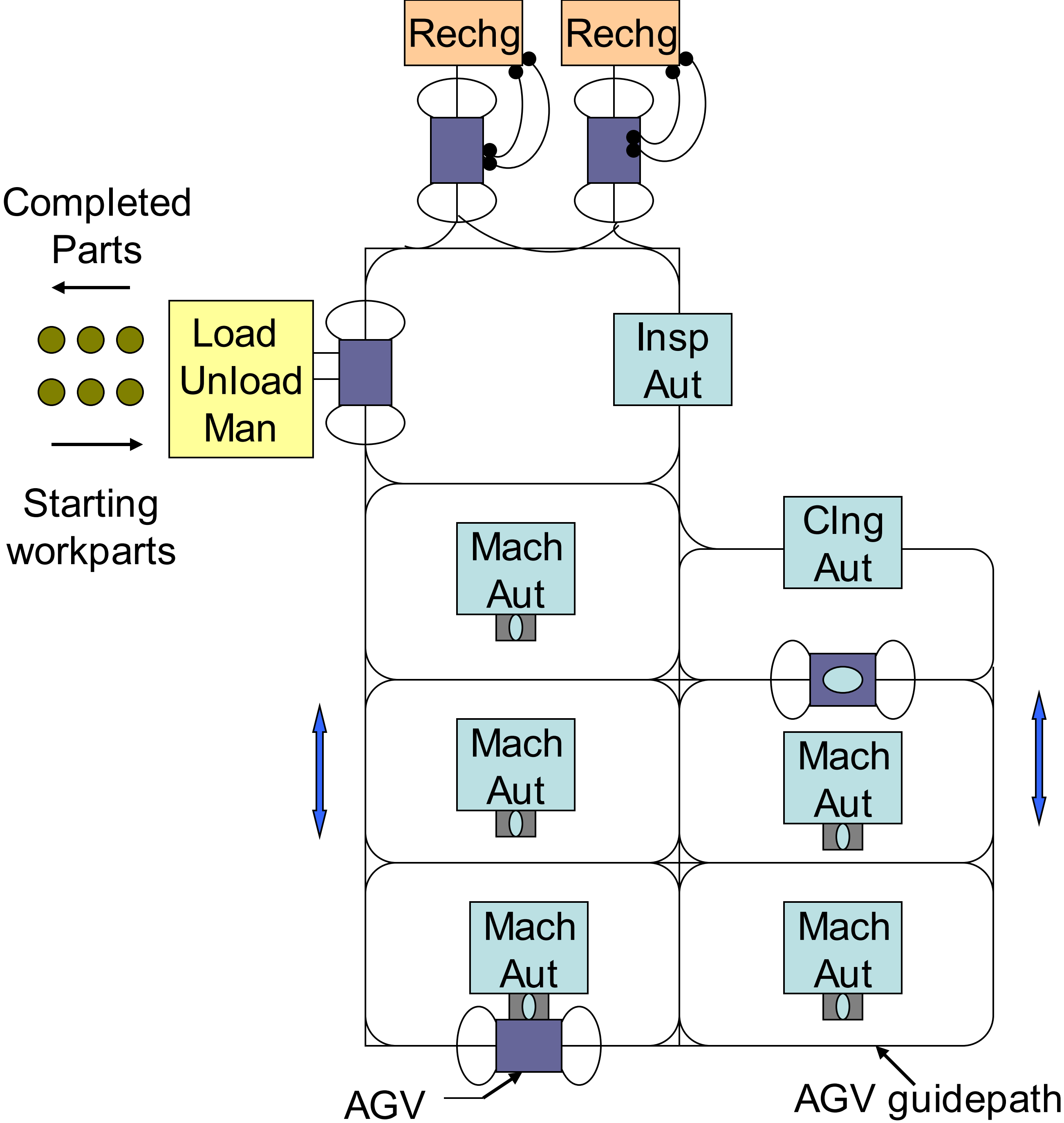
FMS **loop layout** with secondary part handling system at each station to allow unobstructed flow on loop



Gantry Robot Based Cluster Layout

M = Machine

R = Robot



Ladder type FMS layout

Keys:
Load=parts loading
UnLd=parts unloading
Mach=machining
Clng=cleaning
Insp=inspection
Man=manual
Aut=automated
AGV=automated guided Vehicle
Rechg=battery recharging Station for AGVs

Material Handling Equipment typically Used as the primary Handling System for the Five FMS Layouts

Layout configuration	Material Handling System
In-Line layout	In-line transfer system Conveyor system Rail Guided Vehicle system
Loop layout	Conveyor system In-floor towline carts
Ladder layout	Conveyor system Automated Guided Vehicle System Rail guided vehicle system
Open Field layout	Automated Guided Vehicle System In-floor towline carts
Robot-centered layout	Industrial robot

Automated Guided Vehicles System

1954: The first AGV was operated.

1973: Volvo, the Swedish car maker, developed AGV to serve as assembly platforms for moving car bodies through its final assembly plants.

An automated guided vehicles system is a material handling system that use independent operated, self propelled vehicles guided along defined pathways. The vehicles are powered by on board batteries that allow many hours of operation(8-16 hr) between recharging.

AGVs

- An AGVs is appropriate where different materials are moved from various load points to various unload points. An AGVs is therefore suitable for automating material handling in batch production and mixed modal production.
- One of the major application area of AGVs in **FMS.**

Advantages of an AGVs

- Clear floor space
- No floor deck construction
- Simple installation
- High availability/reliability
- Flexible performance
- Short installation times
- Simple expansion

Quantitative analysis of AGVs system

Delivery cycle time consists of:

- i) loading at the pickup station
- ii) travel time to the drop-off station
- iii) unloading at the drop-off station
- iv) empty travel time of the vehicle between deliveries.

Total cycle time per delivery per vehicle is given by:

$$T_c = T_l + L_d / V_c + T_v + L_e / V_e$$

where:

T_c : delivery cycle time (min/del)
T_l : time to load at a load station (min)
L_d : distance the vehicle travels between load and unload station (m)
V_c : carrier velocity (m/min)
T_v : time to unload at unload station (min)
L_e : distance the vehicle travels empty until the start of the next delivery cycle (m)
V_e : empty velocity (m/min)

T_c is used to determine certain parameters such as:

i) rate of deliveries per vehicle

ii) number of vehicles required to satisfy a specific total delivery requirement

The hourly rate of deliveries per vehicle is 60 min divided by the delivery cycle time T_c adjusted for any time losses during the hour.

The possible time losses include:

i) Availability

ii) Traffic congestion

iii) Efficiency of the manual driver, in case of manual operated trucks

Let:

- **A= Availability**
  Is a reliability factor defined as the proportion of total shift time that the vehicle is operational and not broken down or being repaired.

- **T_f= Traffic factor**
  Traffic factor is defined as parameter for estimating the effect of these losses on system performance. Typical values of traffic factor for an AGV ranges between 0.85 to 1.0.

- **E= Efficiency**
  It is defined as actual work rate of the human operator relative to the work rate expected under standard normal performance

With these factors defined we can now explain the available time per hour per vehicle as 60 min adjusted by A, T_f and E.

$$AT=60\ A\ T_f\ E$$

where:

AT= Available time (min/hr per vehicle)

A= Availability

T_f = Traffic factor

E = Human efficiency

The rate of deliveries per vehicle is given by:

$$R_{dv} = AT / T_c$$

where:

R_{dv} = hourly delivery per vehicle (del/hr per vehicle)

The total number of vehicles needed to satisfy a specified total delivery schedule R_f in the system can be estimated by first calculating the total workload required and then dividing by available time per vehicle.

Work load is defined as the total amount of work, expressed in terms of time, that must be accomplished by the material transport system in 1hour. This can be expressed by:

$$WL = R_f T_c$$

where:

WL=workload (min/hr)

R_f = specific flow rate of total delivery per hour for the system (del/hr)

T_c= delivery cycle time (min/del)

Now the number of vehicles required to accomplish this workload can be written as:

$$N_c = WL/AT$$

where:

N_c= number of carriers required

or

$$N_c = R_f / R_{dv}$$

Assumptions

i) vehicles operate at a constant velocity throughout the operation

ii) the effects of acceleration and de-acceleration and other speed difference are ignored

iii) traffic congestion is ignored

Problem

Given the AGVs layout as shown in the figure below.

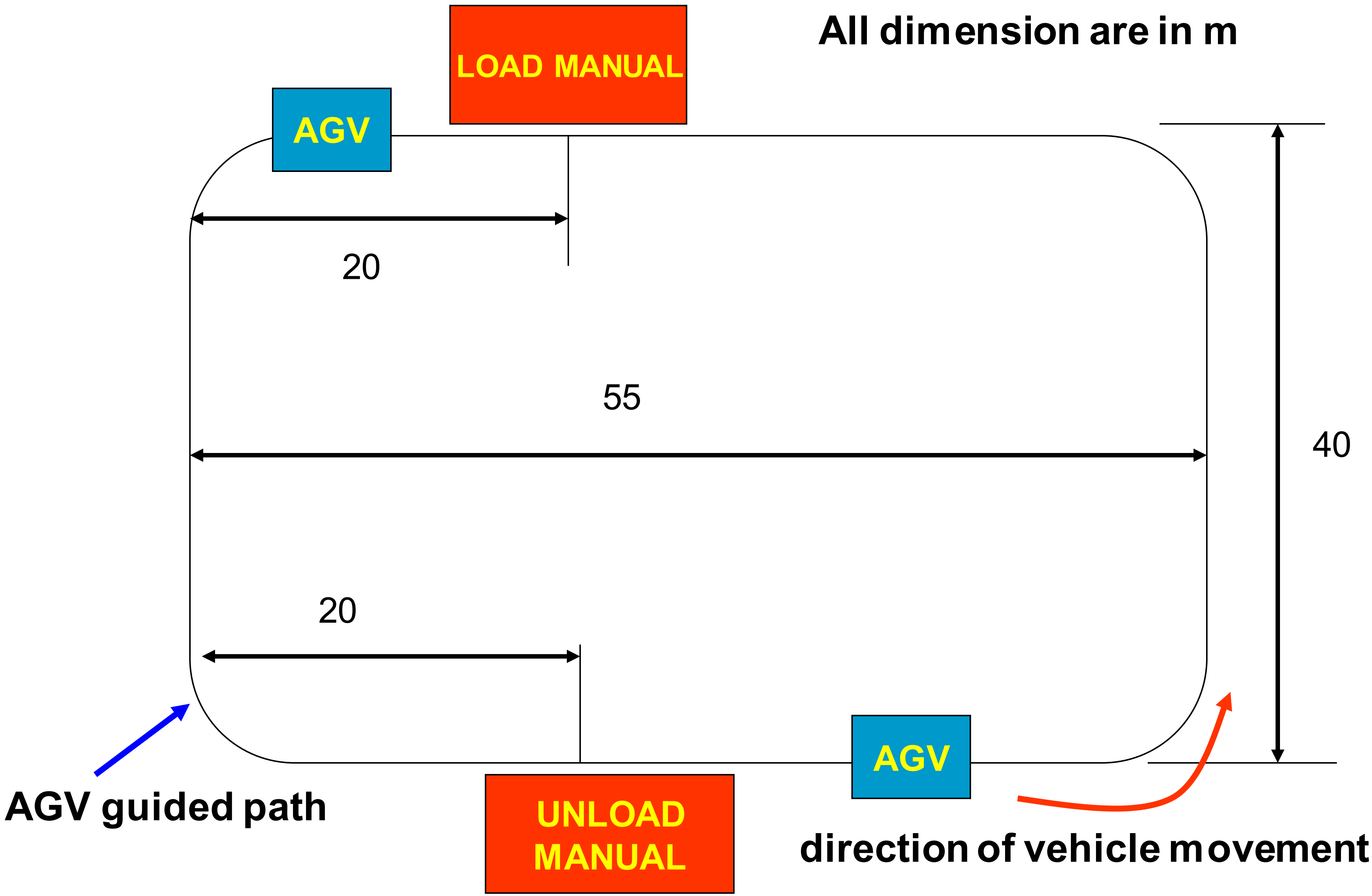
Vehicles travel counterclockwise the loop to deliver loads from the load station to unload station. Loading time at the load station is 0.75 min and unloading time at the unload station is 0.50 min. It is desired to determine how many vehicles are required to satisfy demand for this layout if a load of 40 del/hr must be completed by the AGVs. The following performance parameters are given as:

Vehicle velocity=50m/min

Availability=0.95

Operator efficiency=1.0

Traffic factor=0.90



All dimension are in m
LOAD MANUAL
AGV
20
55
40
20
AGV
AGV guided path
UNLOAD MANUAL
direction of vehicle movement

Determine:

i) travel distance loaded and empty

ii) ideal delivery cycle time

iii) number of vehicles required to satisfy the delivery demand

Solution:

i) Ignoring the effects of slightly shortened distance around the curve at corners of the loop the value of

L_d = 20+40+20)=80

L_e = (55-20)+40+(55-20)= 110 m

ii) Ideal cycle time per delivery per vehicle is given by

$T_c = T_l + L_d / V_c + T_v + L_e / V_e$

= 0.75+80/50+0.50+110/50

= 5.05 min

iii) T_c determines the number of vehicles required to make 40 del/hr, we compute the work load of the AGVs and the available time per hour per vehicle

$$R_f = 40 \text{del/hr}$$

$$WL = R_f T_c = 40 \times 5.05 = 202 \text{ min/hr}$$

$$AT = 60A T_f E$$
$$= 60 \times 0.95 \times 0.90 \times 1 = 51.3 \text{ min/hr per vehicle}$$

The number of vehicle required is

$$N_c = WL/AT = 202/51.3 = 3.94 \text{ vehicles or } 4 \text{ vehicles.}$$

SCHEDULING

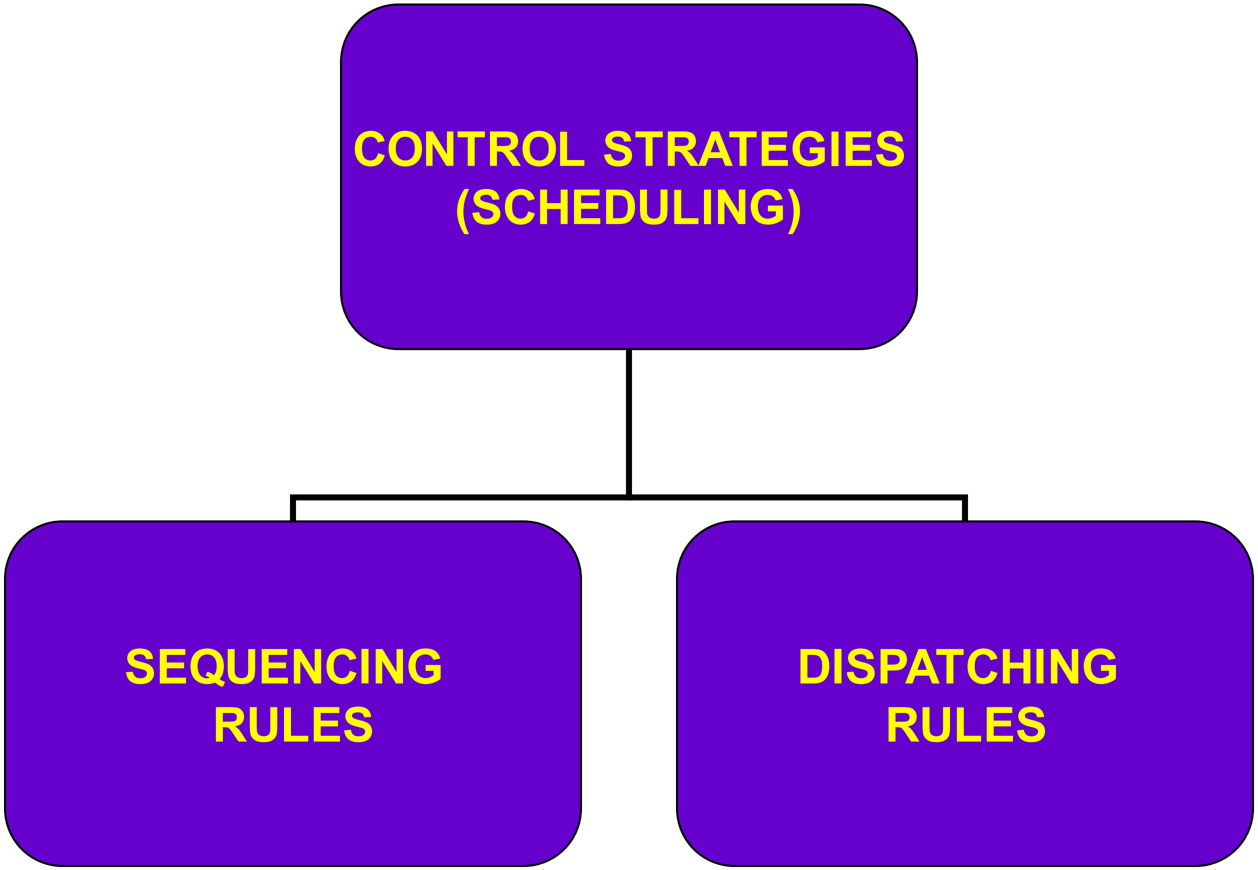
SCHEDULING

- Operations scheduling is concerned with problem of assigning specific jobs to specific work centers on a weekly, daily or hourly basis.

- The problems of scheduling is complicated by the fact that there may be hundreds or thousands of individual jobs competing for time on limited number of work centers.

- Scheduling are the control strategies being implemented in FMS.

SCHEDULING: CONTROL STRATEGIES



SEQUENCING

- Sequencing problems arise when we are concerned with situations where there is a choice as to the order in which a number of tasks can be performed.
- A sequencing problem could involve jobs in a manufacturing plant, aircraft waiting for landing and clearance, maintenance scheduling in a factory, programme to be run on a computer center, customer in a bank etc.
- We shall consider the sequencing problems in request of the jobs to be performed in a factory and study the method of their solution.

- Such sequencing problem can be broadly divided in two groups. In the first one, there are **'n'** jobs to be done each of which require processing on some or all the **'k'** different machines.
- We can determine the effectiveness of each of the sequence that are technologically feasible and chose a sequence which optimize the effectiveness.
- The second type of sequencing problem deal with the situation where we have a system with certain number of machine and a list of job to be done, and every time that a machine complete a job on which it is engaged, we have to decide on the next job to be started.

Three jobs 1,2 and 3 are to be produced on two machines M1 and M2 in the order M1, M2, for which the processing times are given below:

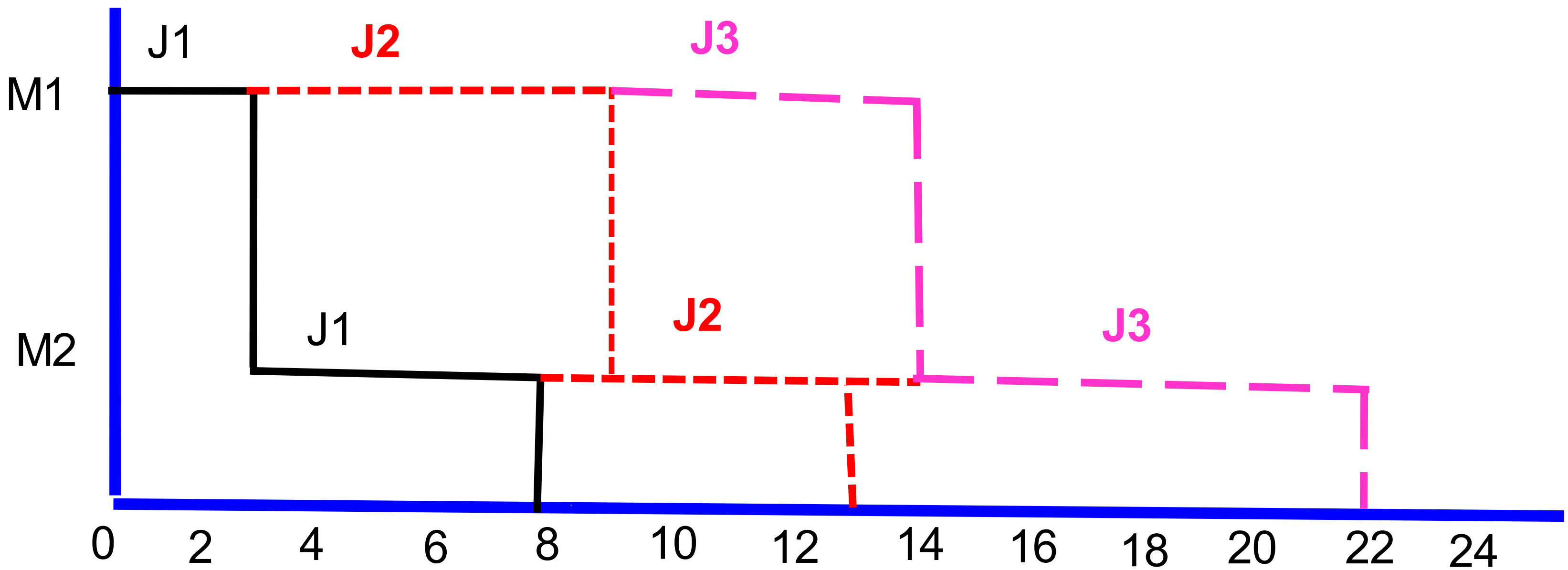
Job	Processing Time	
	M1	M2
1	3	5
2	6	4
3	5	8

In what sequence should the jobs be performed so that the elapsed time T, is the least?

When 3 jobs to be processed on two machines, we have six possible orders. These are 123, 132, 213, 231, 312, 321

For 123 T=22 min

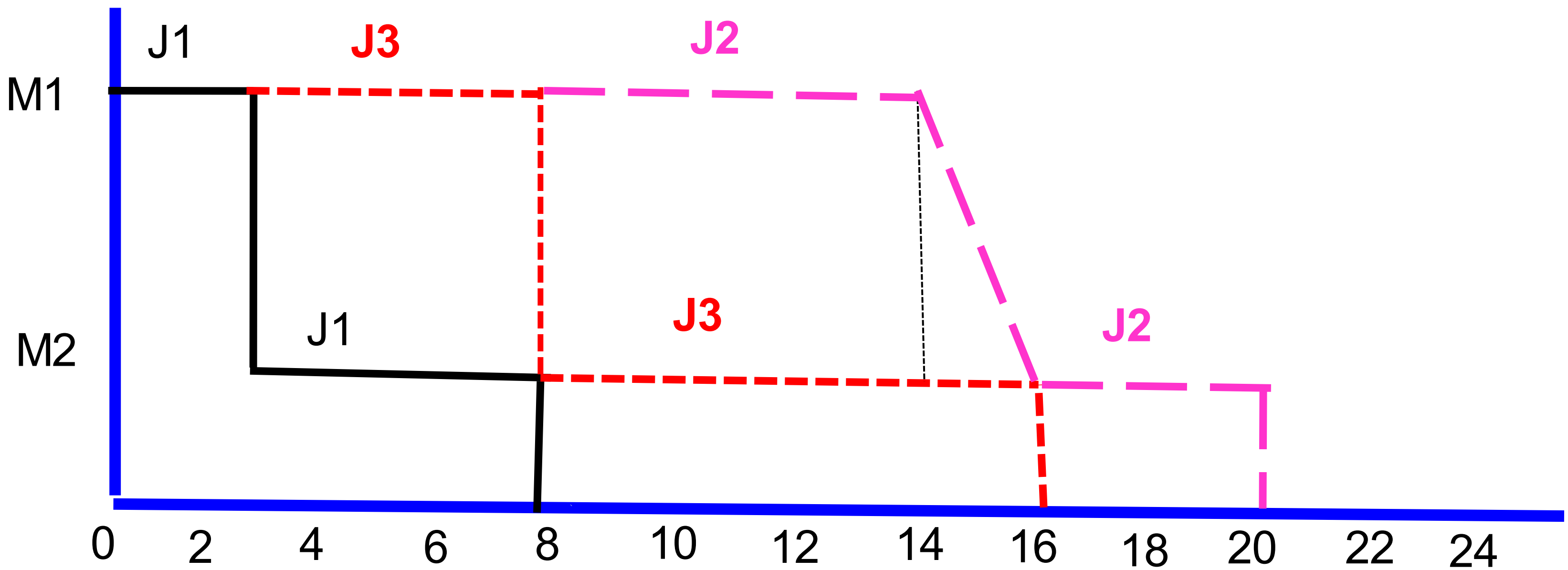
Gantt Chart:



When 3 jobs to be processed on two machines, we have six possible orders. These are 123, 132, 213, 231, 312, 321

Among the above six options 132 will give optimal solution.

Gantt Chart:



Algorithm for solving sequencing problems

The method shall be divided in respect of processing of 'n' jobs through (a) two machines, (b) three machines, and c) k machines.

Processing 'n' jobs through 2 machines

We have the following information:

a) Only two machines are involved

b) Each job is to be processed in the order AB so that first the work would be performed on Machine A and then on Machine B.

c) The processing time for different jobs on first machine A_l , A_2 …A_n are given and so are the processing time on the second machine B_l , B_2 …B_n .

With the objective to determine the sequence in which the job may be performed so that the total time taken is the minimum. We proceed as follows

Let:

A_I = time required by job 'I' on machine A

B_I = time required by job 'I' on machine B

T = total elapsed time for jobs 1,2,3,….n and

t_n = idle time on machine B, from end of the job i-1 to start of the job 1.

The objective is to determine the sequence **'S'** in which the **'n'** jobs may be performed so that 'T' is minimized. We know that the total elapsed time , T, is determined by the point of time at which the first job goes on machine A, and the point of time the last jobs comes off machine B.

At any moment of time , the machine B is either working or idle.

The total time for which the machine B has to work is

$$\sum_{i=1}^{n} Bi \qquad (1)$$

(which is determined by the given job times and has nothing to do with the sequence in which they are performed)

Thus,

$$T = \sum_{I=1}^{n} Bi + \sum_{i=1}^{n} ti \qquad (2)$$

Because the first of the term of RHS of equation (2) is a constant, the problem is to minimize the second of the terms, the total idle time on machine B

If D_n (S) equals total idle on machine B for sequence S, the problem is that of finding S^* of jobs (1,2,3…..n) such that $D_n(S^*) <= D_n(S_o)$ for any S_o . So optimal sequence is obtained by using the following rule

Job j precedes job j+1 if Min $(A_J , B_{j+1}) < $ Min (A_{j+1} , B_j)

Suppose

Jobs	Machines	
	M_A	M_B
J_1	4	10
J_2	8	7

Thus $A_1 = 4$; $B_1 = 10$, $A_2 = 8$; $B_2 = 7$

Here Min of A_1 , B_2 (= 4,7) is 4 and Min of A_2 , B_1 (= 8,10) is 8

Now, since Min of (A_1 , B_2) is less than Min of (A_2 , B_1), in this case , it is clear that job 1 should precede job 2. If this condition were not satisfied, job 2 would have preceded job 1.

Further, if Min (A_J , B_{j+1}) = Min (A_{j+1} , B_j) then job j would be indifferent to job j+1, any of them could precede the other.

This rule can be extended to find the optimal sequence of a set of given jobs. Starting with any sequence $S_{o,}$ the optimal sequence S^* can be obtained by successive interchange of consecutive jobs by applying this rule.

In operational terms, the algorithm can be stated in a stepwise manner as follows:

1. Select the smallest processing time, considering A_1 , A_2 , ...A_n and B_1 , B_2 , ...B_n .

2. (a) If the minimum is for A_r , that is to say for r^{th} job on machine A, do the r^{th} the first.

(b) If minimum is for B_s that is, for the s^{th} job on machine B, do the s^{th} the last.

(c) In case of a tie between A_r and B_s , perform the r^{th} job first and the s^{th} Job in the end.

(d) If there is a tie between 2 or machine in either of the series, select either of the jobs involved and perform the first or last accordingly as the tie is in A_1 , A_2 ,..A_n or B_1 , B_2 , ..B_n .

3. After the job (s) has been assigned, apply steps (1) and steps (2) to the reduced set of processing times obtained by deleting the machine time, corresponding to the job (s) already assigned.

4. Continue in this manner until all jobs are assigned. The sequence of jobs to be performed is obtained in this way shall be optimal, involving the least aggregate time for completion of the jobs.

Problem: In a factory, there are 6 jobs to perform, each of which should go through 2 machines A and B, in the order of AB, The processing times (hr) for the jobs are given below. You are required to determine the sequence for performing the jobs that would minimize the total elapsed time, T. What is the value of T?

Jobs	M_A	M_B
1	7	3
2	4	8
3	2	6
4	5	6
5	9	4
6	8	1

a) The least of all the times given in the table (1 hr) is for job 6 on machine B. So, perform job 6 in the end. Now delete this job from the given data.

b) Of all times now, the minimum is for job 3 on machine A (2 hr). So, do the job 3 first .

c) After deleting job 3 also, the smallest time of 3 hr is for job 1on machine B. Thus perform job 1 in the end before 6.

Jobs	M_A	M_B
1	7	3
2	4	8
3	2	6
4	5	6
5	9	4
6	8	1

3				1	6

d) Having assigned job 1, we observe that the smallest value of 4 hrs is shared by job 2 on machine A and job 5 on machine B. So, perform job 2 first and job 5 in the end before 1 and 6.

e) Now, the only remaining job is 4, it shall be assigned the only place left in the sequence. The resultant sequences

Jobs	M_A	M_B
1	7	3
2	4	8
3	2	6
4	5	6
5	9	4
6	8	1

3	2	4	5	1	6

The total time elapsed T is obtained as follow:

Job	Machine A		Machine B	
	In	Out	In	Out
3	0	2	2	8
2	2	6	8	16
4	6	11	16	22
5	11	20	22	26
1	20	27	27	30
6	27	35	35	36

Jobs	M_A	M_B
1	7	3
2	4	8
3	2	6
4	5	6
5	9	4
6	8	1

Job	Machine A	Machine B
1	7	4
2	8	2
3	10	6
4	3	6
5	7	5
6	4	7
7	5	2
8	8	6
9	5	7
10	6	6

Find the optimal sequence for machining 10 jobs on two machines AB. What is the total time elapsed?

Processing n jobs through 3 machines

No general solution is available for the sequencing problems processing n jobs through 3 machines. However, we do have a method applicable under the condition that no passing of jobs is permissible (that is to say, the same order over each machine is maintained) and if either or both the following conditions is/are satisfied.
For three machines A,B, and C on which some jobs are to be performed in the order ABC.

Condition 1: The minimum of the times for different jobs on Machine A is at least equal to the maximum of the times different jobs on Machine B.

Condition 2: The minimum of the times of various jobs on Machine C is at least equal to the maximum of times of the different jobs on Machine B.

If Min A_i , represent the least of the job times on the machine A, Min. C_i representing the least of the job times on machine C, and Max. B_i indicates the largest of the job times on Machine B), in this case , it is clear that job 1 should precede job 2. If this condition were not satisfied, job 2 would have preceded job 1.

Further, if Min (A_J , B_{j+1}) = Min (A_{j+1} , B_j) then job j would be indifferent to job j+1, any of them could precede the other.

The Method:

Step 1: Replace the given problem with an equivalent problem involving n jobs and 2 fictitious machines G and H, and define the corresponding processing times G_i and H_i , as follows:

$G_i = A_i + B_i$ (i = 1,2,………+n),

$H_i = B_i + C_i$ (i = 1,2,………+n)

Thus, for the job 1, $G_1 = A_1 + B_1$, $H_1 = B_1 + C_1$ for the job 2, $G_2 = A_2 + B_2$, $H_2 = B_2 + C_2$ …. and so on.

Step 2: To the problem obtained in step 1 apply the method discussed for processing n jobs through 2 machines. The optimal sequence resulting from this shall also be optimal for the given original problem.

Problem: You are given the following data regarding the processing some jobs on three machines I, II, and III. The order of processing is I-II-III. Determine the sequence that minimizes the total elapsed time (T) required to complete the jobs. Also evaluate T and idle time of I and II.

Jobs	I	II	III
A	3	4	6
B	8	3	7
C	7	2	5
D	4	5	11
E	9	1	5
F	8	4	6
G	7	3	12

According to the given information

Min I_i = 3

Max I_{il} = 5 and

Min I_{iii} = 5

Clearly, since Min I_{iii} = Max I_{il} the second of the conditions specified is met. Now, we can solve the problem as follows:

Consolidation table

Job	G_i (=I_i + iI_i)	H_i (=iI_i +iiI_i)
A	7	10
B	11	10
C	9	7
D	9	16
E	10	6
F	12	10
G	10	15

According to this, there are two optimal sequences. They are:

S1 : A D G B F C E

S2 : A D G F B C E

We can now evaluate S1 for the value of T. It is done as follows:

Job	Machine I		Machine II		Machine III	
	In	Out	In	Out	In	Out
A	0	3	3	7	7	13
D	3	7	7	12	13	24
G	7	14	14	17	24	36
B	14	22	22	25	36	43
F	22	30	30	34	43	49
C	30	37	37	39	49	54
E	37	46	46	47	54	59

From the table, T=59 hours

The idle time for various machines is given as follows:

Machine I : 46-59=13 hours

Machine II : 0-3=3 + 12-14=2+ 17-22=5+ 25-30=5+34-37=3+39-46=7+47-59=12 =37 hours

Machine III : 0-7 = 7 hours

PRIORITY RULES

- First come, first served
- Last come, first served
- Earliest due date
- Shortest processing time
- Longest processing time
- Critical ratio=
  (Time until due date)/(processing time)
- Slack = time remaining until due date –
  process time remaining

DISPATCHING

- Dispatching involves selecting the potential machines for the next operations.

Dispatching rules:

- Minimum number of parts in the queue (MINQ)
- Minimum waiting time of all the parts in the queue (MWTQ)
- Number in resources (NR) etc.

SCHEDULING
(Numerical Problem)

- Suppose that we are presently at 15 day on the production scheduling calendar for the XYZ Machine Company and that there are three jobs (shop orders A, B, and C) in the queue for a particular work center. The jobs arrived at the work center in the order A, then B, then C. The following table gives the parameters of the scheduling problem for each job:

Job	Remaining Processing Time (Days)	Due Date
A	5	25
B	16	34
C	7	24

ANALYSIS

- EDD = C A B
- SPT = A C B
- FCFS = A B C

Job	Remaining Processing Time (Days)	Due Date
A	5	25
B	16	34
C	7	24

- Slack = time remaining until due date – process time remaining

A = (25-15) - 5 = 5

B = (34- 15) -16 = 3

C = (24-15) -7= 2

Job	Remaining Processing Time (Days)	Due Date
A	5	25
B	16	34
C	7	24

Critical Ratio = time remaining until due date/
process time remaining

A critical ratio = (25-15)/5 = 2

B critical ratio = (34-15)/16 = 1.19

C critical ratio = (24-15)/7 = 1.29

Job	Remaining Processing Time (Days)	Due Date
A	5	25
B	16	34
C	7	24

Earliest due date	C, A, B
SPT	A, C, B
FCFS	A, B, C
Least Slack	C, B, A
Lowest critical ratio	B, C, A

- Five different priority rules have yielded five different job sequence.
- The question of which among the solutions is the best depends on one’s criteria of one defining what is best.
- SPT rule will usually result in the lowest average manufacturing lead time and therefore the lowest WIP.
- However this may result in customers whose job has long processing time to be disappointed.

- FCFS seems like the best criteria , but it denies the opportunity to deal with difference in due dates among customers and genuine rush jobs.
- The earliest due date, least slack, and critical ratio rules address this issues of relative urgency among jobs.
- All the five priority rules are evaluated with respect with **manufacturing lead time** and **job lateness**.

MANUFACTURING LEAD TIME

- The manufacturing lead time for each job is the remaining process time plus time spent in the queue waiting to be processed at the work center.
- The average manufacturing lead time is the average for the three jobs.

EARLIEST DUE DATE (C-A-B)

- The lead time of :
  C = 7 days
  A = 7+5 = 12 days
- B = 7+5+16 = 28 days

- The average manufacturing lead time
  = (7+ 12 + 28)/3 = 47/3
  = 15 2/3 days

Job	Remaining Processing Time (Days)	Due Date
A	5	25
B	16	34
C	7	24

SPT (A-C-B)

- The lead time of:
  A=5 days
  C = 5+7 = 12 days
  B = 5+7+16 = 28 days

- The average manufacturing lead time = (5+ 12 + 28)/3
  = 45/3 = 15 days

Job	Remaining Processing Time (Days)	Due Date
A	5	25
B	16	34
C	7	24

FCFS (A-B-C)

- The lead time:

  A= 5 days

  B = 5+16 = 21 days

  C = 5+16+7= 28 days

- The average manufacturing lead time = (5+ 21 + 28)/3 = 54/3 = 18 days

Job	Remaining Processing Time (Days)	Due Date
A	5	25
B	16	34
C	7	24

LEAST SLACK (C-B-A)

- The lead time:
  C= 7 days
  B = 7+16 = 23 days
  A = 7+16+ 5= 28 days

- The average manufacturing lead time = (7+ 23 + 28)/3 = 58/3 = 19 1/3 days

Job	Remaining Processing Time (Days)	Due Date
A	5	25
B	16	34
C	7	24

CRITICAL RATIO (B-C-A)

- The lead time of:

  B = 16 days

  C = 16 +7 = 23 days

  A = 16 +7+5 = 28 days

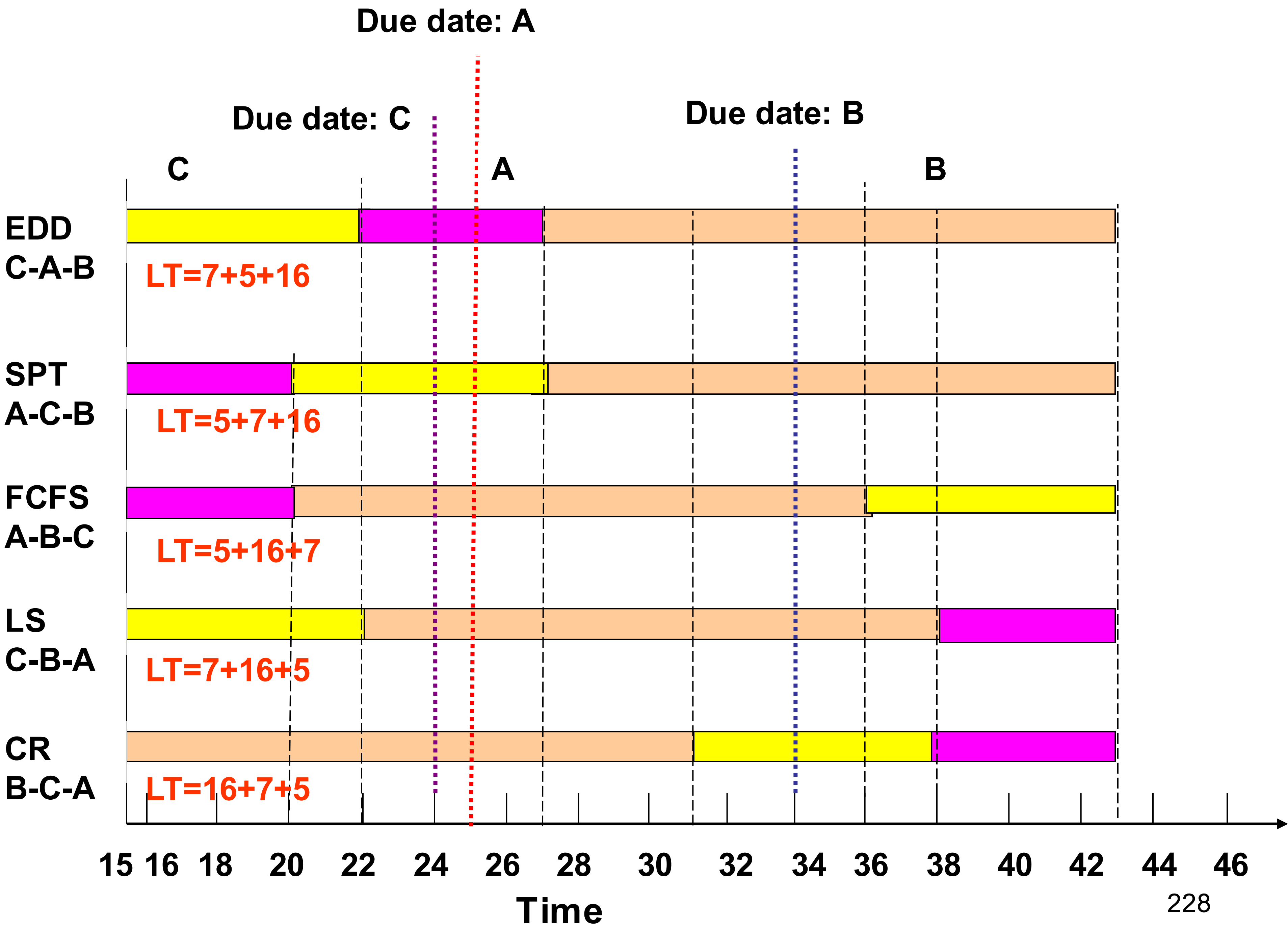
- The average manufacturing lead time = (16+ 23 + 28)/3 = 67/3 = 22 1/3 days

Job	Remaining Processing Time (Days)	Due Date
A	5	25
B	16	34
C	7	24

Priority Rules	Average manufacturing lead time
EDD	**15 2/3**
SPT	**15**
FCFS	18
LS	19 1/3
CR	22 1/3

JOB LATENESS

- Job lateness for each job is defined as the number of days the job is completed after the due date.
- If it is completed before the due date, it is not late. Therefore, its lateness is zero.
- The aggregate lateness is the sum of the lateness times for the individual jobs.



Due date: A
Due date: C
Due date: B
C
A
B
EDD
C-A-B
LT=7+5+16
SPT
A-C-B
LT=5+7+16
FCFS
A-B-C
LT=5+16+7
LS
C-B-A
LT=7+16+5
CR
B-C-A
LT=16+7+5
15 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46
Time

Job Lateness

	A	B	C	Aggregate
EDD	2	9	0	11
SPT	0	9	3	12
FCFS	0	2	19	21
LS	18	4	0	22
CR	18	0	14	32

COMPARISON

Priority Rules	Average manufacturing lead time	Aggregate job lateness
EDD	**15 2/3**	**11**
SPT	**15**	**12**
FCFS	18	21
LS	19 1/3	22
CR	22 1/3	32

MATERIAL STORAGE SYSTEM: AS/RS

Storage Systems

- The function of the material storage system is to store materials for a period of time and to permit access to those materials when required.
- The performance of a storage system in accomplishing its function must be sufficient to justify its investment and operating expenses.
- Various measures used to assess the performance of storage system include:

1) Storage capacity; 2) Storage density; 3) Accessibility; 4) Throughput; 5) Utilization; 6) Reliability

1. Storage capacity:

It can be measured in two ways: i) as the total volumetric space available or ii) as the total number of storage compartments in the system available for items or loads.

2. Storage density:

It is defined as the volumetric space available for actual storage relative to the total volumetric space in the storage facility.

3. Accessibility:

It refers to the capability to access any desired item or load stored in the system.

4. System throughput:

It is defined as the hourly rate at which the storage system i) receive and puts load into storage and/or ii) retrieves and delivers load to the output station

Two additional performance measures applicable to mechanized and automated storage system is Utilization and Availability.

5. Utilization:

It is defined as the proportion of time that the system is actually being used for performing storage and retrieval operations compared with the time it is available.

6. Availability:

It is the measure of the system reliability, defined as the proportion of time that the system is capable of operating compared with the normally scheduled shift hours

Storage location strategies

- There are several strategies that can be used to organize stock in a storage system. These storage location strategies affect several of the performance measures discussed above.
- The two basic strategies are 1) randomized storage and 2) dedicate storage
- In randomized storage, items are stored in any available location in the storage system.
- In dedicated storage, items are assigned to specific location in the storage facility.
- Each item type stored in a warehouse is known as a **stock-keeping unit (SKU).**

Automated storage system

- An automated storage system represents a significant investment and it often requires a new and different way of doing business.

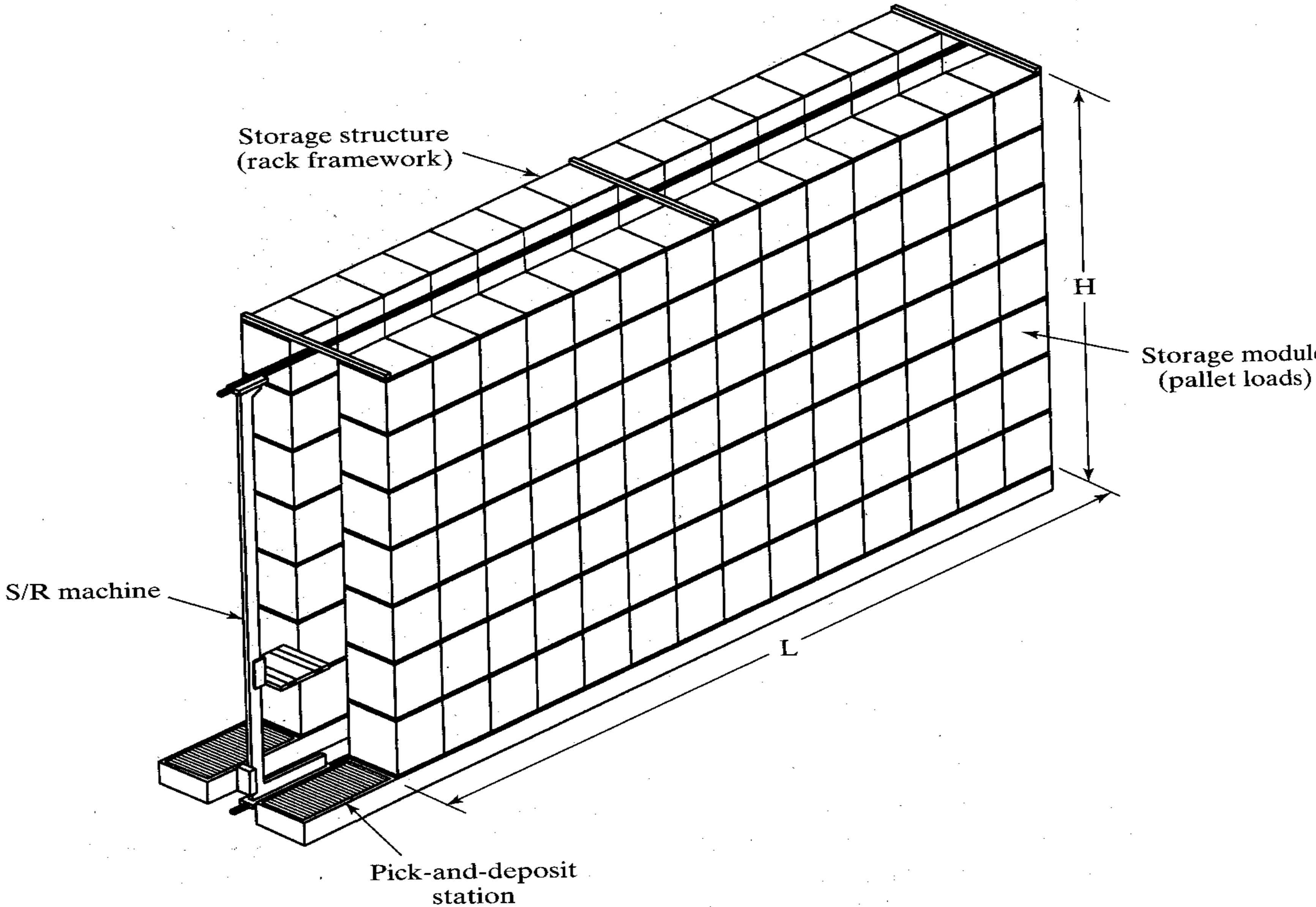
Automated Storage and Retrieval System (AS/RS)

It is defined as a storage system that performs storage and retrieval operations with speed and accuracy under a defined degree of automation. The basic of AS/RS consists of rack structure for storing loads and storage/retrieval mechanism.

Automated Storage/Retrieval Systems (AS/RS)

- A wide range of automation is found in commercially available AS/RS systems.
- At the most sophisticated level, the operations are totally automated, computer controlled, and fully integrated with a factory.
- AS/RS are custom designed for each application, although the designs are based on standard modular components available from each respective AS/RS supplier.
- An AS/RS consists of one or more storage aisles that are each serviced by a storage/retrieval (S/R) machine.

- The aisles have storage racks for holding the stored materials.
- The S/R machines are used to deliver material to the storage racks and to retrieve materials from the racks.
- Each AS/RS aisle has one or more input/output stations where materials are delivered into the storage system or moved out of the system.
- The input/output stations are called pickup-and-deposit (P&D) stations in AS/RS terminology.
- P&D stations can be manually operated or interfaced to some form of automated system.



Storage structure
(rack framework)
H
Storage module
(pallet loads)
S/R machine
L
Pick-and-deposit
station

Analysis of Automated Storage/Retrieval Systems

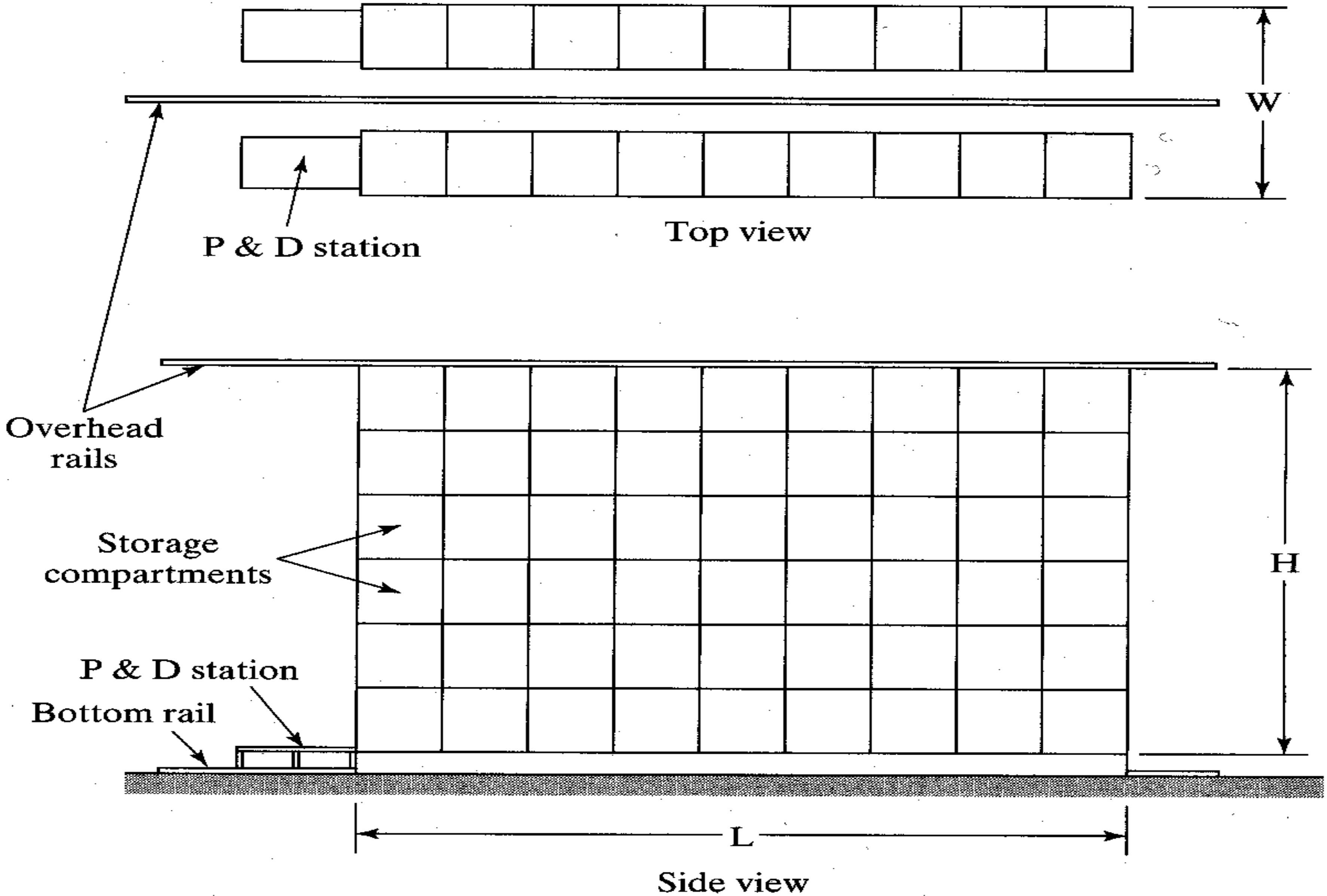
Sizing of the AS/RS Rack structure:

- The total storage capacity of one storage aisle depends on how many storage compartments are arranged horizontally and vertically in the aisle (passageway). This can be expressed as follows:

Capacity per aisle= $2\, n_y\, n_z$

- Where n_y = number of load compartments along the length of the aisle,

  n_z = number of load compartments that make up the height of the aisle.
- The constant 2 accounts for the fact that loads are contained on both sides of the aisle



Top and side views of a unit load AS/RS, with nine storage compartments horizontally ($n_y = 9$) and six compartments vertically ($n_z = 6$).

- If we assume a standard size compartment (to accept a standard size unit load), then the compartment dimensions facing the aisle must be larger than the unit load dimensions.
- Let x and y = the depth and width dimensions of a unit load, and z = the height of the unit load.
- The width, length, and height of the rack structure of the AS/RS aisle are related to the unit load dimensions and number of compartments as follows:

$$W = 3(x + a)$$

$$L = n_y(y + b)$$

$$H = n_z(z + c)$$

Where

W, L, and H are the width, length and height of one aisle of the AS/RS rack structure (mm).

x, y, and *z* are the dimensions of the unit load (mm).

a, b, and c are allowances designed into each storage compartment to provide clearance for the unit load (mm)

EXAMPLE **Sizing an AS/RS System**

Each aisle of a four-aisle AS/RS is to contain 60 storage compartments in the length direction and 12 compartments vertically. All storage compartments will be the same size to accommodate standard size pallets of dimensions: $x = 42$ in and $y = 48$ in. The height of a unit load $z = 36$ in. Using the allowances, $a = 6$ in, $b = 8$ in, and $c = 10$ in, determine: (a) how many unit loads can be stored in the AS/RS, and (b) the width, length, and height of the AS/RS.

Solution: (a) The storage capacity is given by **Capacity per aisle= $2\, n_y\, n_z$**

Capacity per aisle $= 2(60)(12) = 1440$ unit loads.

With four aisles, the total capacity is:

$$\text{AS/RS capacity} = 4(1440) = 5760 \text{ unit loads}$$

(b) we can compute the dimensions of the storage rack structure:

$$W = 3(x + a)$$

$$L = n_y(y + b)$$

$$H = n_z(z + c)$$

$$W = 3(42 + 6) = 144 \text{ in} = 12 \text{ ft/aisle}$$

Overall width of the AS/RS $= 4(12) = 48$ ft

$$L = 60(48 + 8) = 3360 \text{ in} = 280 \text{ ft}$$

$$H = 12(36 + 10) = 552 \text{ in} = 46 \text{ ft}$$

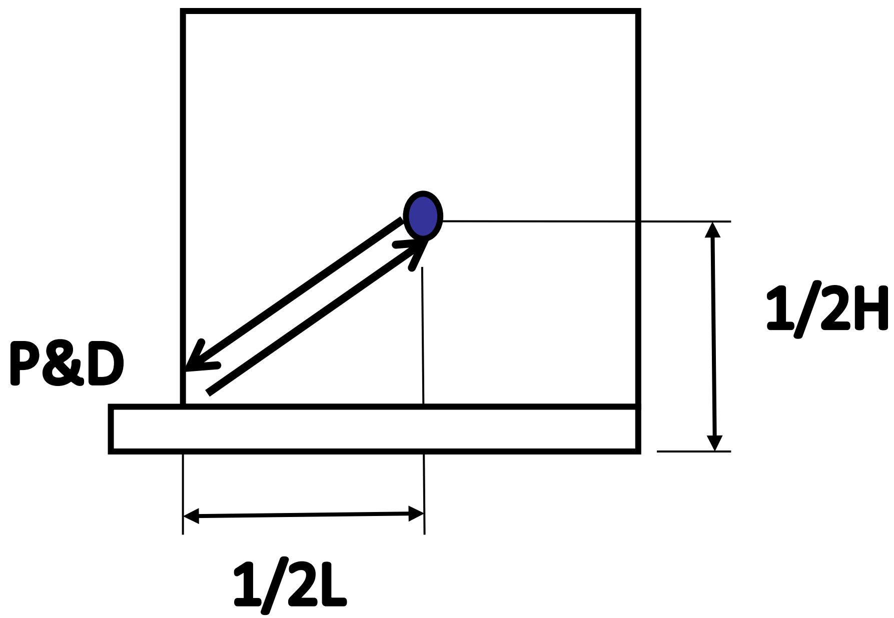
AS/RS Throughput:

- System throughput is defined as the hourly rate of S/R transactions that the automated storage system can perform.
- A transaction involves depositing a load into storage or retrieving a load from storage.
- Either one of these transactions alone is accomplished in a **single command cycle.**
- A **dual command cycle** accomplish both transaction types in one cycles; since this reduces travel time per transaction, throughput is increased by using dual command cycles.
- Several methods are available to compute AS/RS cycle times to estimate throughput performance.

The method we present is recommended by the Material Handling Institute. It assumes:

1) Randomized storage.
2) Storage compartments are of equal size.
3) The P&D station is located at the base and end of the aisle.
4) Constant horizontal and vertical speeds of S/R machine.
5) Simultaneous horizontal and vertical travel.

- For a single command cycle, the load to be entered or retrieved is assumed to be located at the center of the rack structure as shown in the figure below:



Thus, the S/R machine must travel half the length and half the height of the AS/RS, and it must return the same distance.

The single command cycle time can therefore be expressed by

$$T_{cs} = 2\ \text{Max}\ (0.5L/v_y\ ,\ 0.5H/v_z) + 2\ T_{pd}$$

$$= \text{Max}\ (L/v_y\ ,\ H/v_z) + 2\ T_{pd} \qquad (1)$$

Where:

T_{cs} = cycle time of a single command cycle (min/cycle)

L = length of the AS/RS rack structure (m)

v_y = velocity of the S/R machine along the length of AS/RS (m/min)

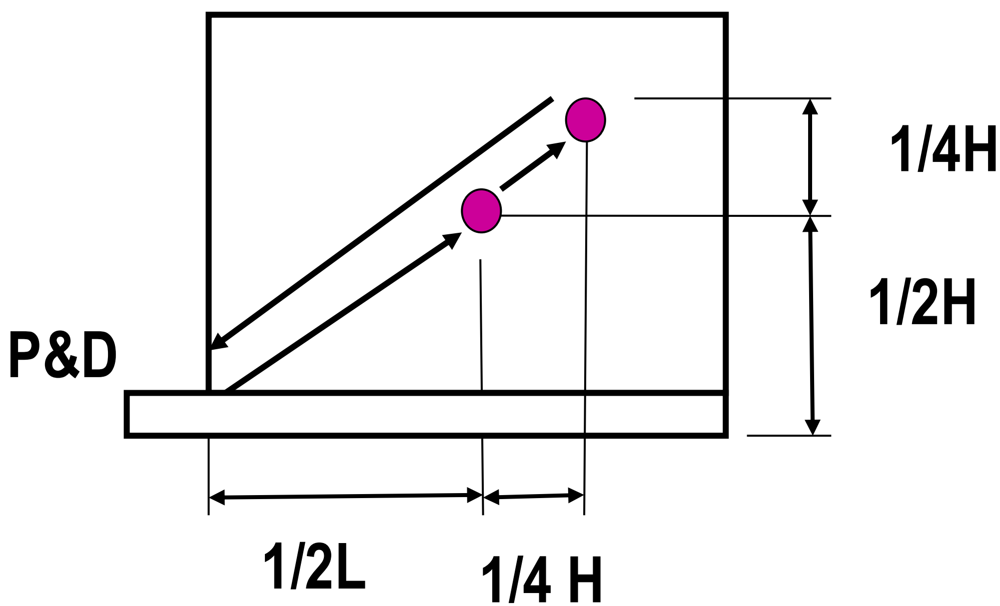
H = height of the rack structure (m)

v_Z = velocity of the S/R machine in the vertical direction of the AS/RS (m/min)

T_{pd} = pick-up-deposit time (min)

Two P&D times are required per cycle , represents load transfer to and from the S/R machine.

For a dual command cycle, AS/RS machine is assumed to travel to the center of the rack structure to deposit load and then it to ¾ the length and height of the AS/RS to retrieve a load as shown in the figure below:



$$T_{cd} = 2\,\text{Max}\,(0.75L/v_y\,,\ 0.75H/v_z) + 2\,T_{pd}$$

$$= \text{Max}\,(1.5L/v_y\,,\ 1.5H/v_z) + 4\,T_{pd} \qquad (2)$$

Where:

T_{cd} = cycle time for a dual command cycle (min/cycle)

System throughput depends on the relative numbers of single and dual cycles performed by the system.

Let R_{cs} = number of single command cycle performed per hour.

R_{cd} = number of dual command cycle per hour at a specified or assumed utilization level.

The amount of time spent in performing single command and dual command cycles each hour:

$$R_{cs} T_{cs} + R_{cd} T_{cd} = 60U \qquad (3)$$

Where:

U= system utilization during the hour. The right hand side of the equation gives the total number of operations per hour.

The total hourly cycle rate is given by:

$$R_c = R_{cs} + R_{cd} \quad (4)$$

Where:

R_c = total S/R cycle rate (cycles/hr.)

Note: the total number of storage and retrieval transaction per hour will be grater than this value unless R_{cd} =0, since there are two transaction accomplished in each dual command cycle.

Let R_t = total number of transaction performed per hour; then

$$R_t = R_{cs} + 2R_{cd} \quad (5)$$

Consider the AS/RS from the previous example in which an S/R machine is use for each aisle. The length of the storage aisle is 289 ft and its height is 46 ft. Suppose horizontal and vertical speeds of the S/R machines are 200 ft/min and 75 ft/min respectively. The S/R machine requires 20 sec to accomplish a P&D operation. Find:

a) The single command and dual command cycle times per aisle, and

b) Throughput per aisle under the assumption that storage system utilization = 90% and the number of single command and dual command cycles are equal.

We first compute the single and dual command cycles times by using equation 1 and 2.

$$T_{cs} = \text{Max}(L/v_y, H/v_z) + 2T_{pd}$$
$$= \text{Max}(289/200, 46/75) + 2(20/60)$$
$$= \text{Max}(\mathbf{1.4}, 0.63) + 0.67$$
$$= 2.07 \text{ min/cycle}$$

$$T_{cd} = \text{Max}(1.5L/v_y, 1.5H/v_z) + 4T_{pd}$$
$$= \text{Max}(1.5X280/200, 1.5X46/75) + 4(20/60)$$
$$= \text{Max}(\mathbf{2.1}, 0.92) + 1.33$$
$$= 3.43 \text{ min/cycle}$$

b) From equation 3, we can establish the single command and dual command activity levels each hour as follows:

$$R_{cs}\,T_{cs} + R_{cd}\,T_{cd} = 60U$$
$$2.07\,R_{cs} + 3.43\,R_{cd} = 60\,(0.90)$$

According to the problem statement, the number of single command cycles is equal to the number of dual command cycles.

Thus $R_{cs} = R_{cd}$

Substituting this relation into the above equation, we have

$$2.07\,R_{cs} + 3.43\,R_{cs} = 54$$
$$5.50\,R_{cs} = 54$$

R_{cs} = 9.82 single command cycles/hr.

$R_{cd} = R_{cs}$ = 9.82 dual command cycles/hr.

System throughput = the total number of S/R transactions per hour from equation 5.

$$R_t = R_{cs} + 2R_{cd}$$
$$= 9.82 + 2X9.82 = 29.46 \text{ transactions/hr}$$

With four aisle, R_t for the AS/RS = 117.84 transactions/hr

GROUP TECHNOLOGY

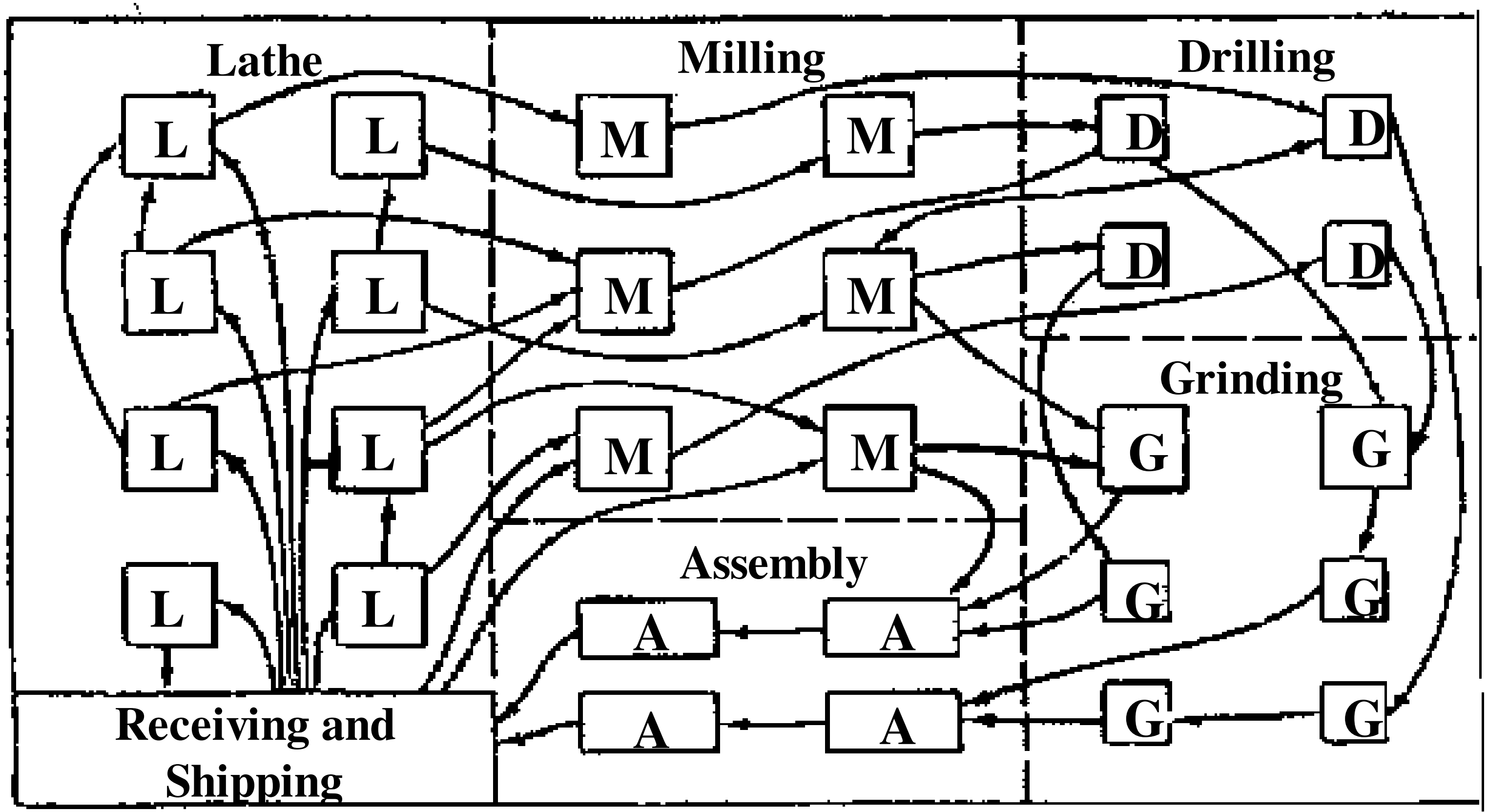
Group Technology

- Group technology was introduced by Frederick Taylor in 1919 as a way to improve productivity.

- Group Technology is a manufacturing philosophy that exploits similarities in the design, fabrication, and assembly attributes of products.

- It refers to grouping machines to process families of components with similar if not exact sequences of operations. The family of parts dictate the processes used to form a specific manufacturing cell.

Functional Layouts Are Inefficient

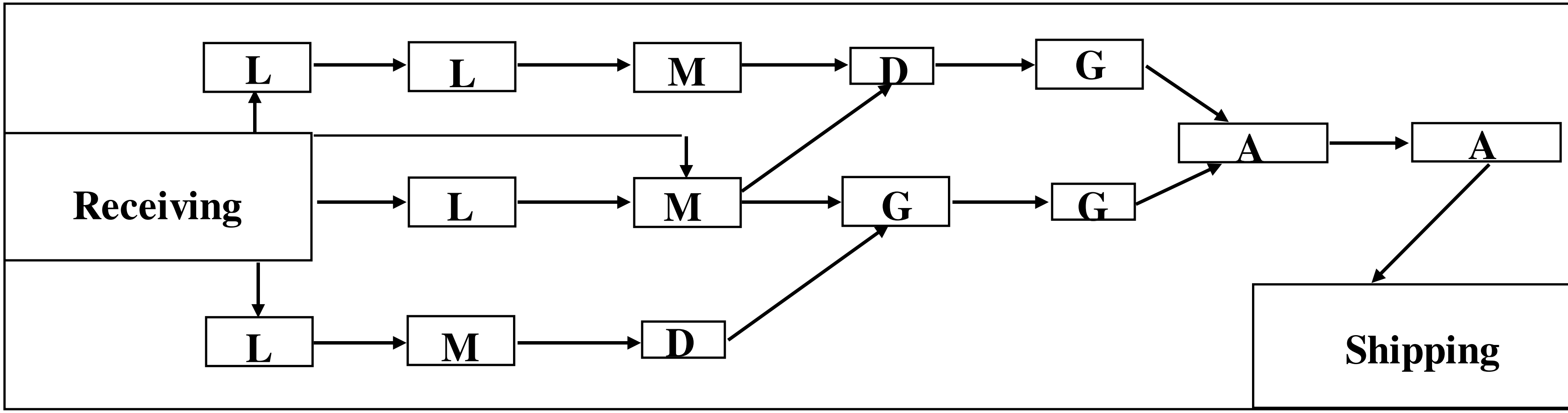


PROCESS-TYPE LAYOUT

- The various machine tools are arranged by function.
- During machining of a given part, the work piece must be moved between sections, with perhaps the same section being visited several times.

- This results:
  - In a significant amount of material handling
  - A large in-process inventory
  - Usually more set-up than necessary
  - Long manufacturing lead time
  - High costs

Group Technology Layout



The machines are arranged into cells

Each cell is organized to specialize in the manufacture of a particular part family

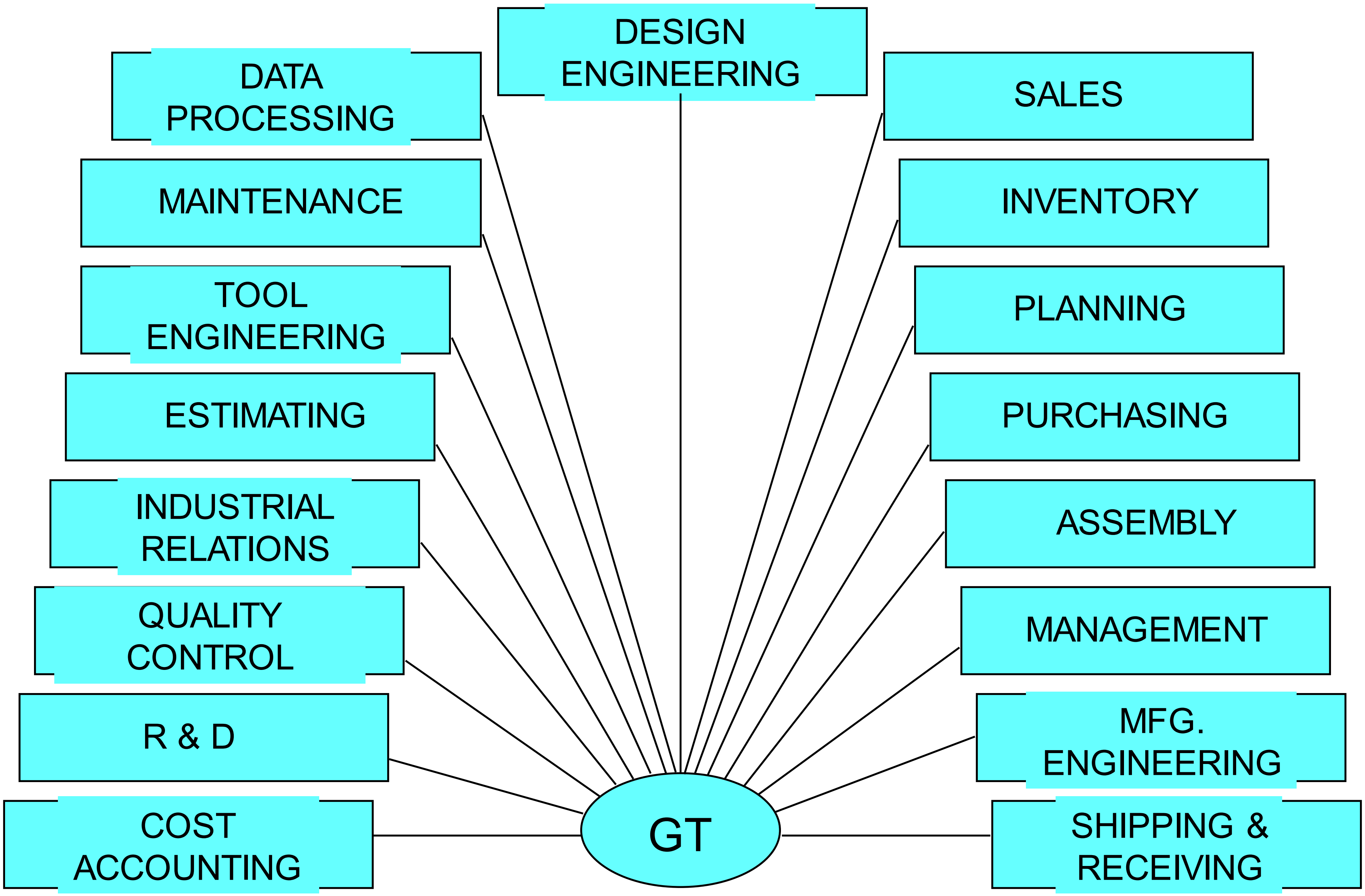
Advantages:

i) Reduced work piece handling, ii) Lower set-up times

iii) Less in-flow inventory, iv) Less floor space

iv) Shorten lead time

GT affects most every operating and staff function. It is more than merely a technique, but a total Manufacturing philosophy.



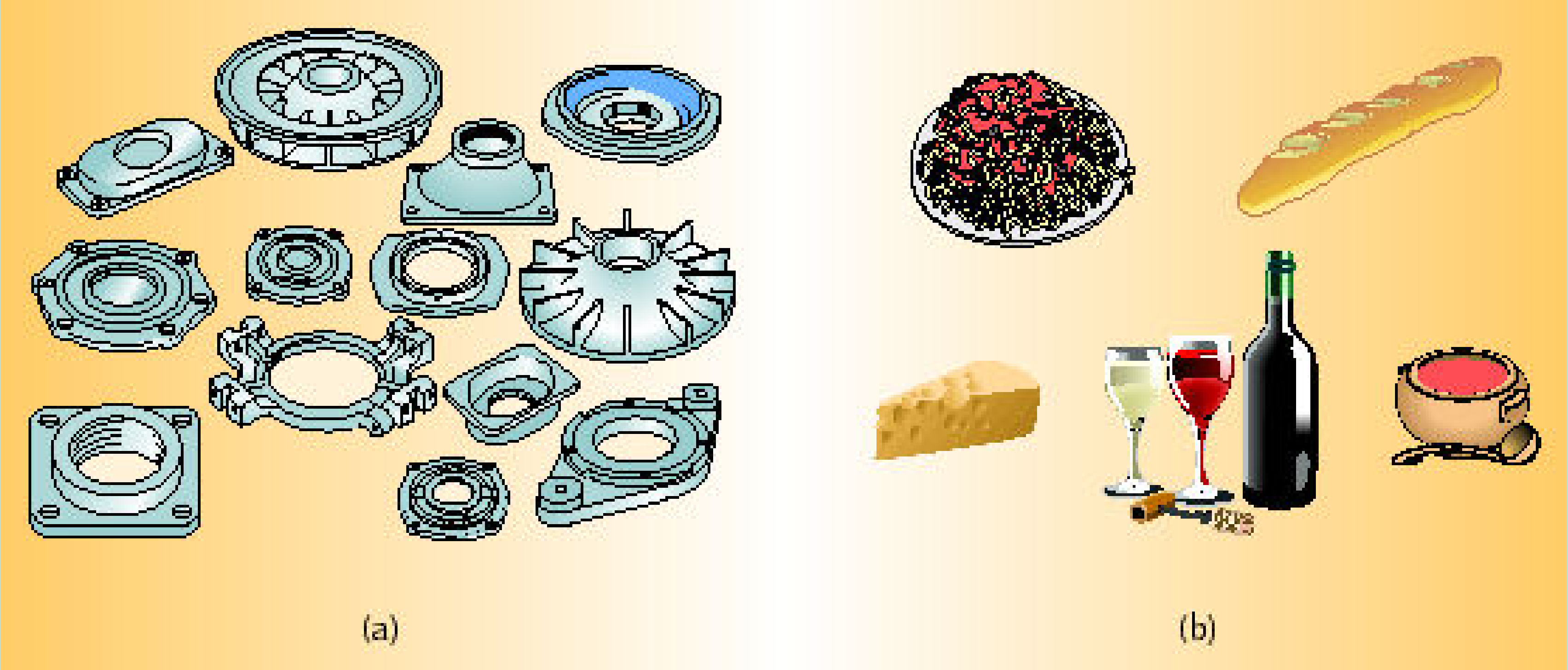
Part Families

Major **obstacles** in changing over to group technology from a traditional production shop is the problem of grouping parts into part families.

Part Families

- The word “Family” is used as a name for any list of similar parts. The families used with group layout are lists of parts which are similar because they are all made on the same group of machines.
- Group Technology (GT) is commonly used to identify product families based on similarities in design or processing.
- These families can be manufactured in well-defined manufacturing cells.

Parts Families



A family of similar parts

A family of related grocery items

Three Techniques To Form Part Families

1. Manual visual inspection

It involves a set of parts into group known as part families by visually inspecting the physical characteristics of the parts.

- Utilizes subjective judgment
- May use photos or part prints
- It gives incorrect results
- Human error
- Least sophistication
- Good for small companies having smaller number of parts.

2. Production Flow Analysis

Parts that go through common operations are grouped into part families. The machines used to perform these operations are grouped in cell.

- Uses information contained on the route sheet
- Parts grouped by required processing

3. Classification And Coding

This method is employed in classifying parts into part families. Coding refers to the process of assigning symbols to the parts. The symbols represents design and manufacturing attributes of parts .

- Information about a component codes are alphanumeric strings.
- Easier to use for other analysis

Classification and coding

- This method of grouping parts into families involves an examination of the individual **DESIGN** and **MANUFACTURING** attributes of each part.

- The attributes of the part are uniquely identified by means of **CODE** number

Design and Manufacturing attributes

Part Design Attributes	Part Mfg. Attributes
Basic external shape	Major processes
Basic internal shape	Minor operations
Material	Fixtures needed

Length/diameter ratio
Surface finish
Tolerances-----machine tool
Operation sequence
Major dimension
Tooling
Batch size

GT Code--a Sequence of Numerical Digits

Three major structures:

1. Monocode (or hierarchical structure)

   A code in which each digit amplifies the information given in the previous digit

   - Difficult to construct
   - Provides a deep analysis
   - Usually for permanent information

2. Polycode (Or Chain-type Structure)

Each digit is independent of all others, presents information not dependent On previous ones

- Easier to accommodate change

3. Mixed Code

Has some digits forming monocodes, but strings them together in the general arrangement of a polycode

ILLUSTRATION

- Consider a two digit code, such as 15 or 25. Suppose that the first digit stands for general part shape. The symbol 1 means round work part and 2 means flat rectangular part.
  - In a monocode structure the interpretation of the second digit would depend on value of the first digit.
  - If preceded by 1, the 5 might indicate some length/diameter ratio and if preceded by 2, the 5 might be interpreted to specify some overall length.
  - In polycode structure the symbol 5 would be interpreted the same way regardless the of the value of the first digit.
  - It might indicate overall part length, or whether the part is rotational or rectangular.

Classification and Coding Schemes

Name of system	Country Developed	Characteristics
TOYODA	Japan	Ten digt code
MICLASS	The Netherlands	Thirty digit code
TEKLA	Norway	Twelve digit code
BRISCH	United Kingdom	Based on four to six digit primary code and a number of secondary digits
DCLASS	USA	Software-based system without any fixed code structure
NITMASH	USSR	A hierarchical code of ten to fifteen digits and a serial number
OPITZ	West Germany	Based on a five digit primary code with a four digit secondary code

OPITZ Code System

- The OPITZ coding system uses the following digits sequence

FORM CODE:

Describes the primary design attributes of the part

1 2 3 4 5

SUPLEMENTARY CODE:

Describes the primary manufacturing attributes of the part

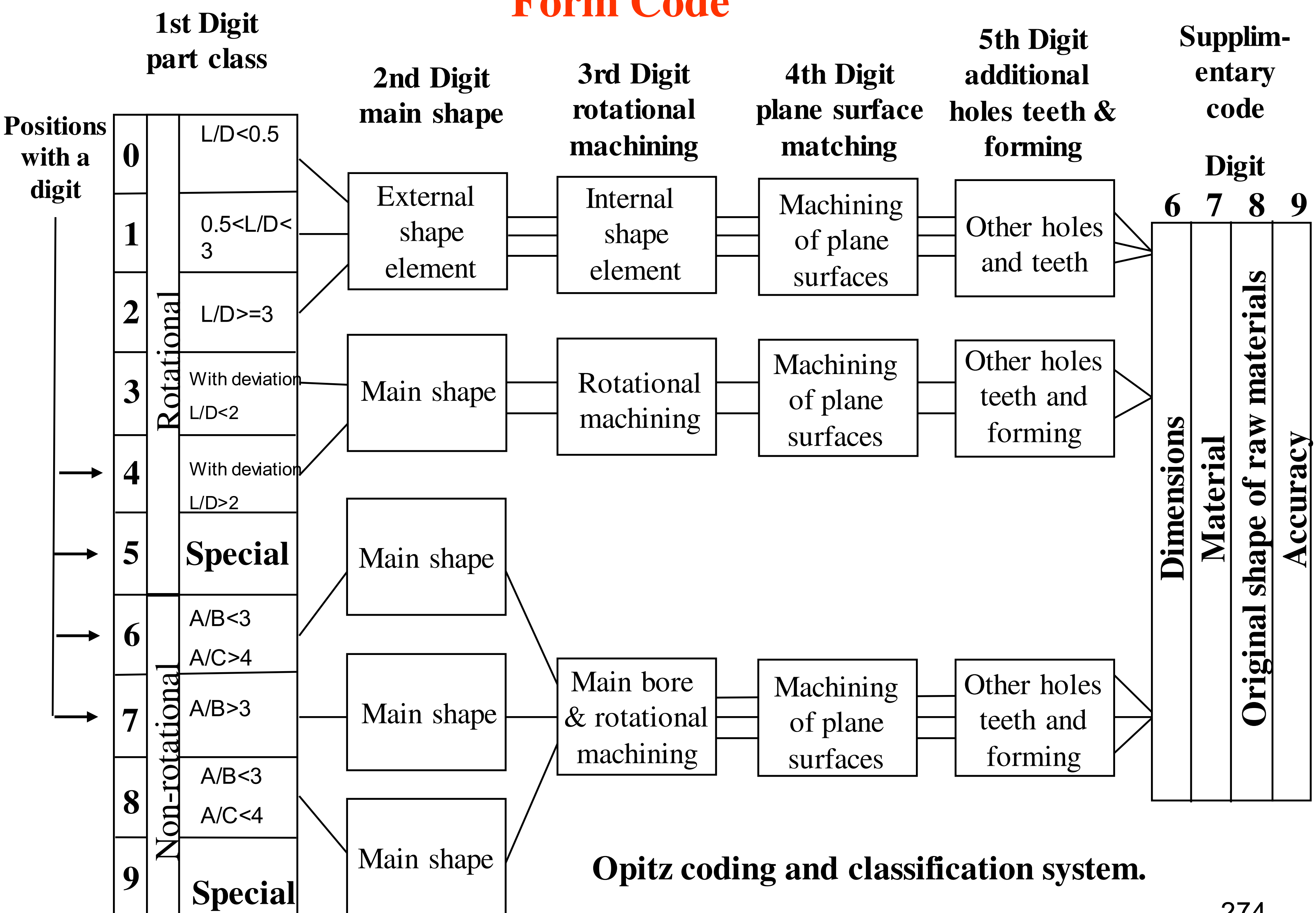
6 7 8 9

SECONDARY CODE:

Identifies the production type and sequence

A B C D

Form Code

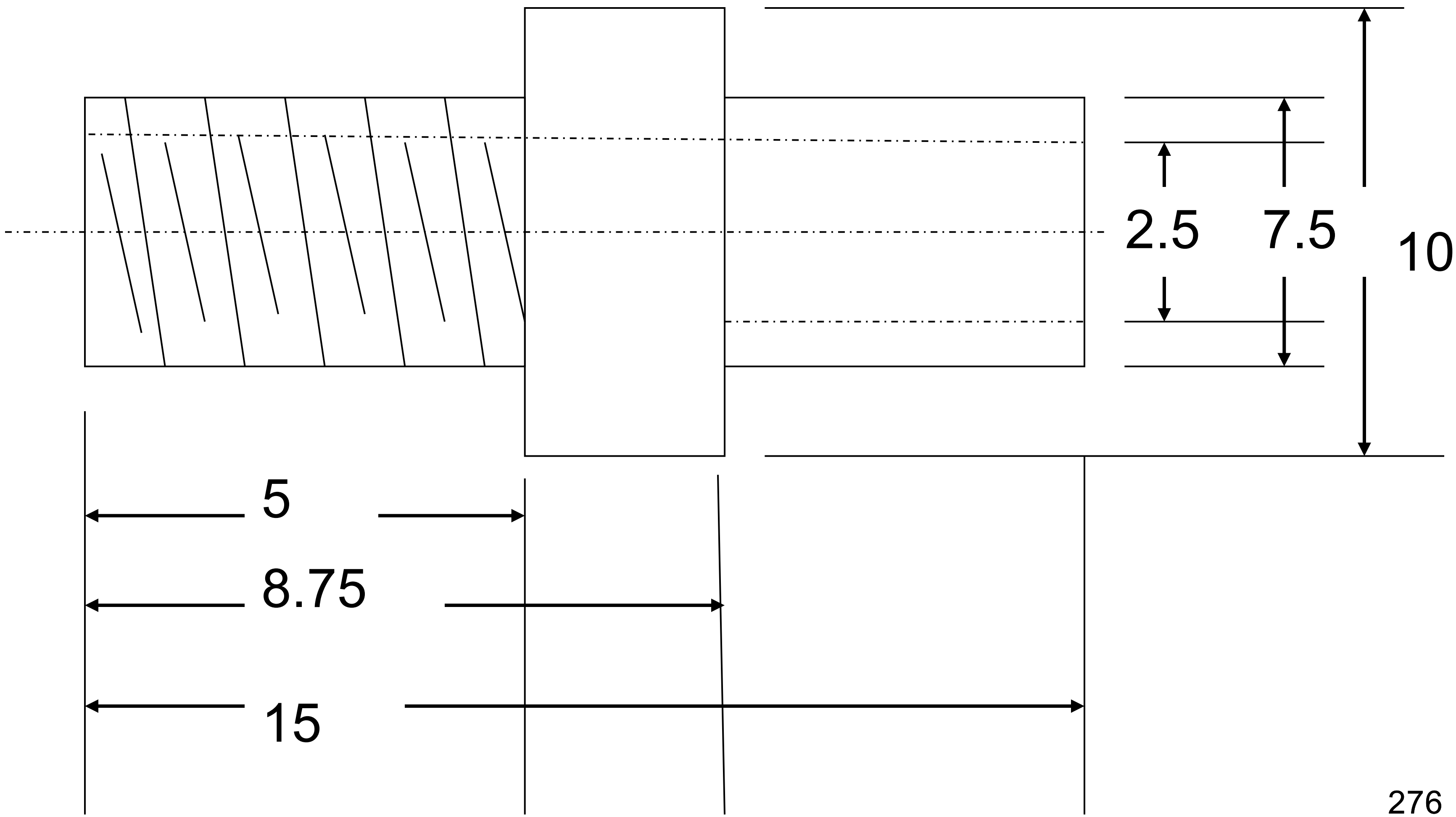


Opitz coding and classification system.

.)

Digit 1 Part class			Digit 2 External shape elements			Digit 3 Internal shape elements			Digit 4 Plane surface machining		Digit 5 Auxiliary holes and gear teeth		
0	RT PRTS	L/D<0.5	0	Smooth, no shape elements		0	Smooth, no shape elements		0	No surface machining	0	No gear teeth	No auxiliary hole
1		0.5<L/D<3	1	Stepped to one end or smooth	No shape element	1	Stepped to one end or smooth	No shape element	1	Surface plane and/or curved in one direction, external	1		Axial not on pitch circle diameter
2		L/D>3	2		Thread	2		Thread	2	External plane surface related by graduation around a circle	2		Axial on pitch circle diameter
3			3		Functional groove	3		Functional groove	3	External groove and/or slot	3		Radial not on pitch circle diameter
4			4	Stepped to both ends	No shape element	4	Stepped to both ends	No shape element	4	External spline	4		Axial and/or radial and/or direction
5			5		Thread	5		Thread	5	External plane surface and/or slot, external spline	5		Axial and/or radial on PCD and/or other direction
6	NRT PRTS		6		Functional groove	6		Functional groove	6	Internal plane surface and/or slot	6	With gear teeth	Spur gear teeth
7			7	Functional cone		7	Functional cone		7	Internal spline	7		Bevel gear teeth
8			8	Operating thread		8	Operating thread		8	Internal and external polygon and/or slot	8		Other gear teeth
9			9	All others		9	All others		9	All others	9		All others

Given the part design define the FORM CODE using OPITZ code system



- The overall length/diameter ratio L.D= 15/10=1.5
  First Digit Code=1
- The part is stepped on both ends with a screw thread on one end

  Second Digit Code=5
- The **Third Digit Code is =1** because of through hole
- The **Fourth and Fifth Digits** are both **0**; since no surface machining is required and there are no auxiliary holes or gear teeth on the part.
- The complete **FORM CODE** in the OPITZ code system is **15100**

A part design is shown in figure. Develop an optiz code for that design

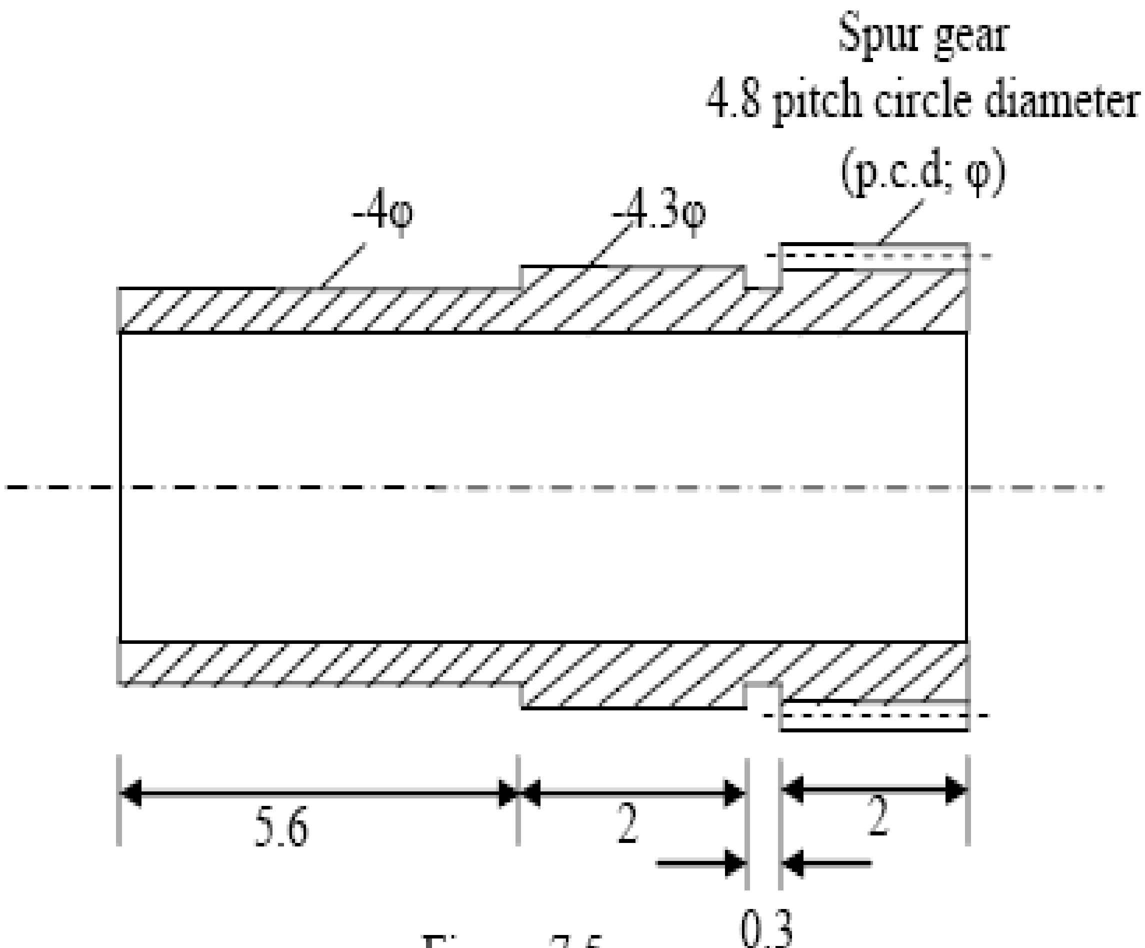


Figure 7.5

By using information from figure 7.5, the form code with explanation is given below

Part class:

Form code

Form code	1	3	1	0	6

- Rotational part, L/D = 9.9/4.8 = 2.0 (nearly) based on the pitch circle diameter of the gear. Therefore, the first digit would be 1.

External shape:

- The part is stepped in one side with a functional groove. Therefore, the second digit will be 3.

Internal shape:

- Due to the hole the third digit code is one.

Plain surface machining:

- Since, there is no surface machining the fourth digit is 0.

Auxiliary holes and gear teeth:

- Because there are spur gear teeth on the part the fifth digit is 6.

Managerial Benefits

1. Reduced Purchasing Cost Through Volume Purchasing
   - Can purchase fewer different items at higher volumes
2. Faster Lead Time
   - Can quickly identify the materials or materials needed
3. Better Negotiation Leverage
   - Value Analysis
4. Accurate Cost Estimation
   - Estimate the future price range with a standard cost database

5. Quicker Reaction to Design Changes
6. Quickly identify newer material or parts that conform to newer designs and specifications
7. Better Communication Between the Buyer and the Supplier
8. Eliminate the human errors with GT classification
9. Reductions in:
    - Throughput time, set-up time and overdue orders
    - Production floor space, raw material stocks and in-process inventory
    - Capital expenditures, tooling costs and engineering time and costs
    - New parts design, new shop drawings and total number of drawings

Potential Obstacles

The Obstacles of Group Technology Classification:

1. Management Resistance to Change
   – Unwilling to devote the time and energy
2. Extensive Data Requirements
   – The proper identification needs detailed item descriptions → extensive purchase records/data
3. High Start-Up Cost
   – Item characteristics are not available without the aid of automated information storage and retrieval systems which usually incur high expenses until GT is in place

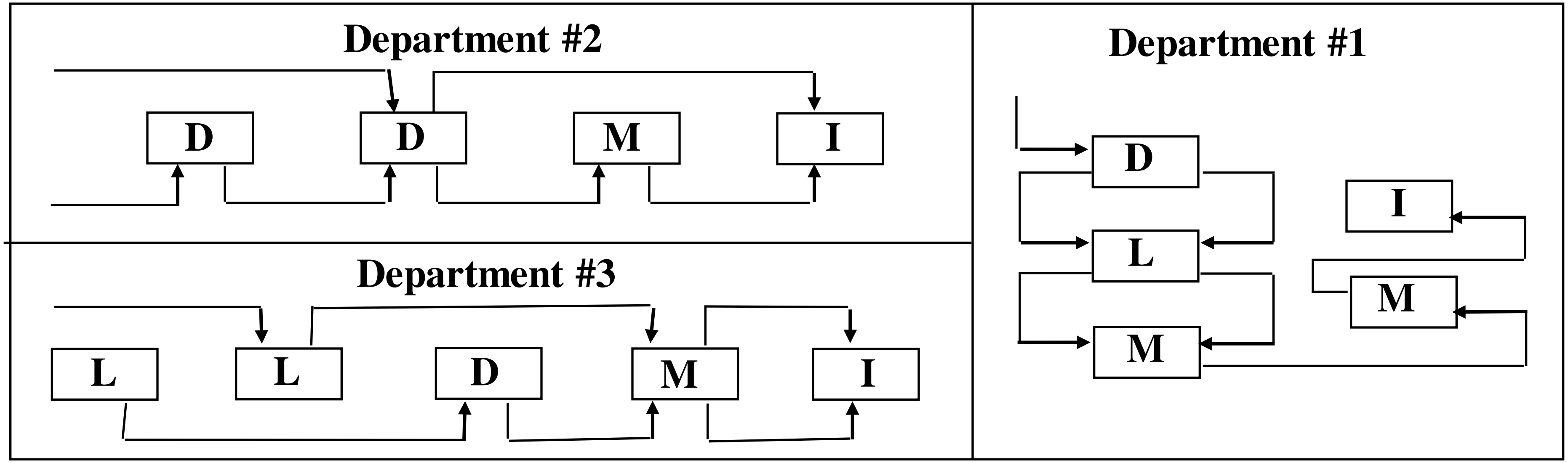
Cellular Manufacturing

Cellular Manufacturing

- Cellular manufacturing has been viewed as an application of group technology philosophy in organizing and managing manufacturing machines, equipment, personnel and production.

- The cellular approach is to organize the entire manufacturing process for particular or similar products into one group of team members and machines known as a "Cell".

Cellular Layout



Quantitative analysis of Cellular Manufacturing

- **Rank order clustering technique**

- Rank order clustering technique is specifically applicable in production flow analysis.
- It is an easy-to-use algorithm for grouping machines in cells
- Rank order clustering works by reducing the part-machine incidence matrix to a set of diagonalized blocks that represent part families and associates machine groups

Starting with the initial part machine incidence part matrix, the algorithm consists of eth following steps:

- 1) In each row of the matrix, read the series of 1 and 0 from left to right as a binary number. Rank the rows in order of decreasing value. In case of a tie, rank the rows in the same order as they appear in the current matrix.
- 2)Numbering from top to bottom , is the current order of rows the same as the rank order determined in the previous step? If yes, go to step 7. If no, go to the following step.
- 3)Reorder the row in the part machine incidence matrix by listing them in decreasing rank order, starting from the top.

- 4) In each column of the matrix, read the series of 1 and 0 from top to bottom as a binary number. Rank the columns in order of decreasing value. In case of a tie, rank the columns in the same order as they appear in the current matrix.

- 5) Numbering from left to right, is the current order of columns the same as the rank order determined in the previous step? If yes, go to step 7. If no, go to the following step.

- 6) Reorder the column in the part machine incidence matrix by listing them in decreasing rank order, starting with the left column.. Go to step 1.

- 7) Stop.

Rank Order Clustering Technique

- Apply the rank order clustering technique to the part-machine incidence matrix in Table given below.

First Iteration

Binary Values	2^8	2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0	Decimal Equivalent	Rank
PARTS											
MACHINES	A	B	C	D	E	F	G	H	I		
1	1			1				1		290	1
2					1				1	17	7
3			1		1				1	81	5
4		1				1				136	4
5	1							1		258	2
6			1						1	65	6
7		1				1	1			140	3

For Row 1

$2^8 \text{ X } 1 + 2^7 \text{ X } 0 + 2^6 \text{ X } 0 + 2^5 \text{ X } 1 + 2^4 \text{ X } 0 + 2^3 \text{ X } 0 + 2^2 \text{ X } 0 + 2^1 \text{ X } 1 + 2^0 \text{ X } 0$

$256+0+0+32+0+0+0+2=290$

Second Iteration

PARTS

MACHINES	A	B	C	D	E	F	G	H	I	Binary Value
1	1			1				1		2^6
5	1							1		2^5
7		1				1	1			2^4
4		1				1				2^3
3			1		1				1	2^2
6			1						1	2^1
2					1				1	2^0
Decimal equivalent	96	24	6	64	5	24	16	96	7	
Rank	1	4	8	3	9	5	6	2	7	

Final solution

PARTS

MACHINES	A	H	D	B	F	G	I	C	E
1	**1**	**1**	**1**						
5	**1**	**1**							
7				**1**	**1**	**1**			
4				**1**	**1**				
3							**1**	**1**	**1**
6							**1**	**1**	
2							**1**		**1**

Benefits of CM

- Common tooling required for many products (fewer setups)
- Tooling can be justified since many products require it (more volume when products are grouped)
- Minimized material handling
- Simple production schedule
- Short cycle time
- Low WIP

Benefits of CM

- Cross-training – employees operate several machines
- Minimized material handling costs – since no paperwork is required and distance is small
- Employees accept more responsibility of supervision (scheduling of parts within cell, scheduling of vacation, purchasing of material, managing a budget)
- Simple flow pattern and reduced paperwork
- Buffers are small if batch size is small

Disadvantages of CM

- Lower equipment utilization
- Increased set-up costs
- Less flexibility than functional departments

Home Assignment

Home Assignment

DISTRIBUTED MANUFACTURING

Home Assignment

RAPIDLY RESPONSIVE MANUFACTURING

Home Assignment

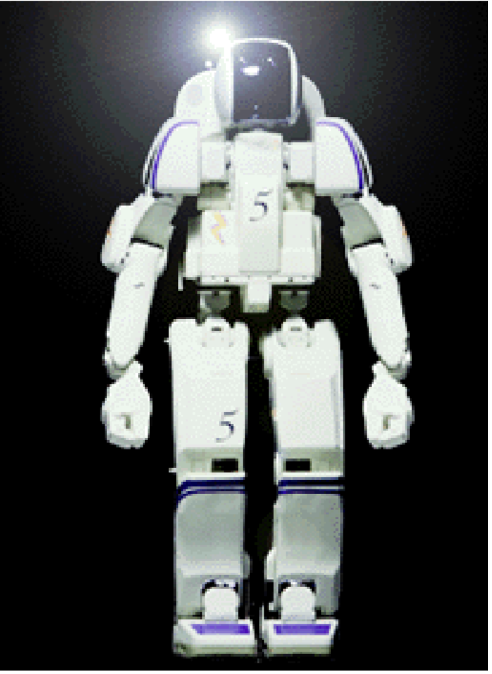
CUSTOMIZED MANUFACTURING

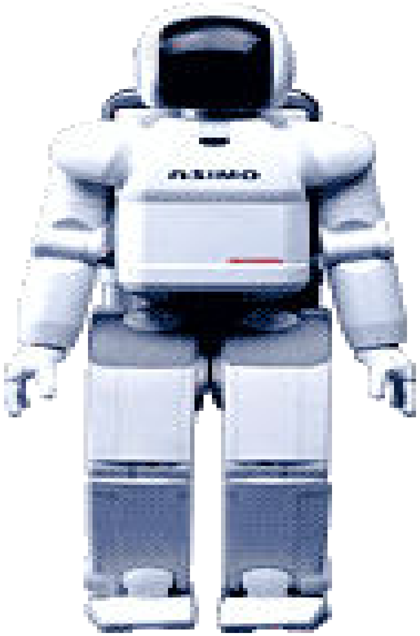
Home Assignment

HUMAN-CENTRED MANUFACTURING

Home Assignment

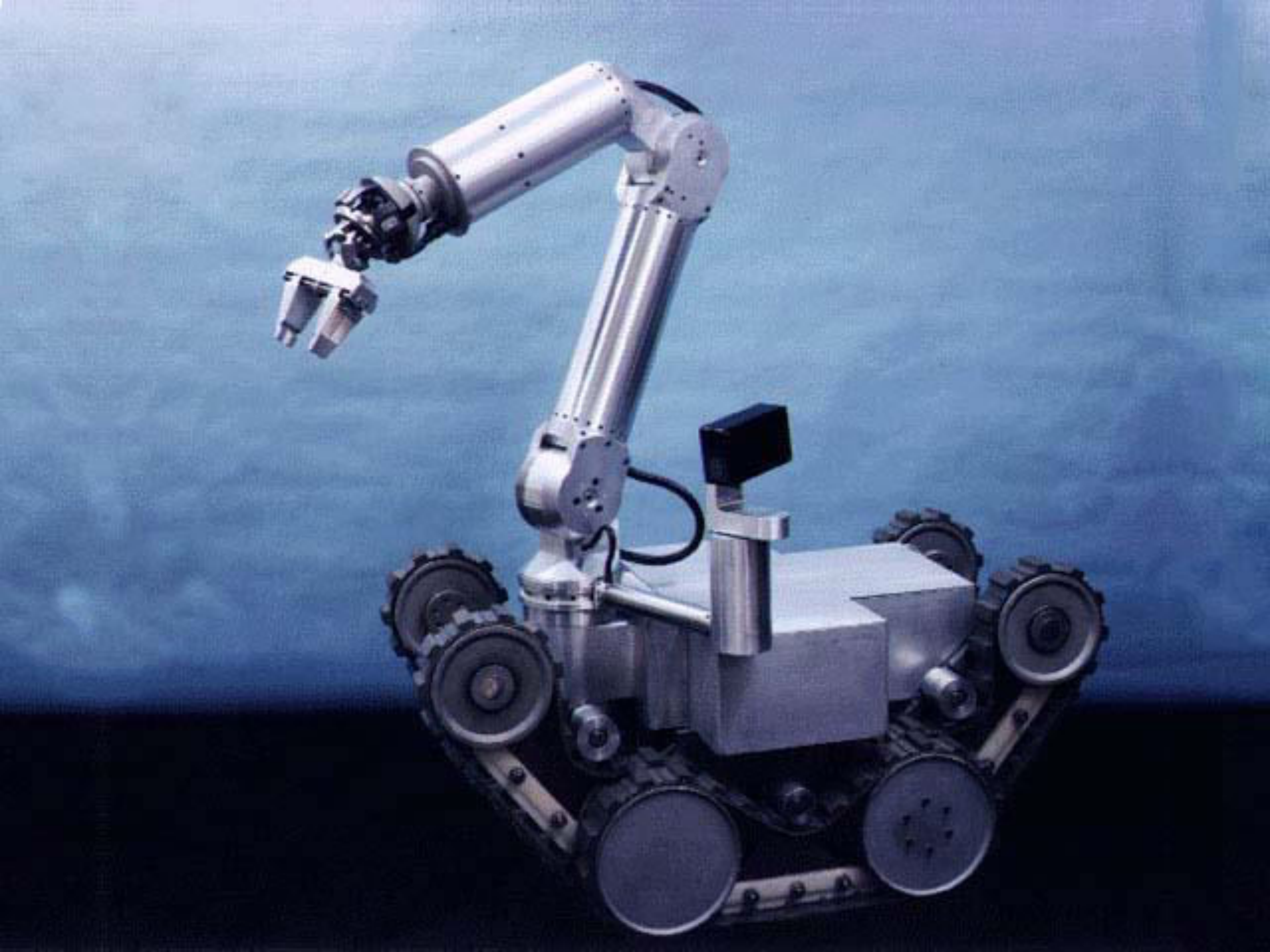
SUSTAINABLE MANUFACTURING

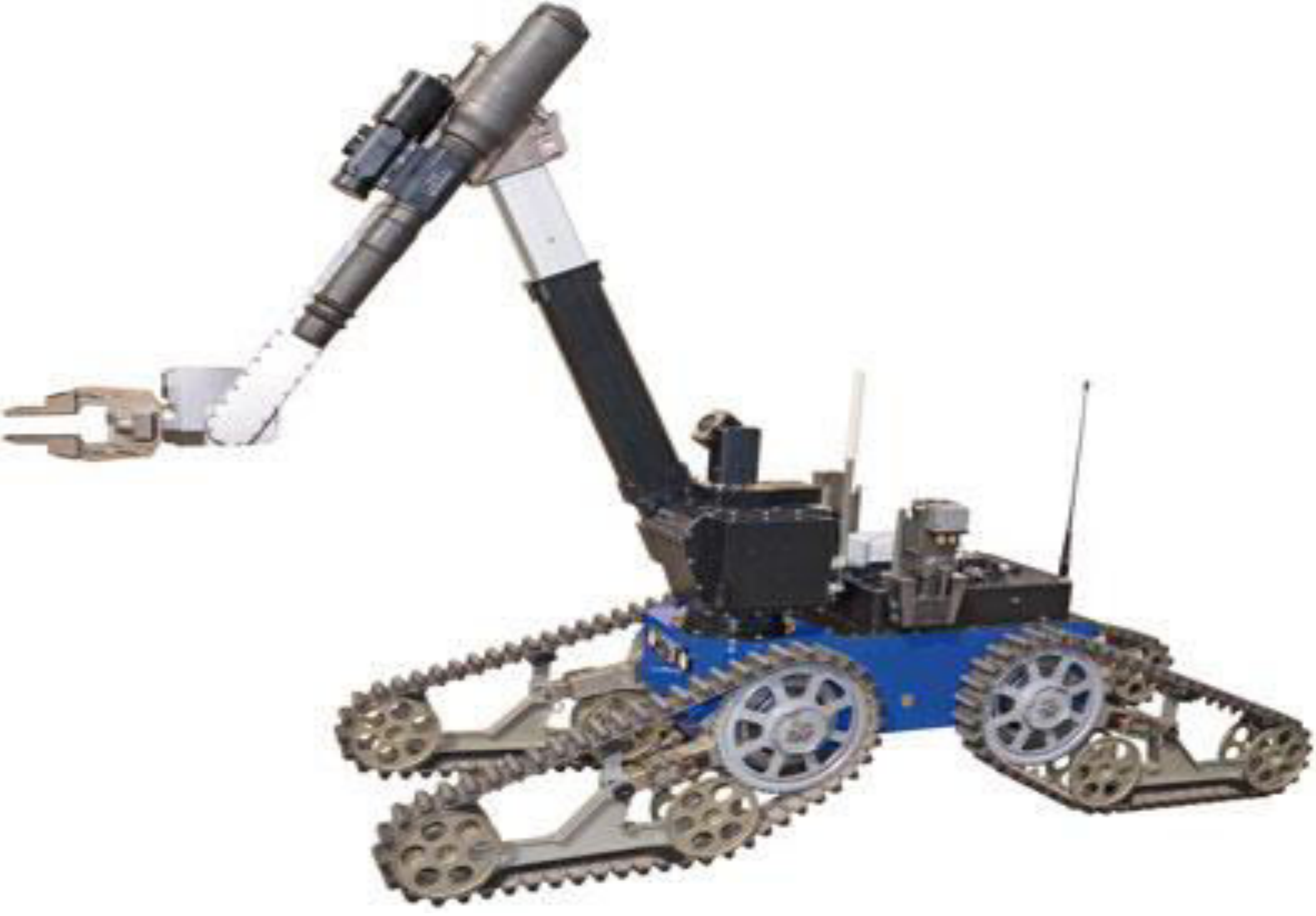




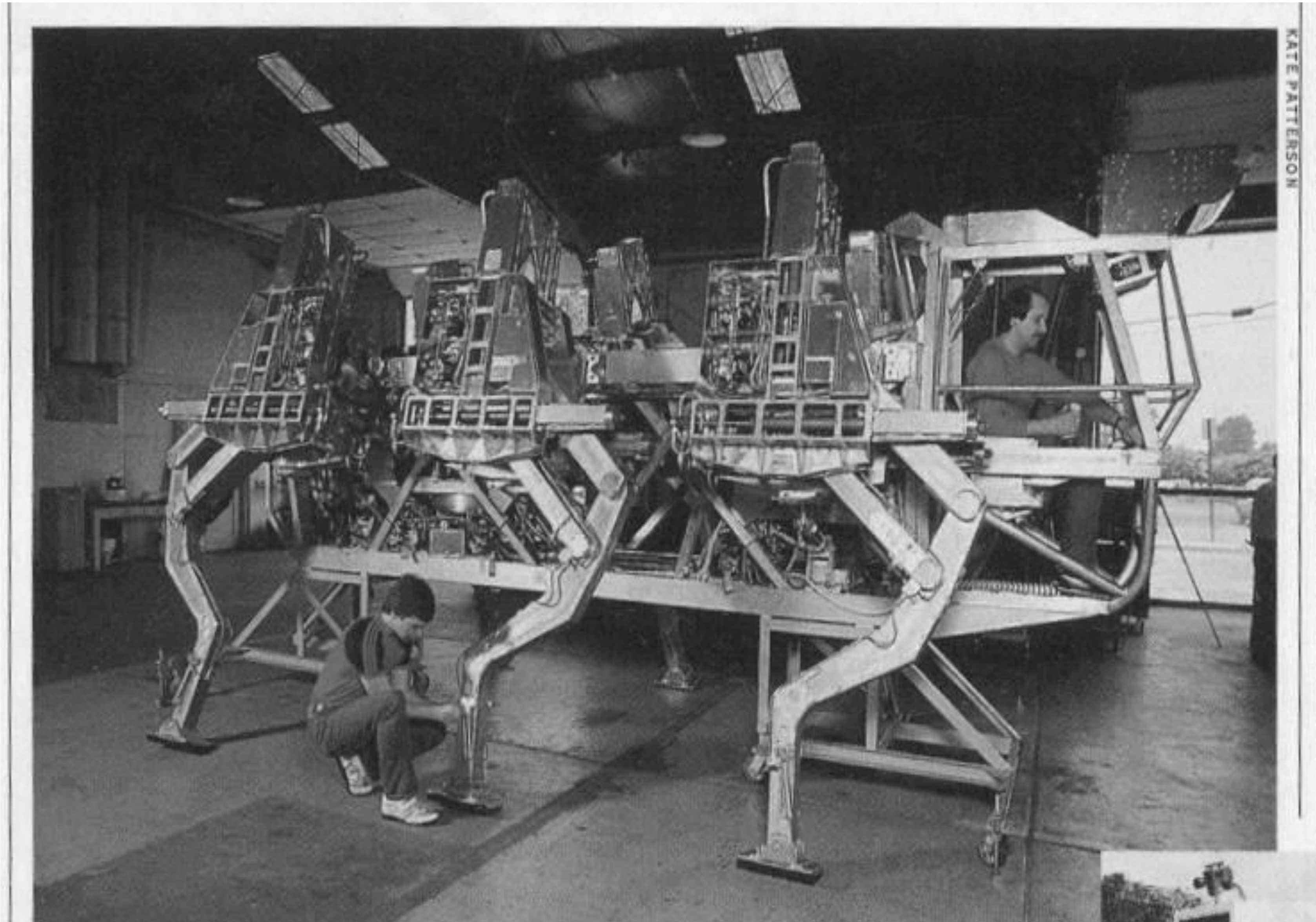
ROBOTS

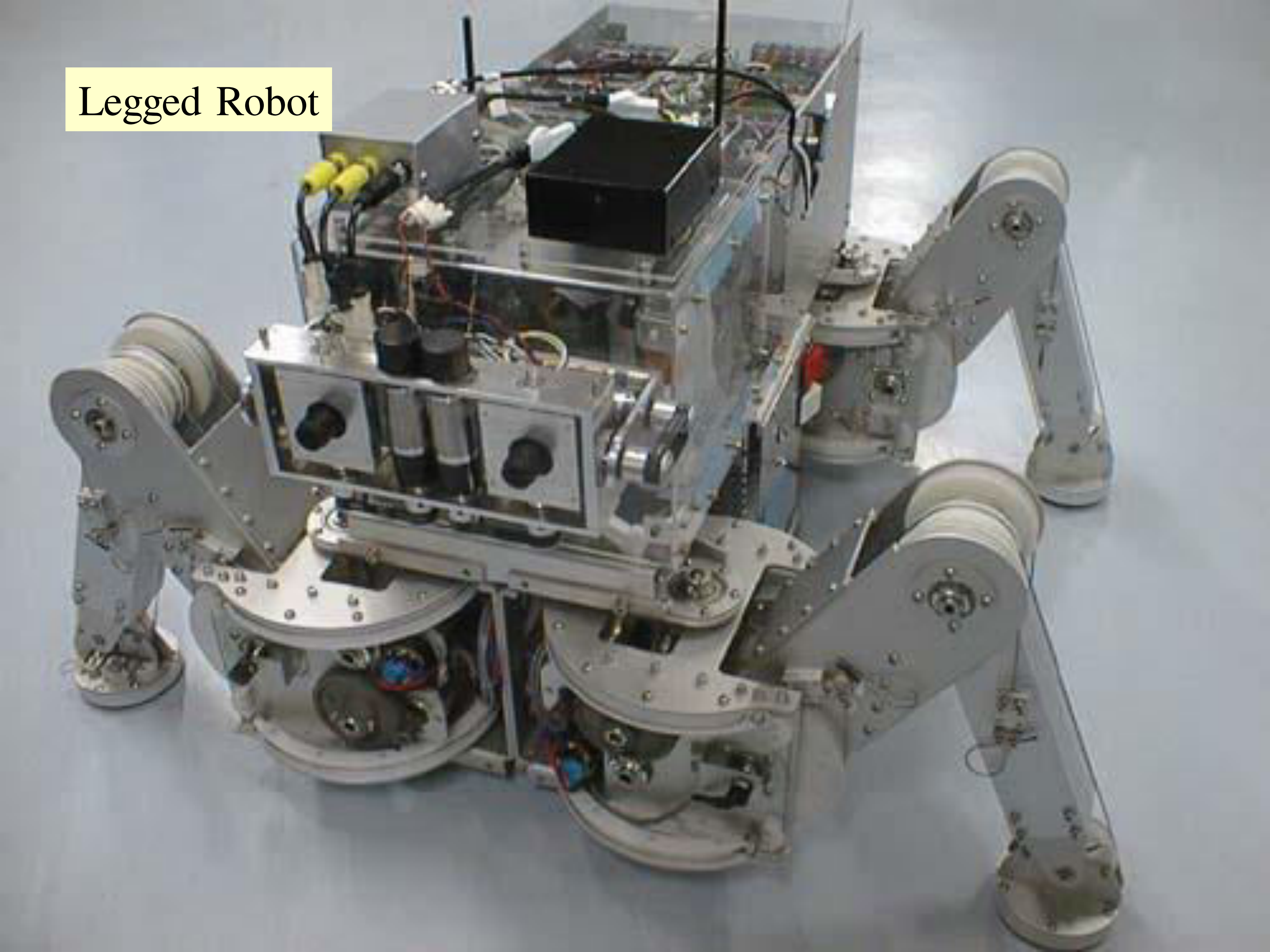
A255 robot



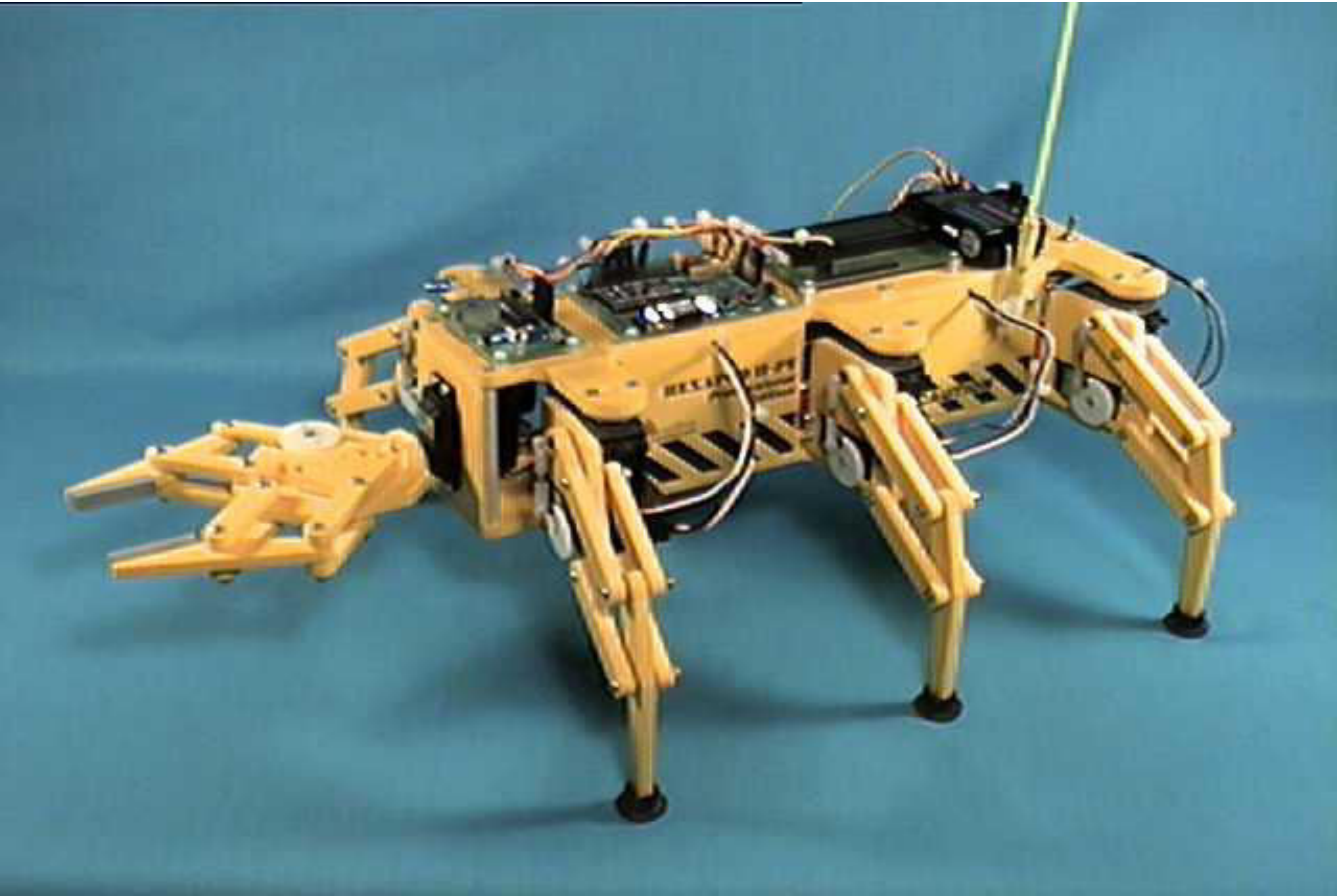


Six-Legged Robot

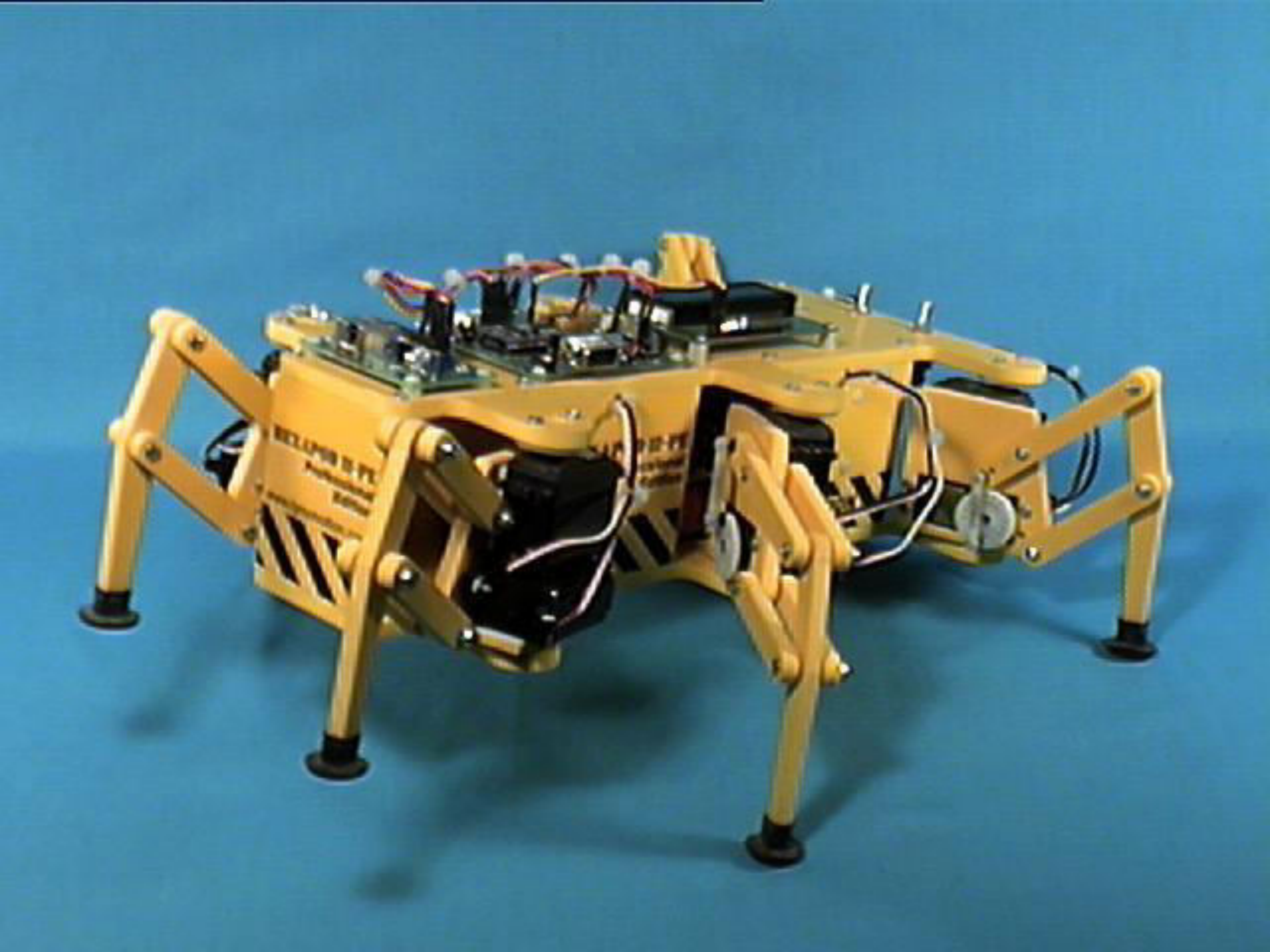


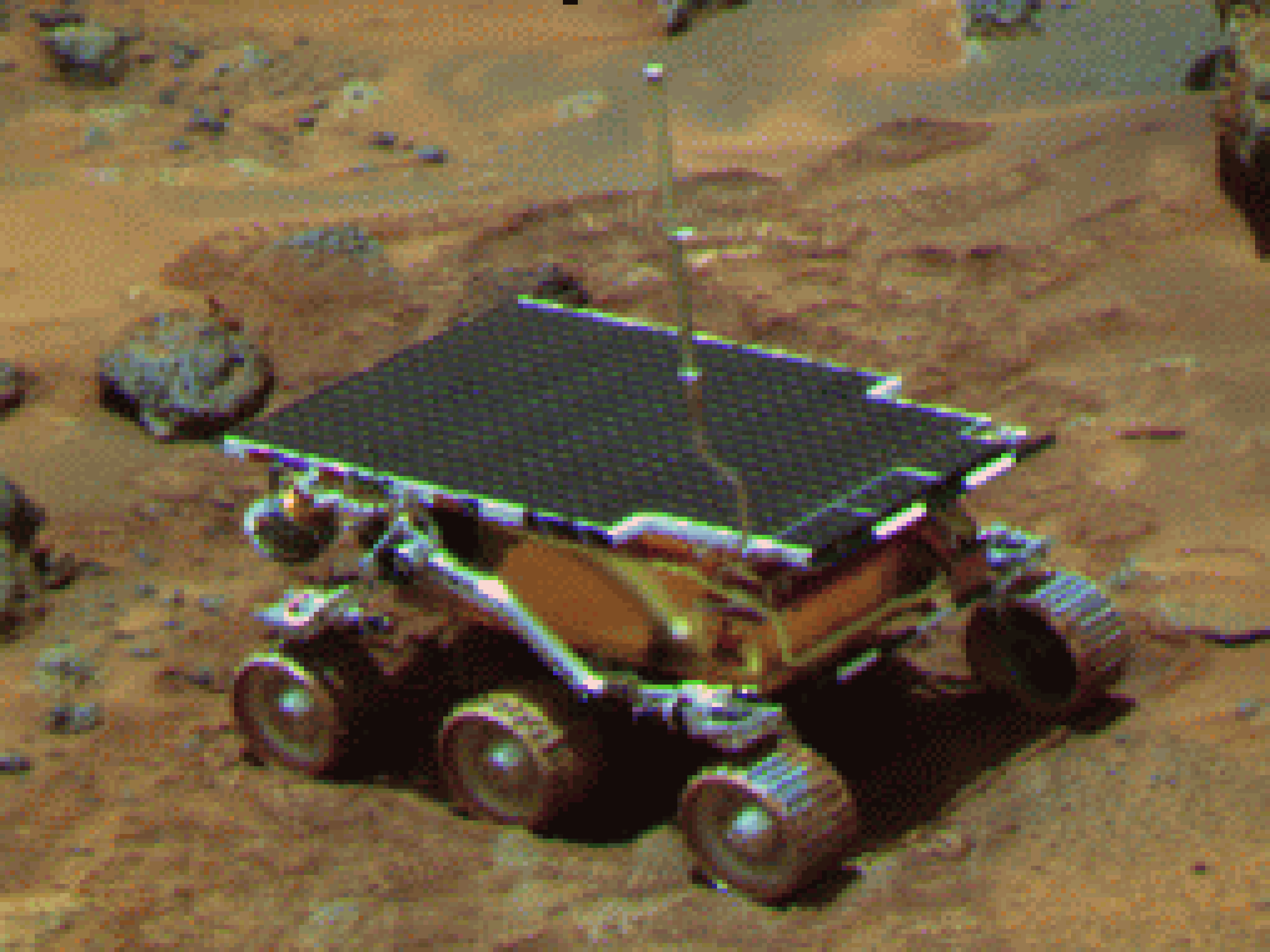

Legged Robot

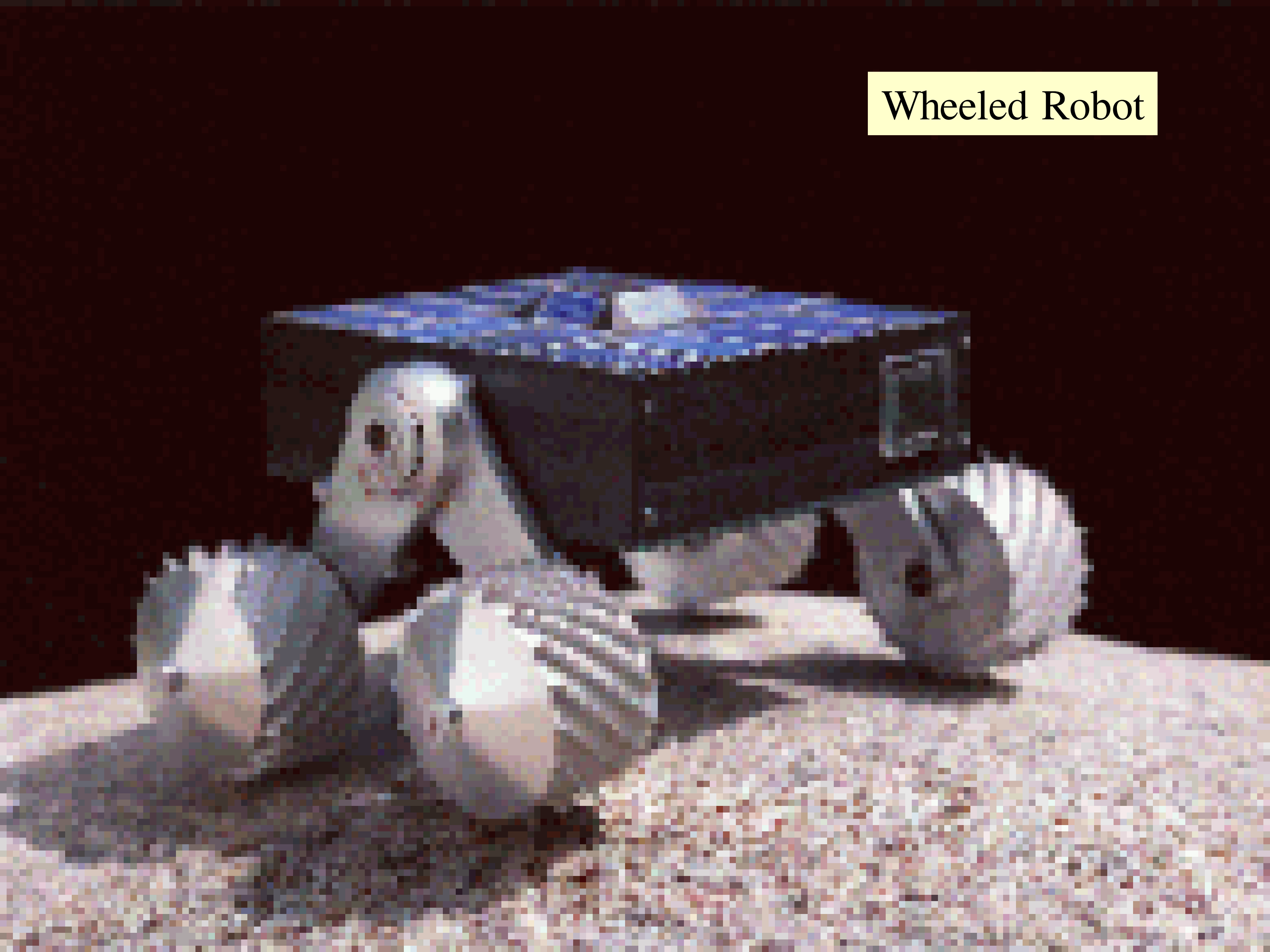
Basic Radio-Controlled Spider Robot

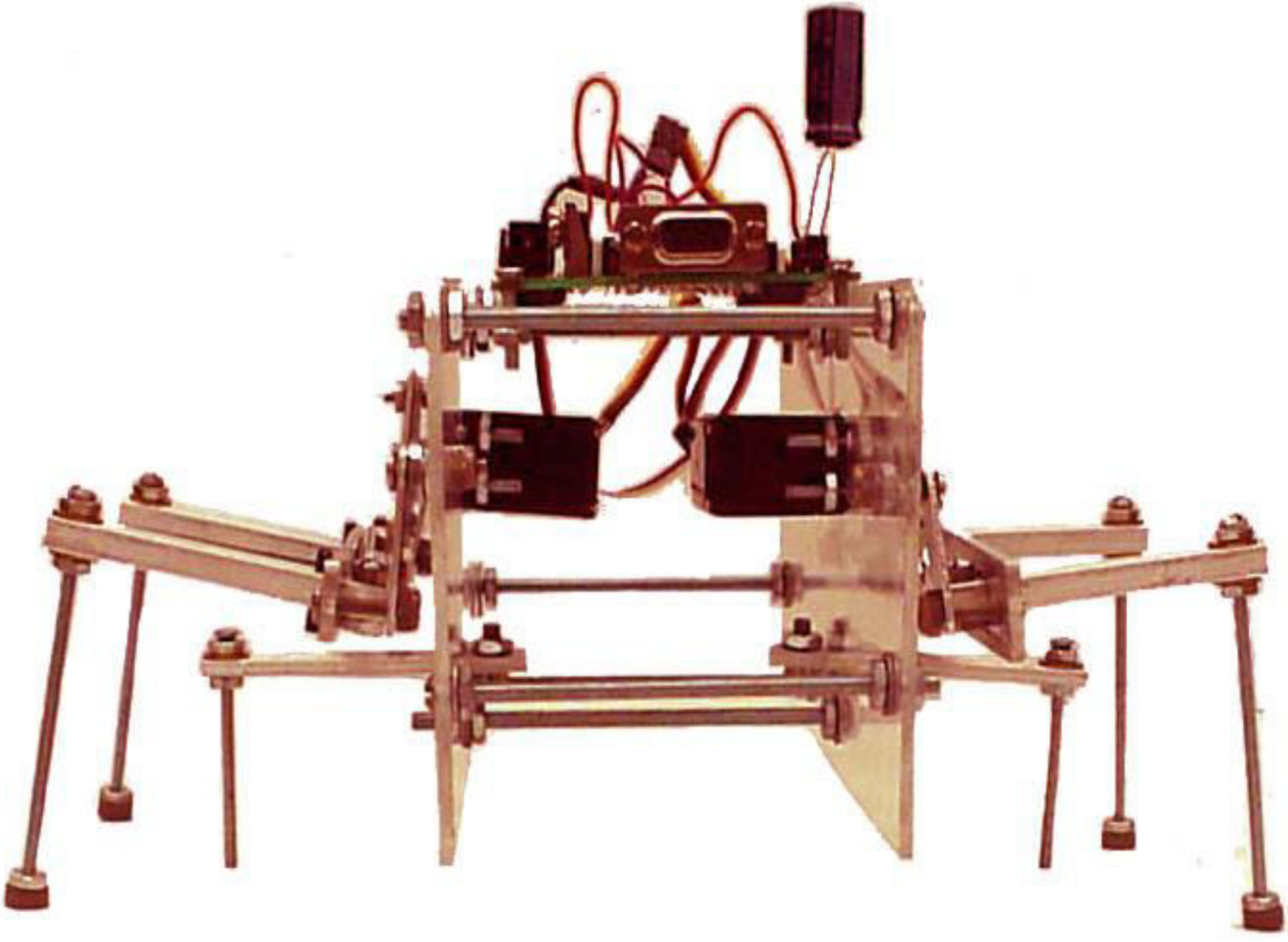


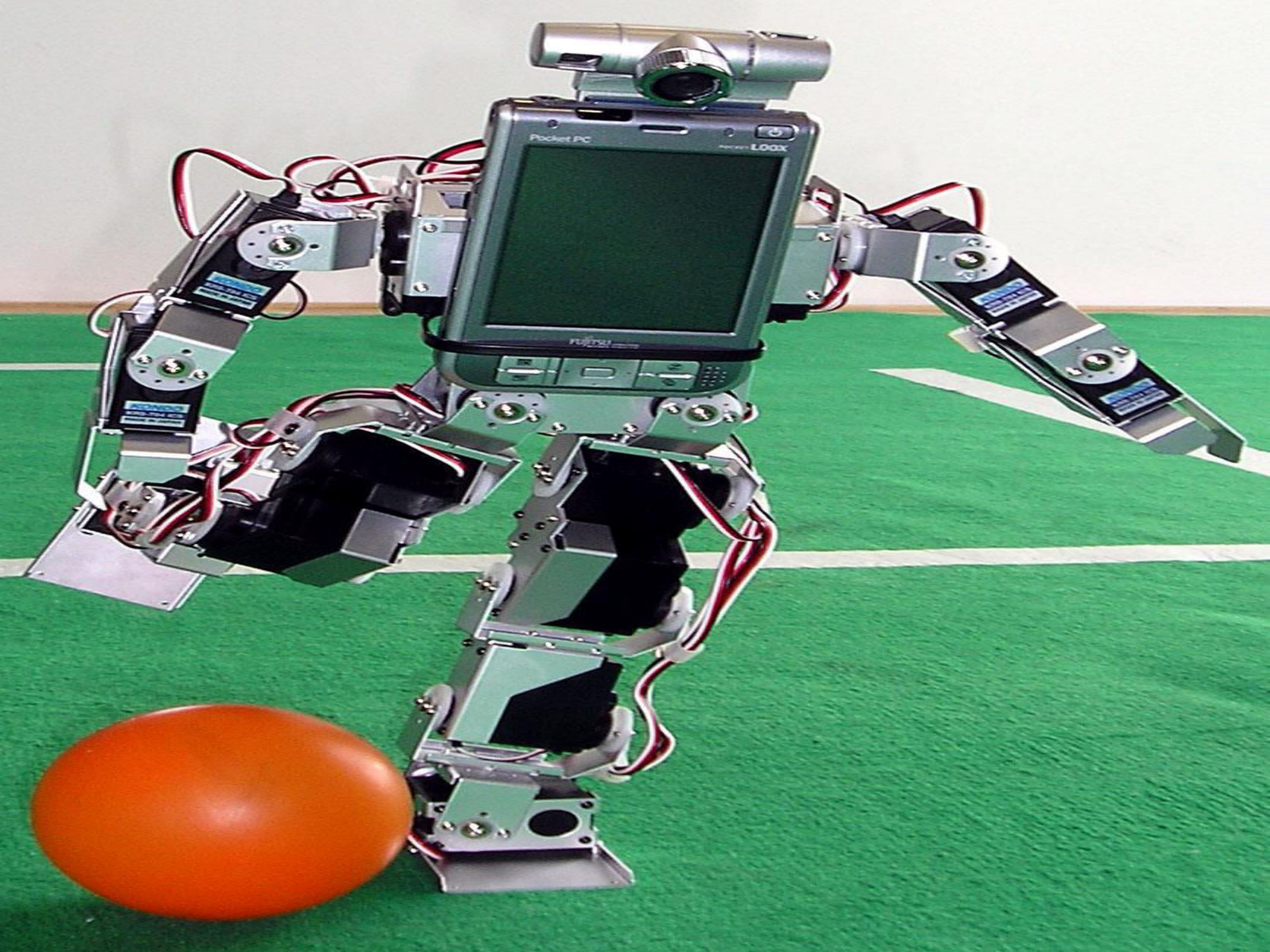
Spider with a camera






Wheeled Robot




Pocket PC
LOOX

DEFINITION

- A robot is a device that performs functions ordinarily ascribed to human beings or operations with what appears to be almost human intelligence.

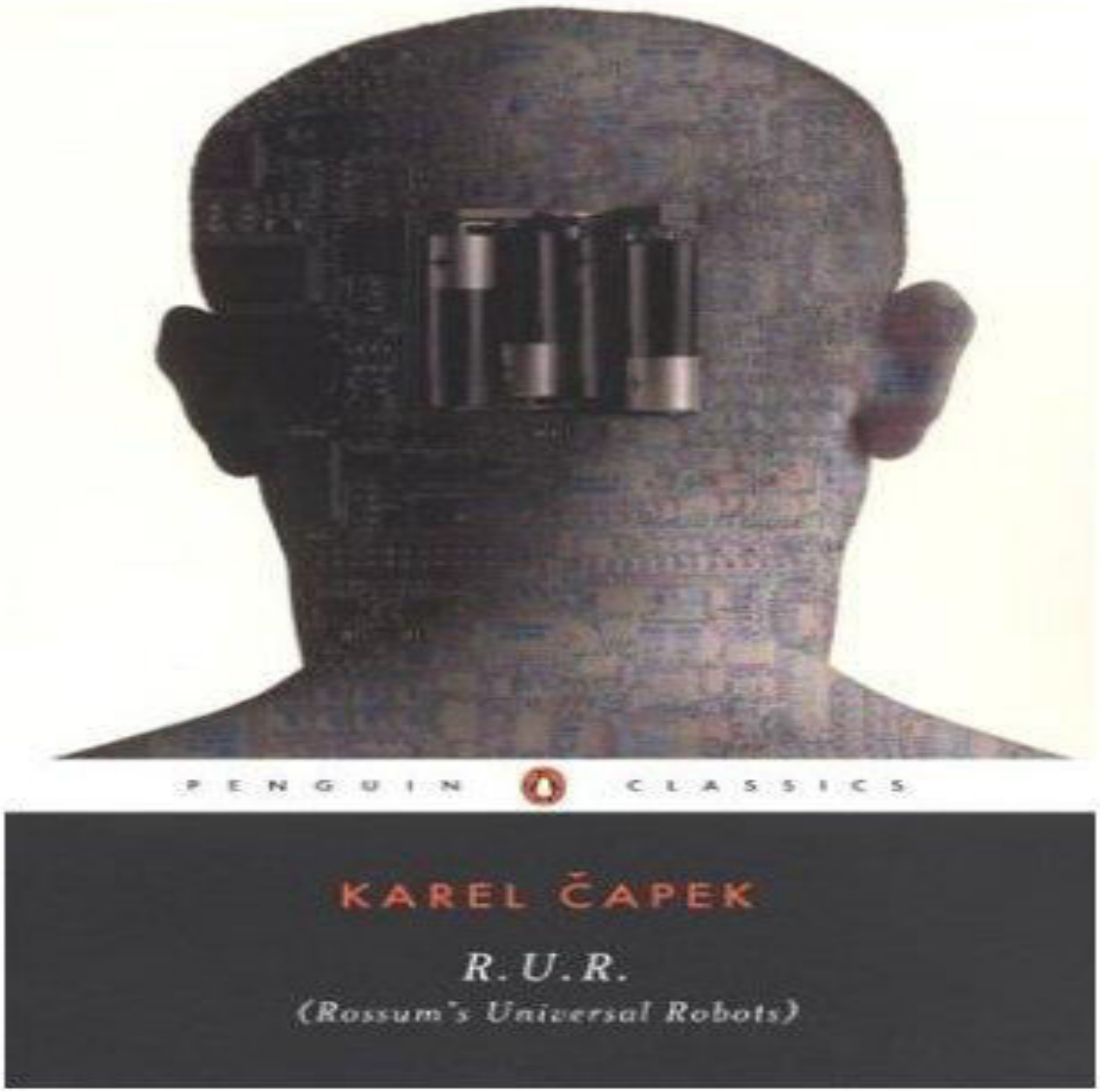
- A robot is a programmable, multifunctional manipulator designed to move materials, parts, tools, or special devices through variable programmed motion for the performance of a variety of task.

BASICS OF A ROBOT

- Many robots do have several qualities in common.
- Almost all robots have a movable body.
- Some only have motorized wheels, and others have dozens of movable segments, typically made of metal or plastic.
- Like the bones in your body, the individual segments are connected together with joints.
- A robot needs a power source to be a functional machine.
- Most robots will use a battery even though some will use a plug in the wall if the robot is stationary.

HISTORICAL DEVELOPMENT OF ROBOT

- **1817:**
  - May Shelly published a fiction novel titled **"Frankenstein"** which deals with the story of a scientist who wants to create a monster human, which then proceeds to raise a havoc in the local community.
- **1921:**
  - Karel Capek, a Czechoslovak playwright wrote a story called **"Rossunis Universal Robot"** and introduced the word Robota meaning slave worker.



"Robot" coined by Karel Capek in a 1921 science-fiction Czech play

- **1942:**
  - The word Robotics was first used in RUNAROUND, a short story published by Isaac Asimov.

- **1956:**
  - George Devol, Normal Schafler and Joseph F. Engelberger made a serious and commercial effort to produce a robot.
  - They started a firm named Unimation and succeeded in building the first robot named Unimate.
  - Joseph F. Engelberger is known as the ‘Father of Robotics’
- **1962:**
  - The first industrial robot appeared General Motors USA, supplied by Unimation.

- **1983:**
  - Odetics, Inc. a US company developed a 6 legged device that could walk over obstacles while lifting loads upto 2-3 times its weight.

- **1985:**
  - The first autonomous walking robot machine was developed at Ohio State University

- **1996:**
  - Honda demonstrated the Honda Humanoid, a robot with 2 legs and 2 arms.

ISSAC ASIMOVA LAWS OF ROBOTICS

- Issac Asimova has contributed a number stories about robots. The robots performs on the basis of three principles known as three laws of robotics.
  - A robot should not injure a human being or life.
  - A robot should obey the order of the master without conflicting the first law.
  - A robot should protect its own existence without conflicting the first and second law.

ELEMENTS OF A ROBOTIC SYSTEM

- A robot is a system made up of several elements of hardware and software.
- These elements are:

(a) Mechanical Components

- Components of robot manipulator
    - A manipulator (the base and arm assembly)
    - End-of –arm tooling such as gripper or end effectors
    - Actuators (motors or drives that moves the links of the robot)
    - Transmission elements like belts, pulleys, ball screws, gearing and other mechanical components.

(b) Control System

- The control system is used to coordinate the movements of the robots It includes
  - Mechanical, Hydraulic, pneumatic, electrical, or electronic controls
  - Sensors, cameras, amplifiers, and related hardware.
  - Equipment interface.

c) Computer System

- This provides the data processing necessary to program and control the robot. It includes :
  - Microprocessor
  - User interface (keyboard, display)
  - Control software
  - Software to manipulate the robot for various applications

CLASSIFICATION OF ROBOTS

1. General Classification

- Industrial robots used for multiple applications can be classified as manipulator robot. Manipulator robot involves working together with other piece of automated or semi-automated equipment.
- There are three broad classes of industrial automation.

- Fixed Automation
- Programmable automation
- Flexible automation

- Manipulators robots are commonly used for programmable automation and flexible automation

2. Robot Generation

- First Generation:
  - Operates according to strict and fixed sequence of operations.
  - Has no sensing and computing power.
- Second Generation
  - Has sensory feedback, a reasonable high level of computing power and an explicit text of high level of language.
  - It is known as cleaver robot.
  - They are more complex and more expensive since they are provided with number of sensors.

- Third generation

    - They are called intelligent robots.
    - They allow decision making and problem solving. through sensory feedback based on artificial intelligence technique.

- Fourth Generation

    - It has all the features of a human being.
    - It is a machine which has a physical strength and intelligence similar humans.
    - Robots has all types of sensors to recognize the objects and environment and it take decision to perform a task as human being.

- Fifth generation
  - It is superior to fourth generation robots, hence it is more complex.
  - It has physical strength and intelligence than humans.
  - It has all the professional decision making ability for a particular task.

3. Structural Capabilities

- According to the structural capabilities all robots are classified as **fixed robots** and **mobile robots.**

- In a fixed robots the base of the robots are always fixed and it acts on open chain mechanism.
- Mobile robots use a locomotive mechanism to move around the fixed environment.
- Mobile robots are classified as wheel robot and walking robot.
- Walking robots are robots that imitate humans beings or animals by having the ability to walk on two or four legs
- Wheel robots are called Automatic Guided Vehicle (AGV).

4. Intelligence

- Robots system are usually classified as low and high technology group according to their intelligence.
- Low technology robots do not use servo control to indicate relative position of their joints.
- Their control system are intended for single motion cycles such as pick and place of the components.
- High technology robots are servo controlled systems. They accept more sophisticated sensors and programming language.
- The intelligent control robots is capable of performing some of the function and task carried out by human being.

5. Operation Capabilities

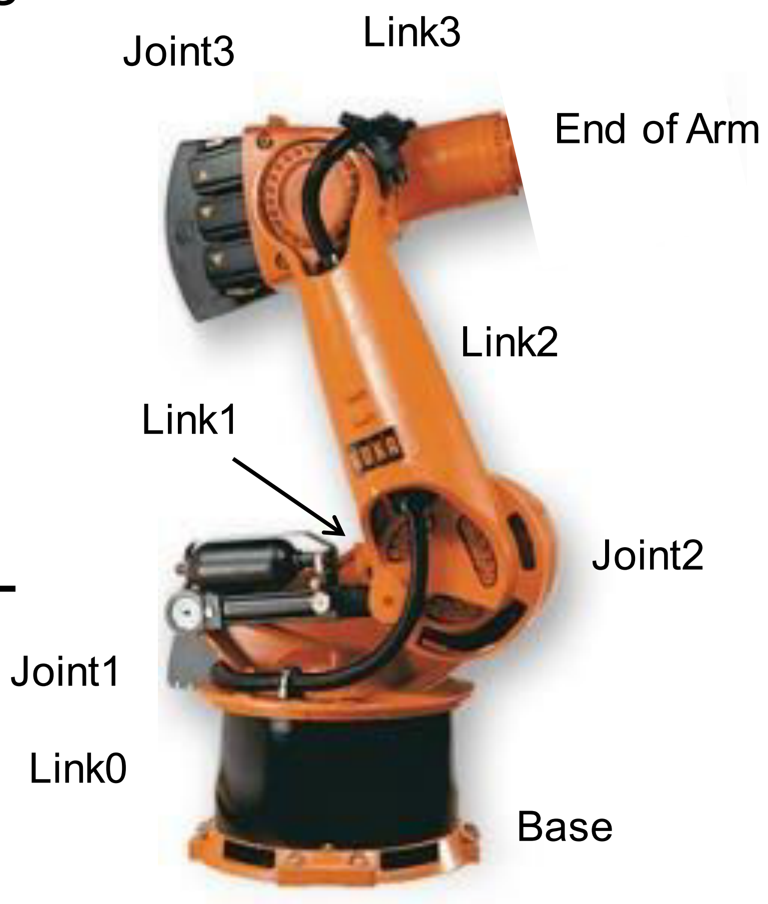
- Commercially available industrial robots can be classified according to their operation capabilities as:
  - Limited sequence control robot
  - Play back robot
  - Controlled path robot
  - Adaptive control robot
  - Artificial intelligence robot

6. Uses

- Robots are best suited in the environment where human cannot perform the task. The use of robot can be classified in five major categories according to its use. They are:
  - Automatic manufacturing
  - Remote exploration
  - Biomedical application
  - Hazardous material handling
  - Service robot.

ROBOT ANATOMY

- Robot manipulator consists of joints and links
  - Joints provide relative motion
  - Links are rigid members between joints
  - Various joint types: linear and rotary
  - Each joint provides a "degree-of-freedom"
  - Most robots possess five or six degrees-of-freedom

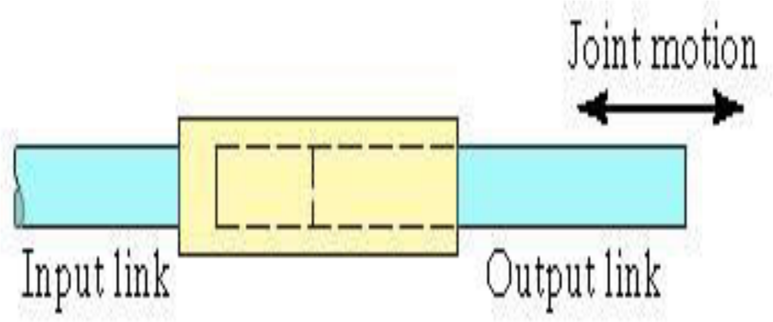


- Robot manipulator consists of two sections:
  - Body-and-arm – for positioning of objects in the robot's work volume
  - Wrist assembly – for orientation of objects

MANIPULATOR JOINTS

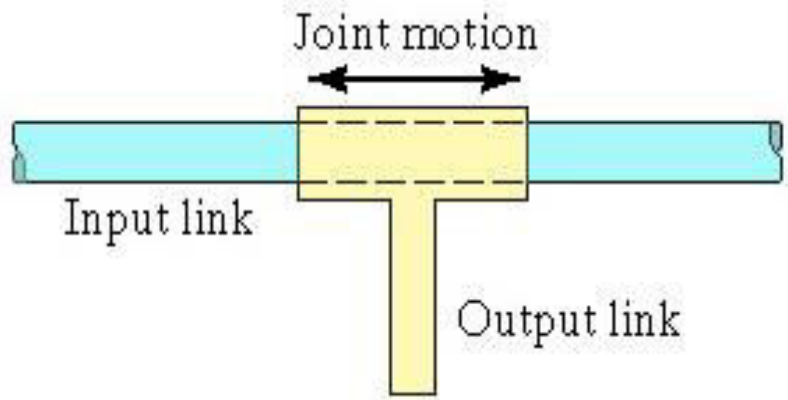
- Translational motion
  - Linear joint (type L)

  The relative movement between the input link and the output link is a translation sliding motion, with the axes of the two links being parallel



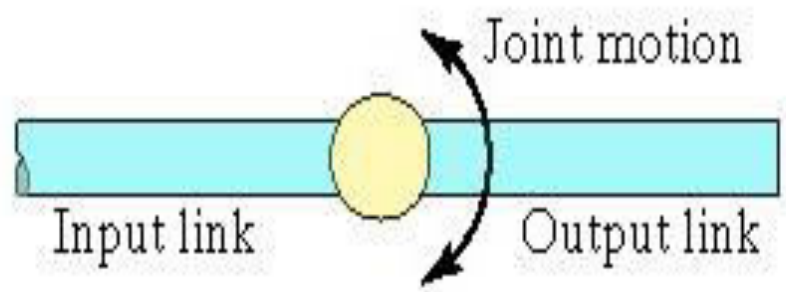
– Orthogonal joint (type O)

This is also a translation sliding motion, but the input and the output links are perpendicular to each other during the move.



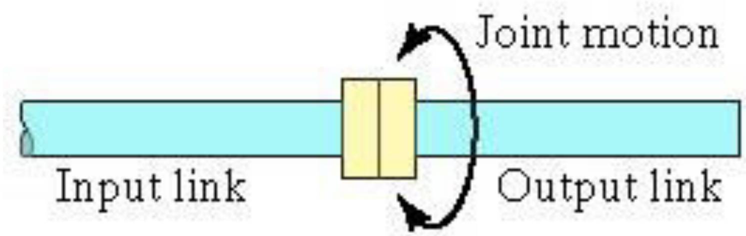
- Rotary motion
  – Rotational joint (type R)

  This type provides rotational relative motion, with the axis of rotation perpendicular to the axes of the input and output links



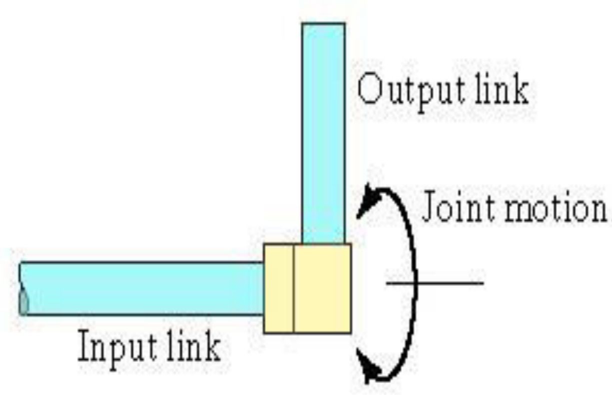
– Twisting joint (type T)

This joint also involves rotary motion, but the axes of rotation is parallel to the axes of the two links.



– Revolving joint (type V)

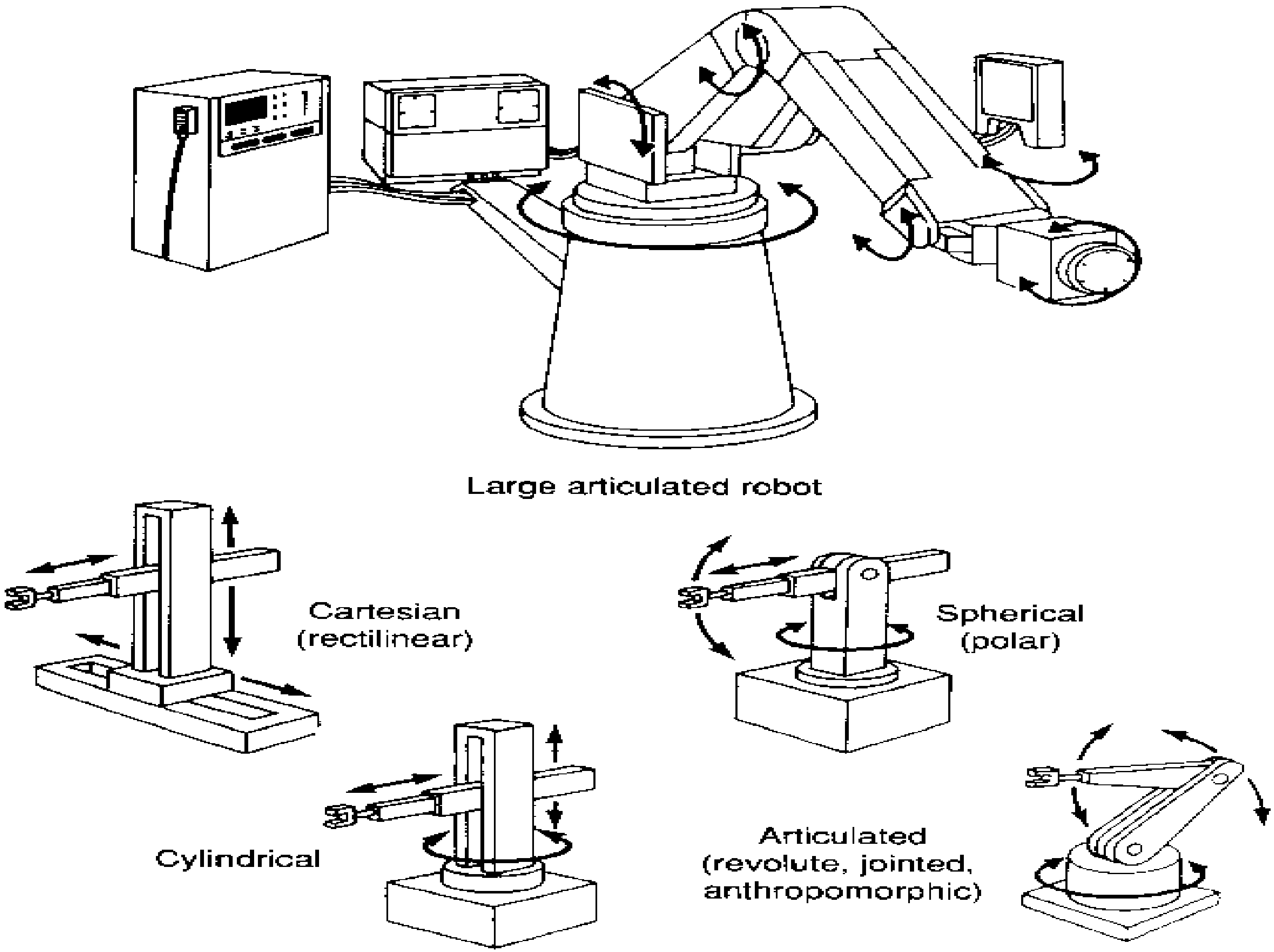
In this joint type , the axes of the input link is parallel to the axes of rotation of the joint, and the axes of the output link is perpendicular to the axes of rotation.



JOINT NOTATION SCHEME

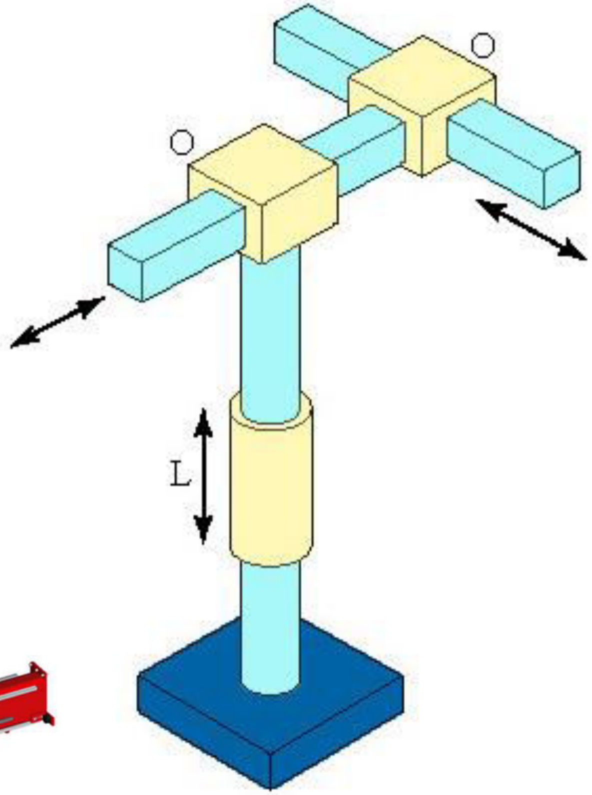
- Uses the joint symbols (L, O, R, T, V) to designate joint types used to construct robot manipulator
- Separates body-and-arm assembly from wrist assembly using a colon (:)
- Example: TLR : TR
- Based on common body-and-arm configurations there are different types of robots.

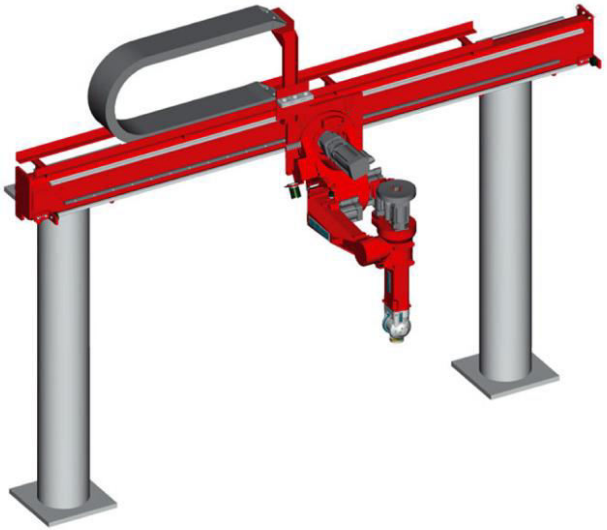
TYPES OF ROBOTS



CARTESIAN ROBOTS
Body-and-Arm Assembly

- Notation LOO:
- Consists of three sliding joints, two of which are orthogonal
- Other names include rectilinear robot and x-y-z robot





Characteristics of Cartesian Robots

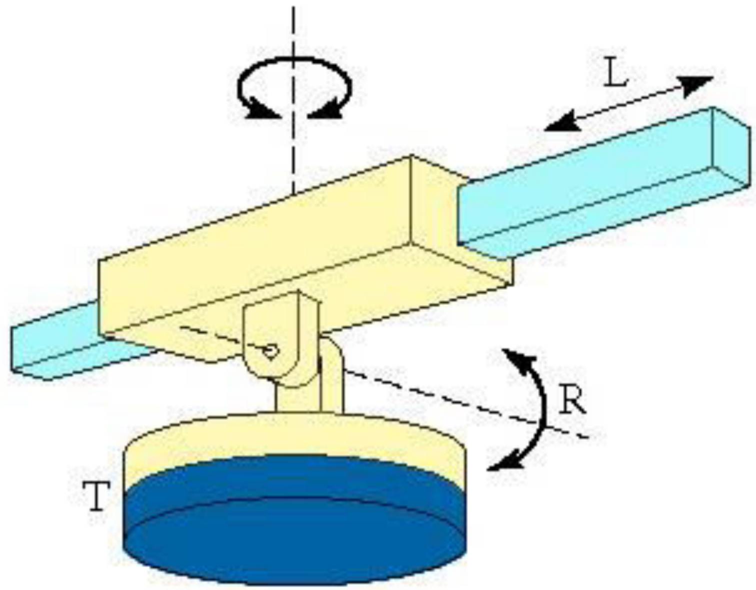
- High resolution and greater accuracy
- Good obstacle avoidness and collision preventiveness
- Independent of gravity in case of parallel joint motion control.
- Large structure frame
- More complex mechanical design
- Requirement of large floor space

Example: Gantry Robot, Cincinnati Milcron T886

- IBM RS 7565

POLAR COORDINATE
Body-and-Arm Assembly

- Notation TRL:



- Consists of a sliding arm (L joint) actuated relative to the body, which can rotate about both a vertical axis (T joint) and horizontal axis (R joint)

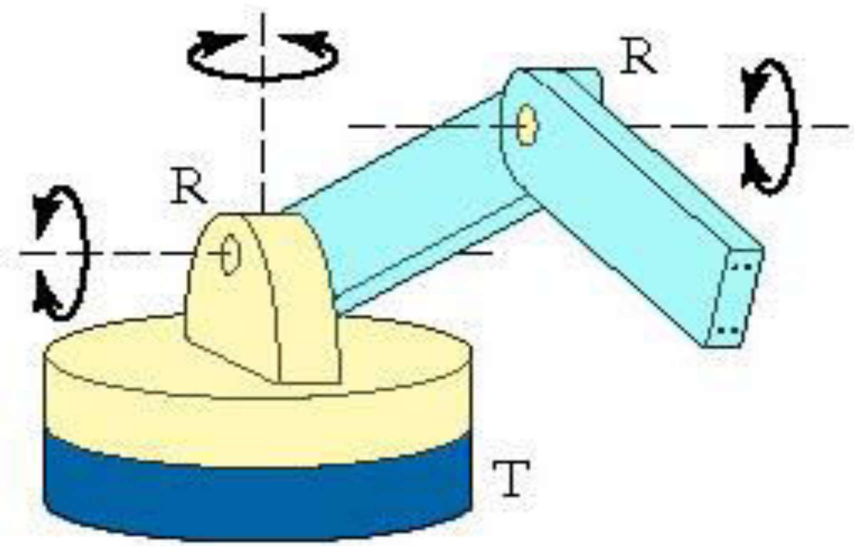
Characteristics of Polar robot

- The polar robot consists of rotary base elevated pivot and a telescopic arm which moves in and out.
  - Lower weight and minimal structural complexity.
  - Sharp joint level.
  - Comparability with robots especially with the machines in common workspace.
  - Large and variable torque required.
  - Counter balancing is difficult
  - Limited ability to avoid collision with obstacles.

Examples: Unimate 2000 SERIES, PUMA

ARTICULATED OR JOINTED-ARM ROBOT

- Notation TRR:
- Consists of a twisting base (T joint) actuated and two rotational axis (R joint)

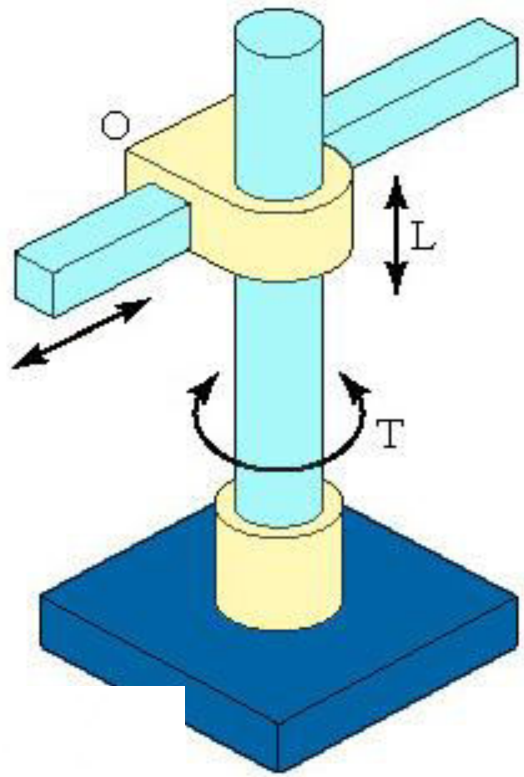


Characteristics of Articulate Robot

- Articulate arm is also known as revolute robot.
  - Excellent mechanical flexibility
  - Compatibility with other robots
  - The robot can rotate at high speed.
  - Poor accuracy and resolution due to revolute joints
  - Large and variable torque
  - High moment of inertia
- Example: Unimate, PUMA, Cininnati Milacron 735

CYLINDRICAL ROBOT
Body-and-Arm Assembly

- Notation TLO:
- Consists of a vertical column, relative to which an arm assembly is moved up or down
- The arm can be moved in or out relative to the column



Characteristics of Cylindrical Robot

- In this configuration, the robot body is a vertical column that swivels about a vertical axis.

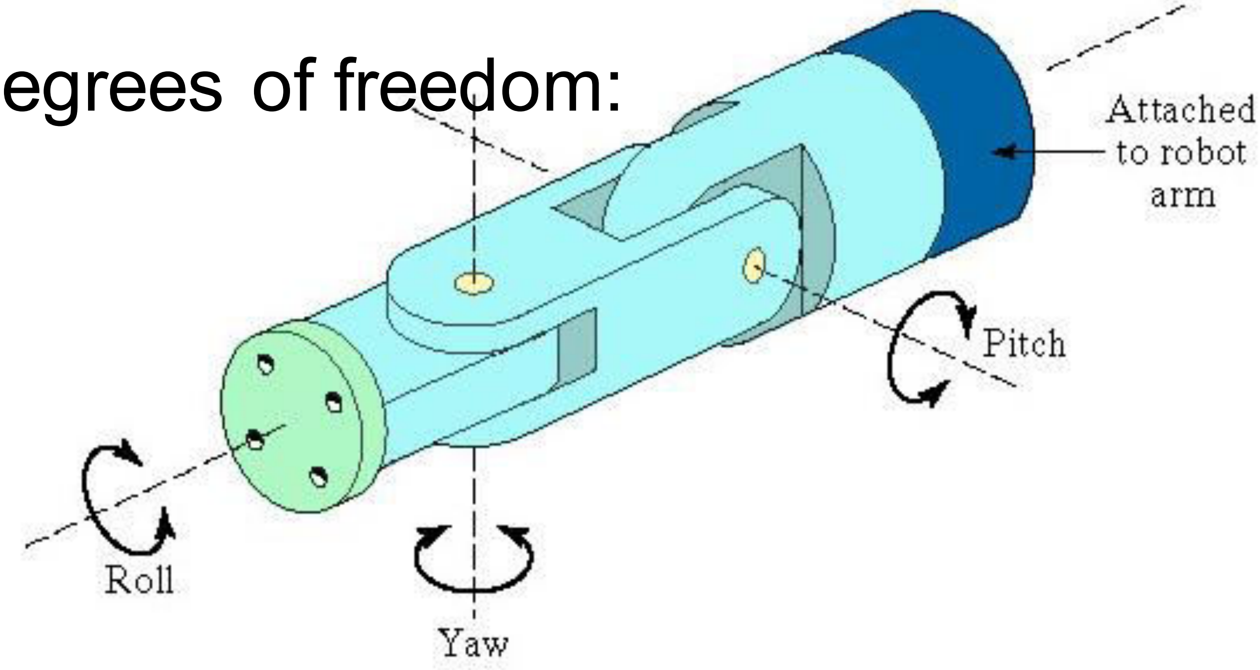
- The arm consists of several orthogonal slides which allow the arm to be moved up or down and in and out with respect to the body.

Example:

  – The Prab Versatran FC Model

WRIST CONFIGURATIONS

- Wrist assembly is attached to end-of-arm
- End effector is attached to wrist assembly
- Function of wrist assembly is to orient end effector
  - Body-and-arm determines global position of end effector
- Two or three degrees of freedom:
  - Roll
  - Pitch
  - Yaw
- Notation :RRT



BASIC ROBOT MOTIONS

- Whatever the configurations, the general purpose is to perform a useful task.
- To accomplish the task, an end effectors, or hand, is attached to the end of the robot's arm.
- To do the task, the robot arm must be capable of moving the end effectors through a sequence of motions and/or positions.
- There are six basic motions, or degrees of freedom, which provide the robot with the capability to move the end effectors through the required sequence of motions.

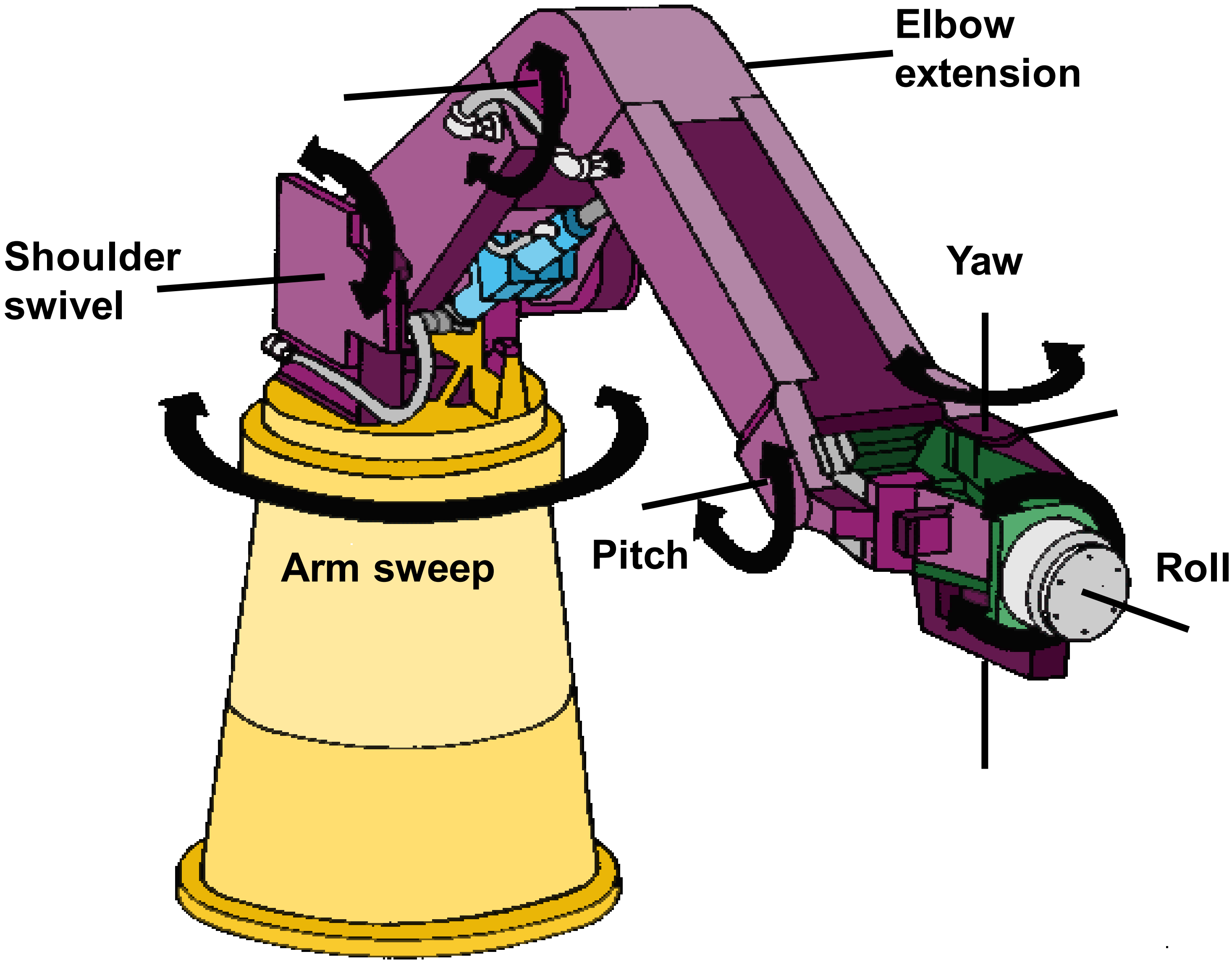
- AI robots are equipped with the ability to move in all six degrees.
- The six basic motions consist of three arm and body motions and three wrist motions.
- These motions are:

Arm and body motions

1. **Vertical traverse:** up and down motions of the arm, caused by pivoting the entire arm about a horizontal axis or moving the arm along a vertical slide.
2. **Radial traverse:** extension and retraction of the arm (in-and-out movement).
3. **Rotational traverse:** rotation about the vertical axis (right or left swivel of the robot arm).

Wrist motions

1. **Wrist swivel:** rotation of the wrist.
2. **Wrist bend:** up-or-down movement of the wrist, which also involves a rotational movement.
3. **Wrist yaw:** right-or-left swivel of the wrist.



Elbow
extension
Shoulder
swivel
Yaw
Arm sweep
Pitch
Roll

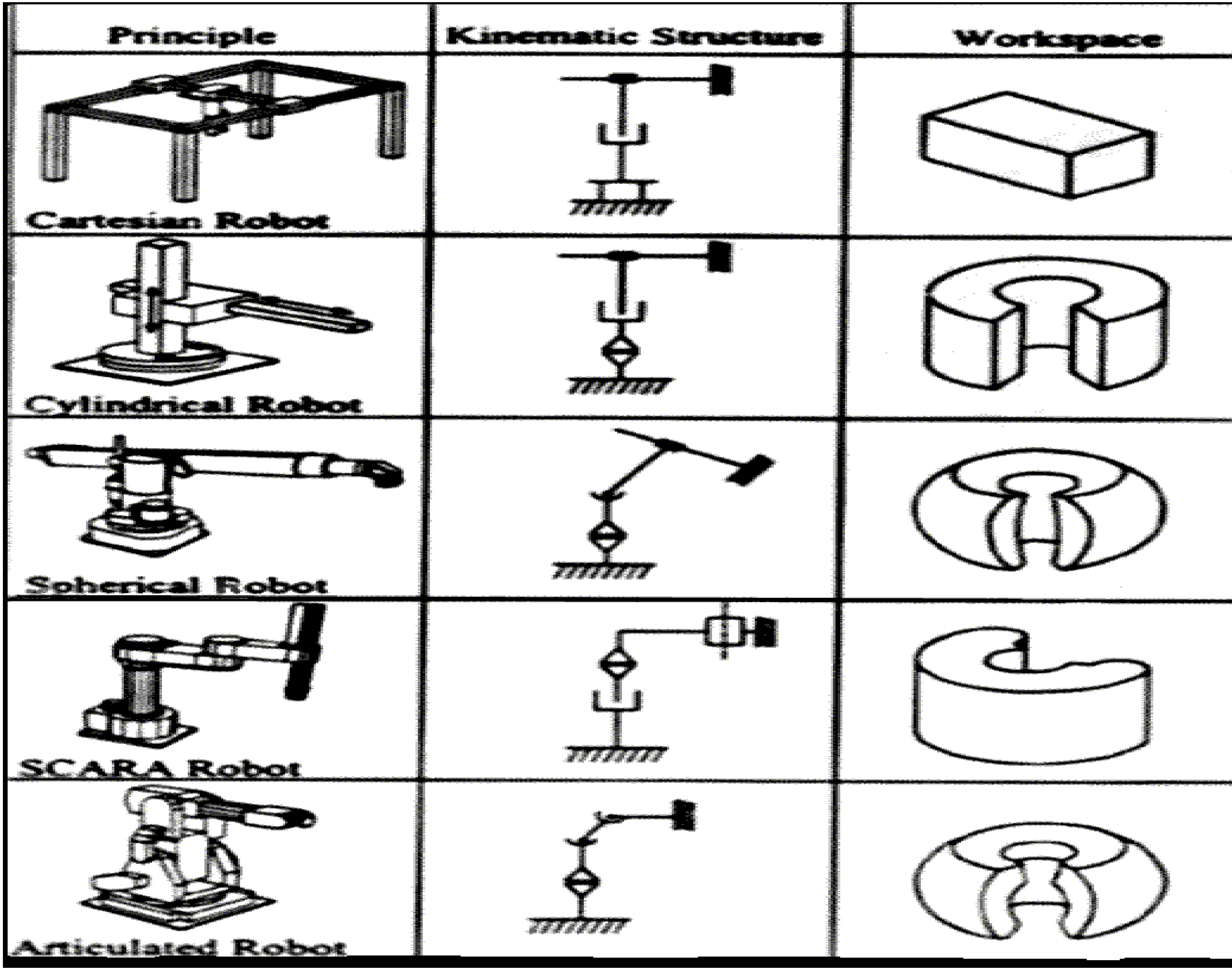
TECHNICAL FEATURES OF ROBOTS

Important Technical Features of the robots are:

- Work Volume
- Precision of movement
- Speed of movement
- Weight carrying capacity
- Type of drive system

Work Volume

- Work volume refers to the space within which the robot can operate.
- The work volume of a industrial is determined by its physical configuration, size and the limits of its arm and joint manipulations.
- The work volume of a cartesian robot will be rectangular.
- The work volume of a cylindrical robot will be cylindrical.
- A polar robot will generate a work volume which is partial sphere.
- The work volume of a jointed arm robot will be somewhat irregular.


Principle
Kinematic Structure
Workspace
Cartesian Robot
Cylindrical Robot
Spherical Robot
SCARA Robot
Articulated Robot

Precision of movement

Precision of movement consist of three attributes.

- Spatial resolution
- Accuracy
- Repeatability

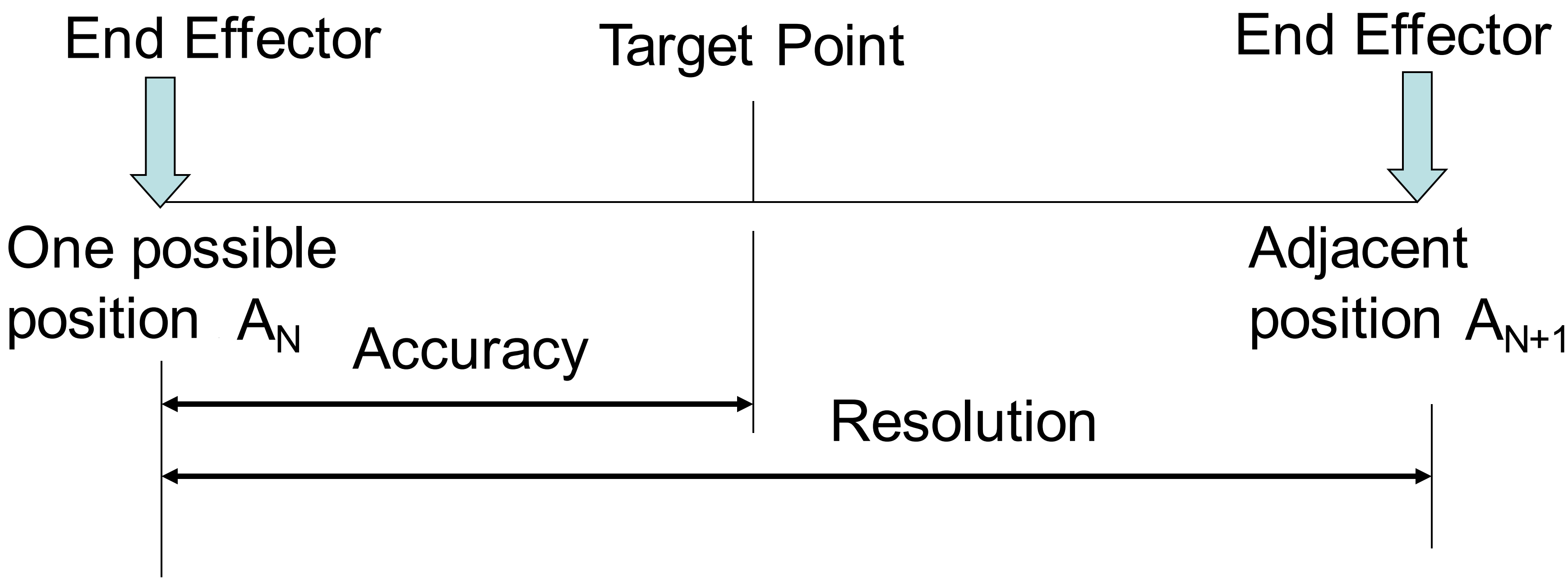
These attributes are generally interpreted in terms of wrist end with no end effectors attached and with arm fully extended.

Spatial Resolution:

- It refers to the smallest increment of motion at the wrist end that can be controlled by the robot.
- This is determined largely by the robot's control resolution, which depends on its position control system and/or its feedback measurement system.
- The spatial resolution is the sum of the control resolution plus some mechanical inaccuracies.

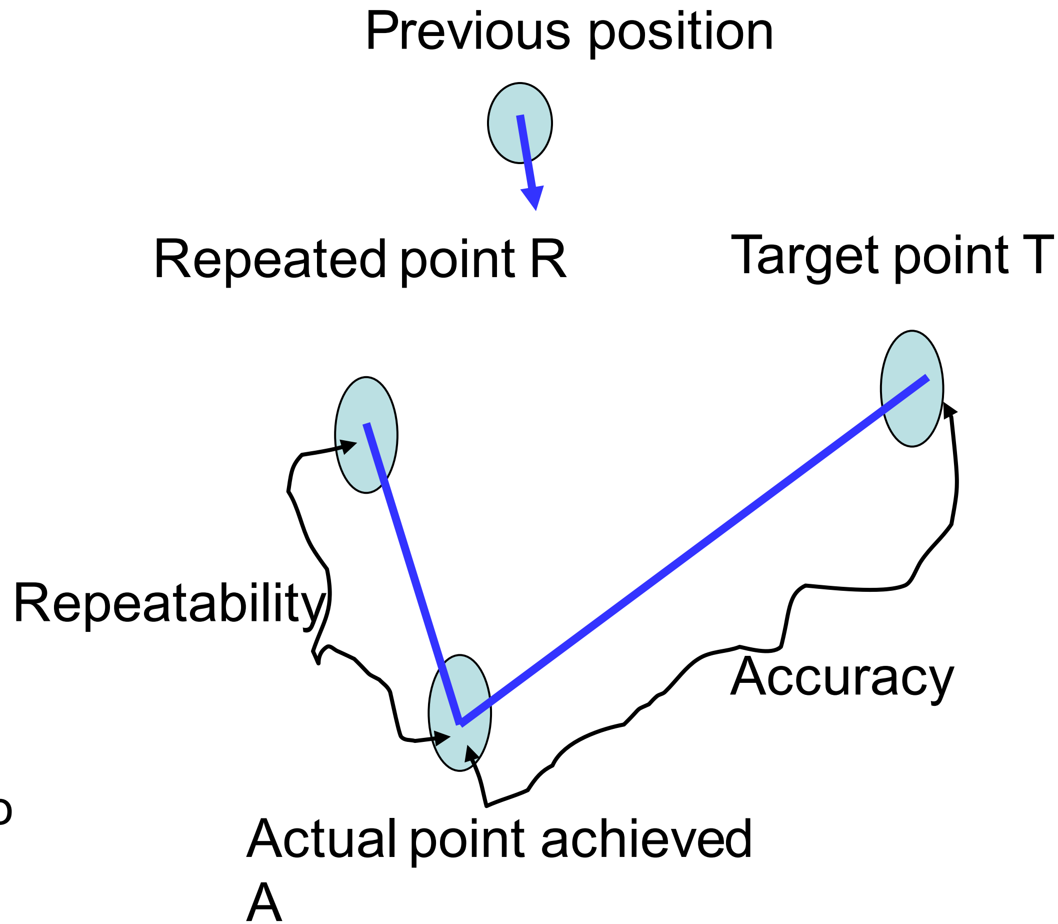
Accuracy

- The accuracy of the robot refers to its capability to position its wrist end at a given target point within its work volume.
- Accuracy is closely related to spatial resolution , since the robots ability to reach a particular point in space depends on its ability to divide its joint movement into small increments.
- Accuracy of the robot is normally one half the distance between two adjacent resolution point.
- Accuracy is affected by mechanical inaccuracies.


End Effector
Target Point
End Effector
One possible position A_N
Adjacent position A_{N+1}
Accuracy
Resolution

Repeatability

- This refers to the robot ability to position its wrist end back to a point in space that was previously taught.
- Repeatability is different from accuracy.
- The robot was initially to move the wrist end to the target point T.
- Because it is limited by its accuracy, the robot was only capable of achieving point A.
- The distance between A and T is the accuracy.
- Later the robot is instructed to return to this previously programmed point A.
- However , because it is limited by its repeatability , it is only capable of moving to point R.
- The distance between points R and A is a measure of the robot's repeatability.



Speed of movement

- The speed with which the robot can manipulate the end effector ranges up to a maximum of about 1.5m/s.
- The speed is determined by such factors as the weights of the object being moved, the distance moved, and the precision with which the object must be positioned during the work cycle.

Weight carrying capacity

- The weight carrying capacity of commercially available robots covers a wide range.

- A t the upper end the range, there are robots are capable of lifting over 1000 lb.

- At the lower end of eth range the robot can lift the load of 2.5 lb.

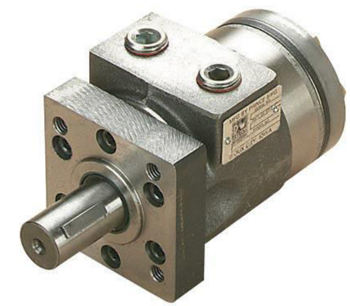
Type of drive system

- There are three drive systems used in commercially available are:

- Hydraulic
- Electric motor
- Pneumatic

- Electric
  - Uses electric motors to actuate individual joints
  - Preferred drive system in today's robots

- Hydraulic
  - Uses hydraulic pistons and rotary vane actuators
  - Noted for their high power and lift capacity



- Pneumatic
  - Typically limited to smaller robots and simple material transfer applications

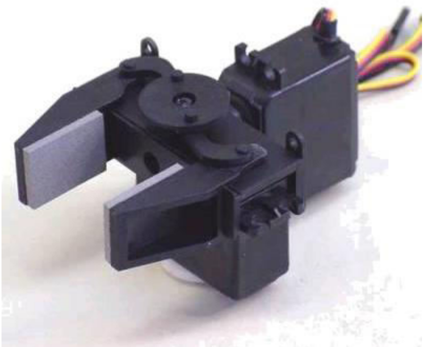
MODULAR ROBOT COMPONENTS

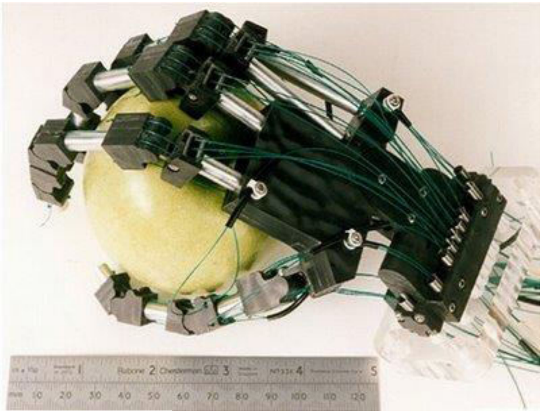
- Most of the industrial robots are custom built to the specification of the buyer.
- However modular component and other parts are assembled to make the required robot.

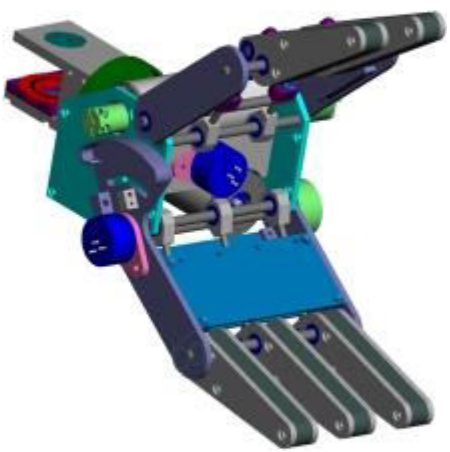
BASIC MODULAR COMPONENTS

- End Effectors
  - » Grippers: to grasp and manipulate objects (e.g., parts) during work cycle
  - » Tool Holding devices: to perform a process, e.g., spot welding, spray painting
- Wrist Mechanism
- Sensors

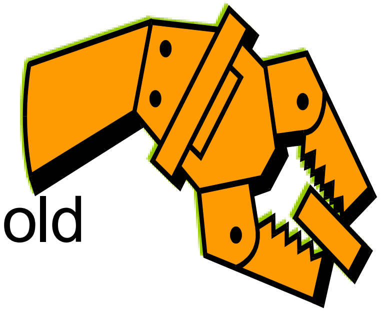
GRIPPERS AND TOOLS







GRIPPERS

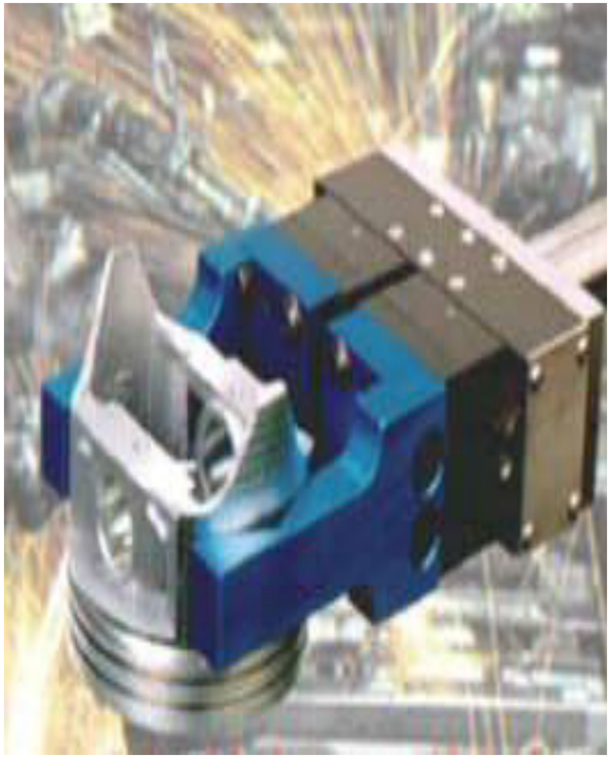


- Grippers are end effectors used to grasp and hold objects.
- A grippers regardless of its type and capacity, it must fulfill the following characteristics:
  - Gripers must be capable of gripping, lifting and relocating the part of family of parts required by the process.
  - Some gripper sense the presence of the parts with their gripping action.
  - Tooling weight must be kept minimum.
  - The gripper must be simple in design and accurate in operation.
  - It must be equipped with collision sensor to accommodate overload conditions and safe guarding.

- The following is a list of the most common grasping methods used in robot grippers.
  - Mechanical grippers, where friction or the physical configuration of the gripper retains the object.
  - Suction cups also called vacuum cups, used for flat objects.
  - Magnetized gripper devices, used for ferrous objects.
  - Hooks, used to lift parts off conveyors.
  - Scoops or ladles, used for fluids, powders etc.

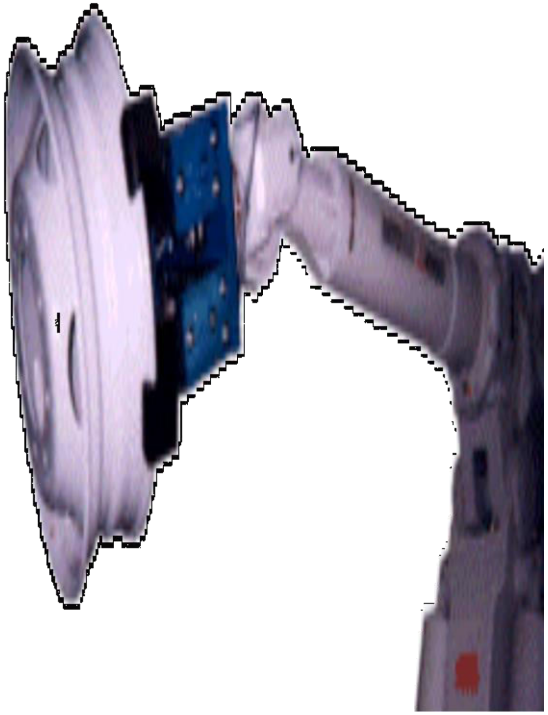
Main Types of Mechanical Grippers

Parallel

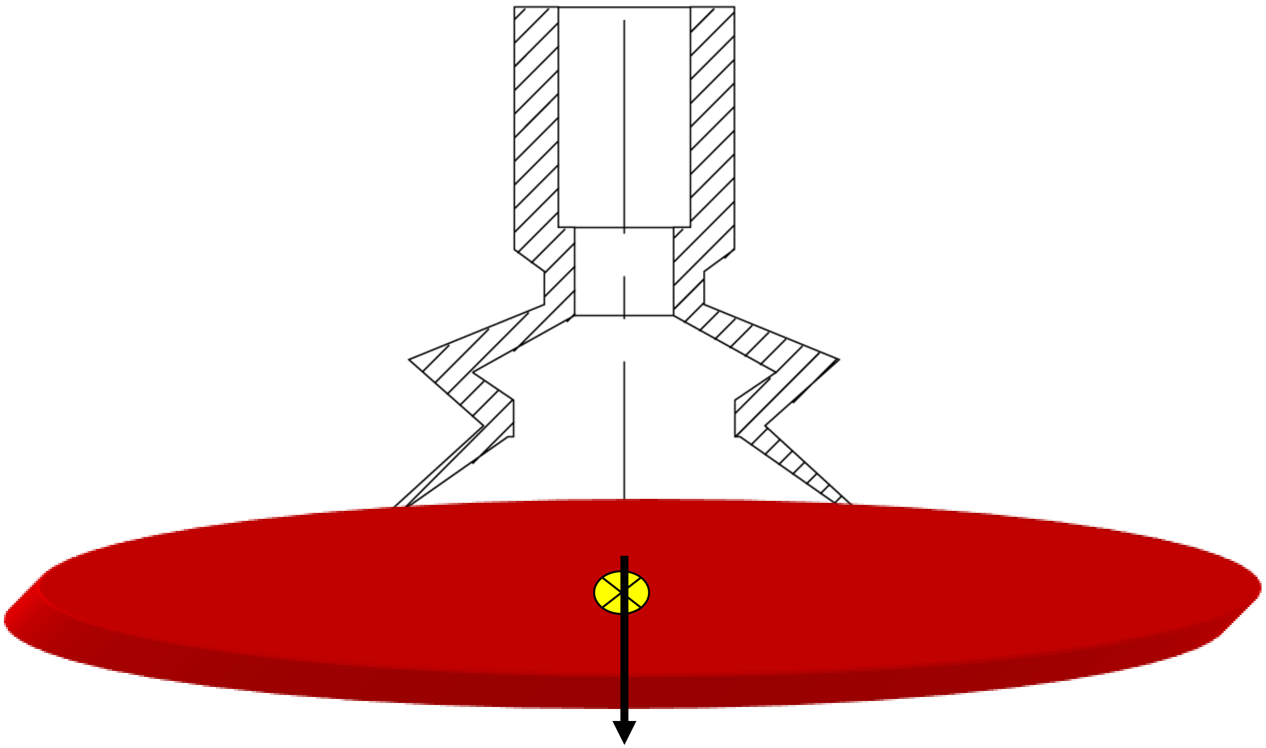


Angular

2 or more "fingers"



Vacuum Grippers (suction cups)



Vacuum Grippers Application

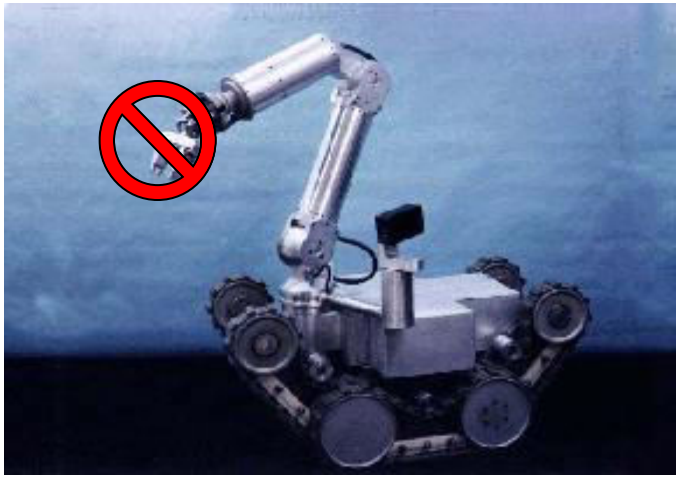
PACKAGING:

Canning
Tray Making
Bottling
Box Making
Capping
Labeling
Bagging & Sealing

MATERIAL HANDLING:

Auto Manufacturing
Steel Fabricators
Conveyors
Manufacture & Packaging of Compact Dics
Electronics
Heavy Industry

TOOLS AS END EFFECTORS



- Process tool holder is an end effectors designed to perform work rather than to pick and place a work part.
- Tools
  - Spot welding
  - Arc welding
  - Drilling, grinding, de-burring, etc.
  - Cutting device (laser, water jet, torch, etc.)
  - Spray painting

ROBOTIC SENSORS

- What is Sensing ?
- Collect information about the world

- Sensor - an electrical/mechanical/chemical device that maps an environmental attribute to a quantitative measurement

- Each sensor is based on a *transduction principle* - conversion of energy from one form to another..
- Also known as transducers

ROBOTIC SENSORS

- Human senses: sight, sound, touch, taste, and smell provide us vital information to function and survive.

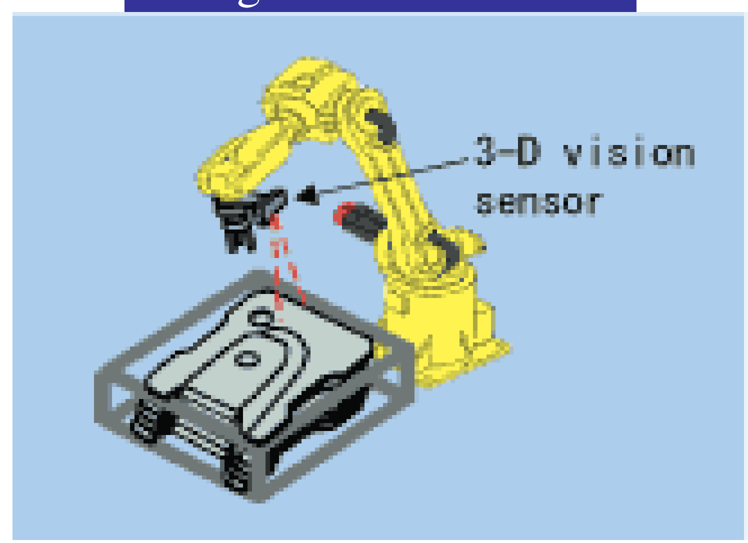
- Robot sensors: measure robot configuration/condition and its environment and send such information to robot controller as electronic signals (e.g., arm position, presence of toxic gas)

Vision Sensor:

Robot vision is made possible by means of a video cameras, a sufficient source of light and a computer programme to process image data.

The computer software enables the vision system to sense the presence of an object and its position and orientation.

In-Sight Vision Sensors



- Vision capability will enable the robot to carry out the following operations:

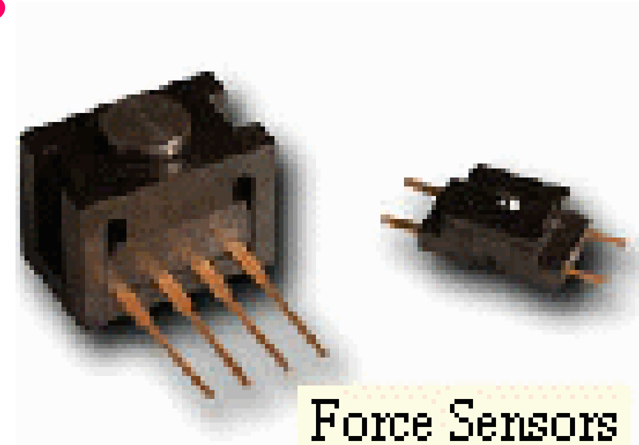
- Retrieve parts which are randomly oriented on a conveyor.
- Recognize particular parts which are intermixed with other objects.
- Perform visual inspection tasks
- Perform assembly operations which require alignment

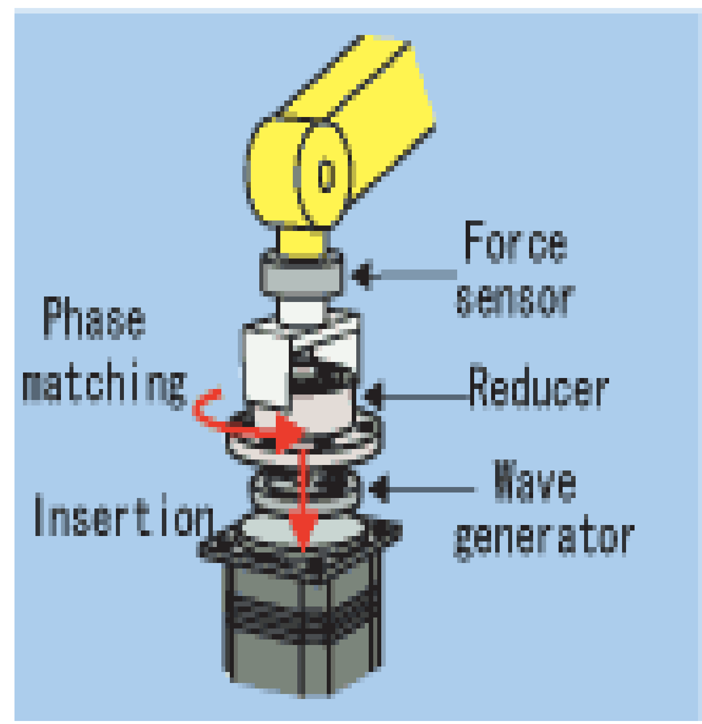
Tactile and Proximity Sensors

Tactile sensors provide the robot with the capability to respond to contact forces between itself and other objects with its work volume.

Tactile sensor s are of two types:

- Touch Sensors
- Stress Sensors (Force sensors)





- Touch sensors are used simply to indicate whether contact has been made with an object.
- Stress sensors are are used to measure the magnitude of the contact force .
- Strain gauge devices are typically employed in force measuring sensors.
- Potential use of robots with tactile sensing capabilities would be in assembly and inspection operations.
- Proximity sensors are used to sense when one object is close to another object.
- Proximity sensors is used to indicate the presence or absence of of a work part or other object

Voice sensors

- Voice sensing can be defined as the oral communication of commands to the robot or other machine.
- The robot controller is equipped with a speech recognition system which analyze the voice input and compare it with a set of stored word patters
- When a match is found between the input and the stored vocabulary word, the robot performs some action which compares to teat word.

Robot Programming

Robot Programming methods are classified as :

- Physical set-up programming (Manual method)
- Teach Mode Programming (Walkthrough method)
- Teach by showing program off-line programming

•Physical set-up programming

- In this type of programming the operator set–up program by fixing limit, switches, stops, etc.

- In most cases these robots are adequate only for simple pick and place jobs.

•Teach mode Programming

- Teach mode is when the operator leads the robot through the desired locations by means of a teach pendant which is interfaced with the robot controller.

- This method of robot programming is most commonly used for paint spraying, welding, etc.

•Teach by showing program off-line programming

- Off-line programming involves higher level robot programming language.

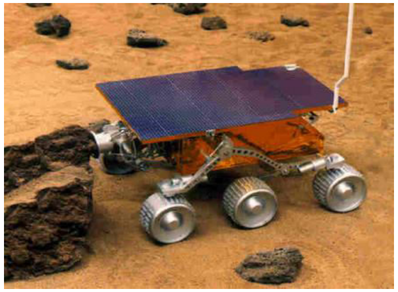
- This allows writing editing programs in language which closer to operator language than the machine.

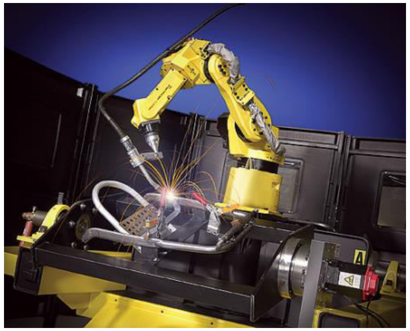
Robot programming languages

- **WAVE** is the first robotic language allowing the implementation of relatively complex manipulation algorithm developed in 1970-74.
- **AL** programs are prepared in a file and then complied and executed.
- **POINT** implements the advanced teaching by guiding philosophy with interactive software support (1975-77)
- **SIGLA** used for the assembly robot
- **RAPT** is also a assembly purpose programming language.
- **MCL** (machine control language) is a structured programming language and is a extension of APT language.

ROBOT APPLICATIONS

- Need to replace human labor by robots for tasks which are:
  - Dangerous
    - Space exploration
    - chemical spill cleanup
    - disarming bombs
    - disaster cleanup
  - Boring and/or repetitive
    - Welding car frames
    - part pick and place
    - manufacturing parts.
  - High precision or high speed
    - Electronics testing
    - Surgery
    - precision machining.

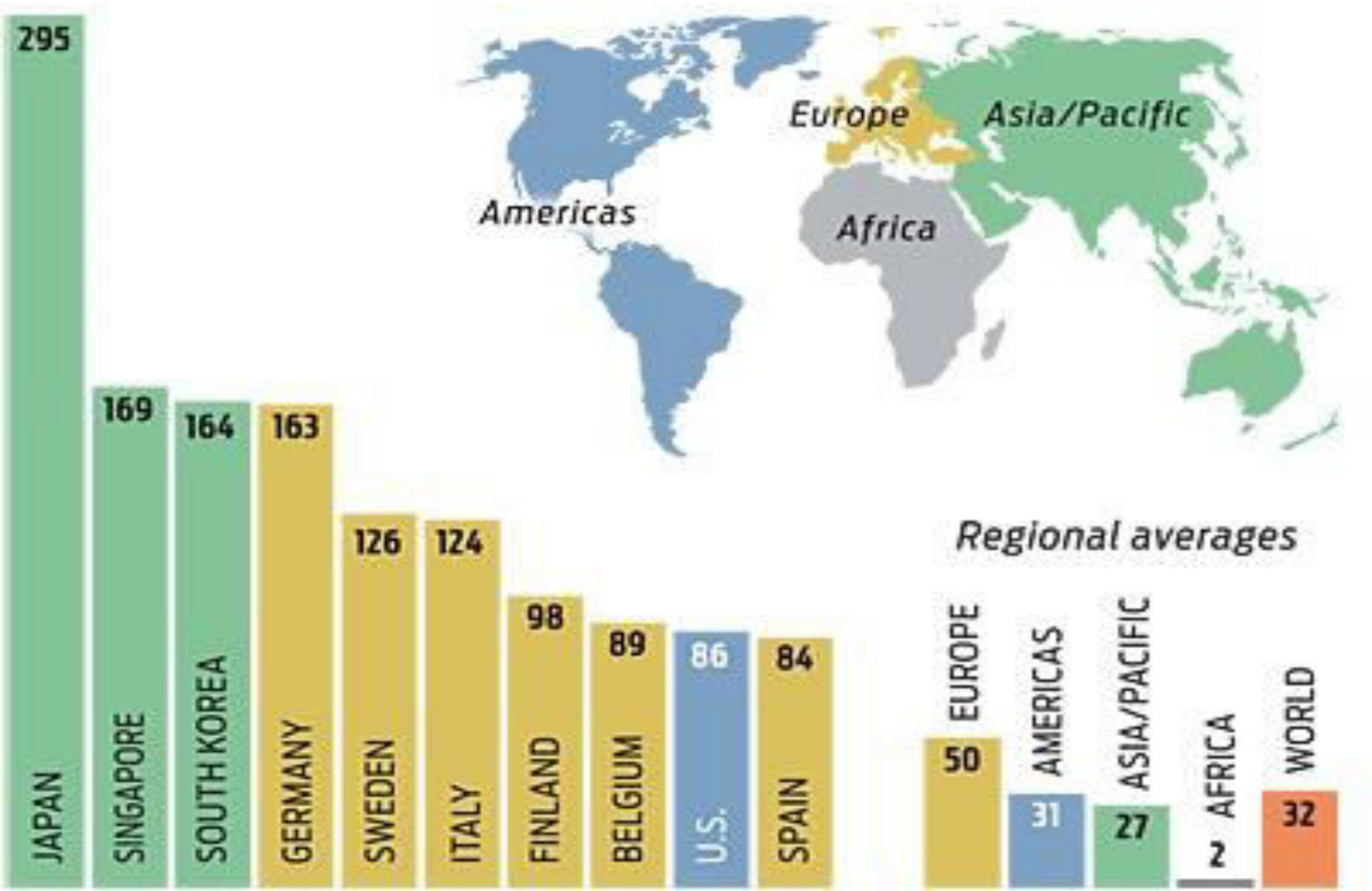




INDUSTRIAL APPLICATION OF ROBOTS

- The requirements of robots in industry are:
  - To minimize the process in industry.
  - To minimize direct and indirect labour.
  - To minimize tool change and set up.
  - To maximize the equipment utilization.
  - To maximize flexibility.
  - To minimize lead time.
  - To improve the quality of the products.
  - To maximize productivity.

TOP 10 COUNTRIES BY ROBOT DENSITY
(Industrial robots per 10 000 manufacturing workers)



INDUSTRIAL APPLICATION OF ROBOTS

- Industrial Robot Applications can be divided into:
  - Material-handling applications:
  - Processing Operations:
  - Assembly Applications:
  - Inspection Operations:

Material Handling Applications

Part Placement:

- The basic operation in this category is the relatively simple pick-and-place operation.
- This application needs a low-technology robot of the cylindrical coordinate type.
- Pneumatically powered robots are often utilized.

Palletizing and/or Depalletizing

The applications require robot to stack parts one on top of the other, that is to palletize them, or to unstack parts by removing from the top one by one, that is depalletize them.

Material Handling Applications

- Machine loading and/or unloading:
  - Machine loading in which the robot loads parts into a production machine, but the parts are unloaded by some other means.
    - Example: a pressworking operation, where the robot feeds sheet blanks into the press, but the finished parts drop out of the press by gravity.
  - Machine loading in which the raw materials are fed into the machine without robot assistance. The robot unloads the part from the machine assisted by vision or no vision.
    - Example: bin picking, die casting, and plastic moulding.
  - Machine loading and unloading that involves both loading and unloading of the workparts by the robot.
  - Example: Machine operation

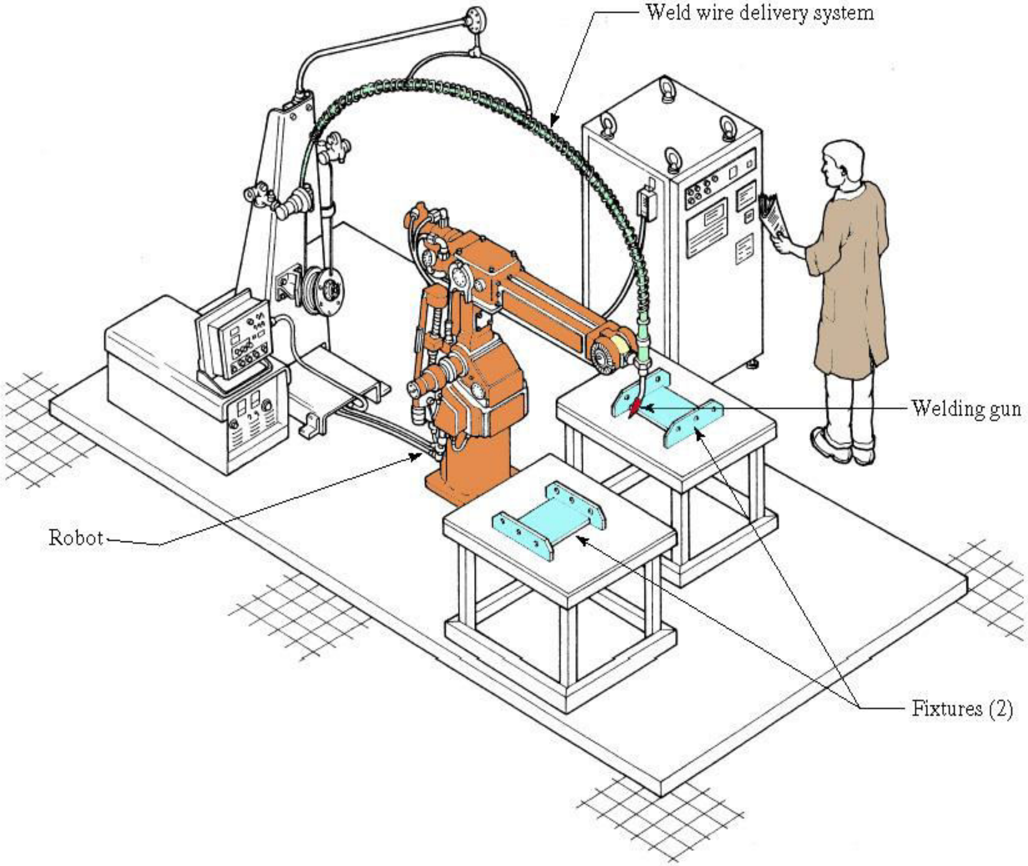
Processing Operations

- Processing Operations:
  - Robot performs a processing procedure on the part.
  - The robot is equipped with some type of process tooling as its end effector.
  - Manipulates the tooling relative to the working part during the cycle.
  - Industrial robot applications in the processing operations include:
    - Spot welding
    - Continuous arc welding
    - Spray painting
    - Metal cutting and deburring operations
    - Various machining operations like drilling, grinding, laser and waterjet cutting, and riveting.
    - Rotating and spindle operations
    - Adhesives and sealant dispensing

Robotic Arc-Welding Cell

- Robot performs flux-cored arc welding (FCAW) operation at one workstation while fitter changes

  parts at the other workstation



Assembly Operations

- Assembly Operations:
  - They typically include components to build the product and to perform material handling operations.
  - Are traditionally labor-intensive activities in industry and are highly repetitive and boring. Hence are logical candidates for robotic applications.
  - One of the well suited area for robotics assembly is the insertion of odd electronic components.

Inspection Operations

- Inspection Operation:
  - Inspection work requires high precision and patience, and human judgment is often needed to determine whether a product is within quality specifications or not.
  - Inspection tasks that are performed by industrial robots can usually be divided into the following three techniques:
    - By using a feeler gauge or a linear displacement transducer the part being measured will come in physical contact with the instrument or by means of air pressure, which will cause it to ride above the surface being measured.
    - By utilizing robotic vision, video cameras are used to obtain an image of the area of interest, which is digitized and compared to a similar image with specified tolerance.
    - By involving the use of optics and light, usually a laser or infrared source is used to illustrate the area of interest.

ADVANTAGES AND DISADVANTAGES OF ROBOTS

- Advantages:
  - Robotics can in many situations increase productivity, safety, efficiency, quality and consistency of products.
  - Robots can work in hazardous environment without the need for life support, comfort concern about safety.
  - Robots can be much accurate than humans.
  - Robots can perform multiple task simultaneously.
  - 24 hour operation
  - Precision
  - Reliability
  - Flexible operations, but not as flexible as humans!

- Disadvantages:
  - Robot lack the capability to respond in emergencies.
  - Lack of decision making powers.
  - Human injuries.
  - Robots are costly due to initial cost of equipment, installation cost, need for training and need for programming.

Home Assignment

a) Prepare a report on the above topic (about 7 pages)
b) Prepare PPT presentation (15 minutes)
c) Add one latest research paper on the above topic

Decision Support Systems

Guiding thoughts from Albert Einstein. . .

- *"If you can't explain it simply, you don't understand it well enough"*

- *"Information is not knowledge"*
- *"If we knew what it was we were doing, it would not be called research, would it?"*

Primary Decision Support Technologies

Management Support Systems (MSS)

- Decision Support Systems (DSS)
- Group Support Systems (GSS), including Group DSS (GDSS)
- Executive Information Systems (EIS)
- Expert Systems (ES)
- Artificial Neural Networks (ANN)
- Hybrid Support Systems
- Cutting Edge Intelligent Systems (Genetic Algorithms, Fuzzy Logic, Intelligent Agents, ...)

What is a Decision Support System?

- A decision support system (DSS) is a computer-based information system that supports business or organizational decision-making activities. DSSs serve the management, operations, and planning levels of an organization and help to make decisions, which may be rapidly changing and not easily specified in advance.

Categories of Decision

- For each decision you make, the decision will fall into one of the following categories:
  - Structured Decisions
  - Unstructured Decisions
  - Semi-Structured Decisions

- **Structured Decisions**: Often called “programmed decisions” because they are routine and there are usually specific policies, procedures, or actions that can be identified to help make the decision.
- **Unstructured Decisions:** Decision scenarios that often involve new or unique problems and the individual has little or no programmatic or routine procedure for addressing the problem or making a decision.
- **Semi-structured Decisions:** Decision scenarios that have some structured components and some unstructured components.

Treating certainty, uncertainty and risk

- Decision making under certainty
  - Assume complete knowledge
  - All potential outcomes known
  - Easy to develop
  - Can be very complex

Decision-Making under uncertainty

- Uncertainty
  - Several outcomes for each decision
  - Probability of occurrence of each outcome unknown
  - Insufficient information
  - Assess risk and willingness to take it
  - Pessimistic/optimistic approaches

Decision-Making under risk

- Probabilistic Decision-Making
  - Decision under risk
  - Probability of each of several possible outcomes occurring
  - Risk analysis
    - Calculate value of each alternative
    - Select best expected value

Types of DSS

- Model-driven
- Data-driven
- Communication-driven
- Document-driven
- Knowledge-driven

DSS Models

- Algorithm-based models
- Statistic-based models
- Linear programming models
- Graphical models
- Quantitative models
- Qualitative models
- Simulation models

Simulation

- Simulation is the process of designing computerized **model** of a **system** and conducting experiments with the model for the purpose of either of understanding the behavior of the system or for evaluating various strategies for the operation of the system.

- A system is defined to be a collection of **entities**, e.g., people or machines, that act and interact together toward the accomplishment of some logical end.

Why Simulation?

1. Simulation enables the study of an **complex** system.
2. The alteration on the behavior of **informational**, **organizational** and **environmental** changes can be observed.
3. The **knowledge** gained in designing a simulation model may be of great value toward improvement in the system.
4. System insight may be obtained in to which **variable** are most important and how variables interact.

Why Simulation?

5. Simulation can be used as a device to reinforce **analytical solution** methodologies.
6. Simulation can be used to experiment with **new design or policies** prior to implementation.
7. Simulation can be used to verify **analytical solutions.**

Effective Use of Simulation

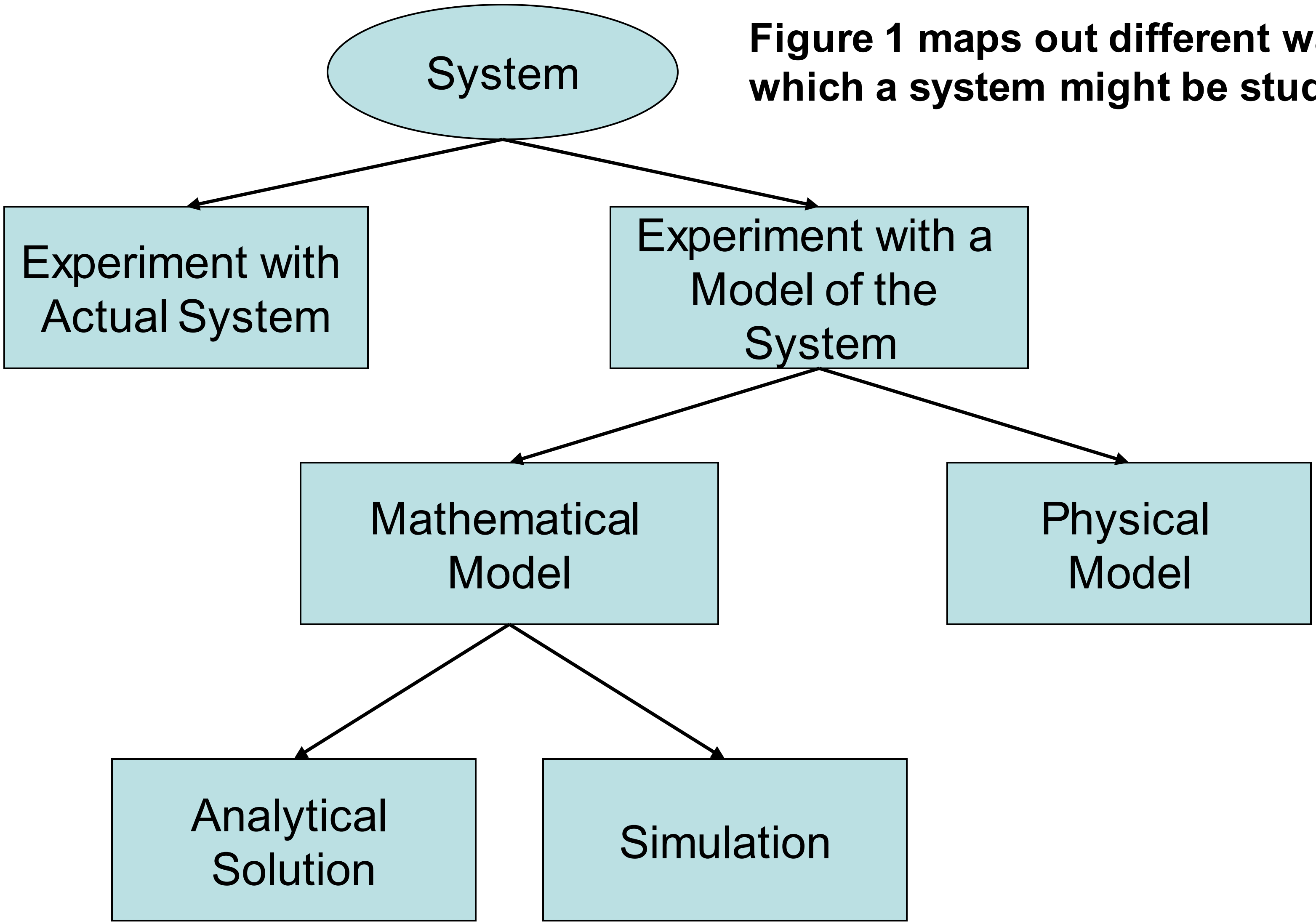
- **Simulation is Skill Intensive and Expensive**

Judicious Use:

- When no other analytical solution exists
- Detailed model of a complex system needed
- Management needs assurance / understanding
- Intuitive Knowledge needs to be Tested
- Ideal Situation : Knowledge + Simulation

Systems and Models

Figure 1 maps out different ways in which a system might be studied.



Simulation models are classified as :

- **Static** or **Dynamic** simulation models:
  - A static simulation model is a representation of a system at a particular time, or one that may be used to represent a system in which time simply plays no role.
    - Example: Monte Carlo Models.
  - A dynamic simulation models represents a system as it evolves over time, such as conveyor system in a factory.

- **Deterministic** or **Stochastic** Simulation Models
  - If a simulation model does not contain any probabilities (i.e., random) components, it is called deterministic.
  - In deterministic models, the output is ‘determined’ once the set of input quantities and relationships in the model have been specified.
  - Many systems must be modeled as having at least some random input components, and these give rise to stochastic simulation models.
  - Stochastic simulation models produces output that is itself random, and must therefore be treated as only an estimate of the true characteristics of the model.

- **Discrete or Continuous** Simulation Models
  - A discrete simulation model is one for which the state variables change instantaneously at separate point of time.
    - A manufacturing system is an example of discrete system since state variables such as the number of parts in the system change only when a part arrives or when a part finishes being served and depart.
  - A continuous simulation model is one for which the state variables change continuously with respect to time.
    - An airplane moving through the air is an example of a continuous system, since the state variable such as position and velocity can change continuously with respect to time.

Computer Simulation Approaches

- Acquire a simulation package, write the model in that language (SLAM II, GPSS, ARENA etc.)
- Write your program, in a general purpose computer languages (VB, VC, JAVA etc.)
- Acquire, use an already written domain specific model - Data Driven Model (MAST, FASIM etc)
- Engage a consultant to carry out the simulation project for you or to provide you with a working model (ARENA, WITNESS etc. popular)

Steps Required in a Simulation Study

1. Formulation of the problem
2. Data collection
3. Formulation of the model
4. Estimation of the parameters
5. Evaluation of model
6. Formulation of program logic
7. Verification/validation of computer model
8. Design of experiments
9. Analysis of results
10. Recommendations…Implementation… Documentation

- Requires iterative procedure
- Experimentation oriented
- What-if analysis

Areas of Application

1. Simulation of the operations by an **airlines** company to test changes in company policies and practices.
2. Simulation of the passage of **traffic** across a junction to determine the best time sequences.
3. Simulation of the **maintenance operation**.
4. Simulation of the **flux** of uncharged particles through a radiation shield.
5. Simulation of **steel making operations**.
6. Simulation of the **Indian economy** to predict the effect of economic policy decisions.

Areas of Application

7. Simulation of large scale **military** battles to evaluate weapons system.
8. Simulation of large scale **distribution** and **inventory systems**.
9. Simulation of the **overall operation** of an entire business firm.
10. Simulation of **telephone communication** system.
11. Simulation of a **shop floor** to determine optimum number of machines, layout of machines etc.

Advantages of Simulation

1. Once a model is built, it can be used repeatedly to analyze proposed design or policies.
2. Simulation methods can be used to help analyze a proposed system even though the input data are some what sketchy.
3. It is usually the case that simulation data are much less costly to obtain than similar data from the real system.
4. Simulation methods are usually easier to apply than analytic methods. Thus there are many more potential users of simulation methods than of analytical methods.

Advantages of Simulation

4. Whereas analytical methods usually require many simplifying assumptions to make them mathematically tractable, simulation model have no such restrictions.
5. With analytical models, the analyst usually can compute only a limited number of system performance measures. With simulation models, the data generated can be used to estimate any conceivable performance measure.
6. In some instance simulation is the only means of deriving a solution to a problem.

Limitations of Simulation

1. Simulation models for digital computers maybe costly, requiring large expenditures of time in their construction and validation.
2. Numerous runs of simulation model are usually requires and this can result in high computer costs.
3. Simulation is sometimes used when analytical techniques will suffice. This situation occur as users become familiar with simulation methodology and forget about their mathematical training.

Discrete Event Simulation

- It concerns the modeling of a system as it evolves over time by representation in which the **state variables** change instantaneously at a separate points in time.
- These points in time are the ones at which an event occurs, when the event is defined as an instantaneous occurrences that may change the state of the system.

Discrete Event Simulation

- In a discrete event simulation: There is no time loop.
  - There are events that are scheduled.
  - At each **run** step, the next scheduled event with the *lowest* time gets processed.
    - The current time is then *that* time, the time that event is supposed to occur.
- Key: We have to keep the list of scheduled events *sorted* (in order).

Discrete Event Simulation

- **Some terminology.**

A) **System Environment**: the collection of external factors capable of causing a change in the system.

B) **State of a System**: the minimal collection of information with which the future behavior of a system can be reliably (uniquely?) predicted.

C) **Activity**: any events that causes a State Change.

D) **Endogenous Activity**: one occurring **inside** the system.

E) **Exogenous Activity**: one occurring **outside** the system.

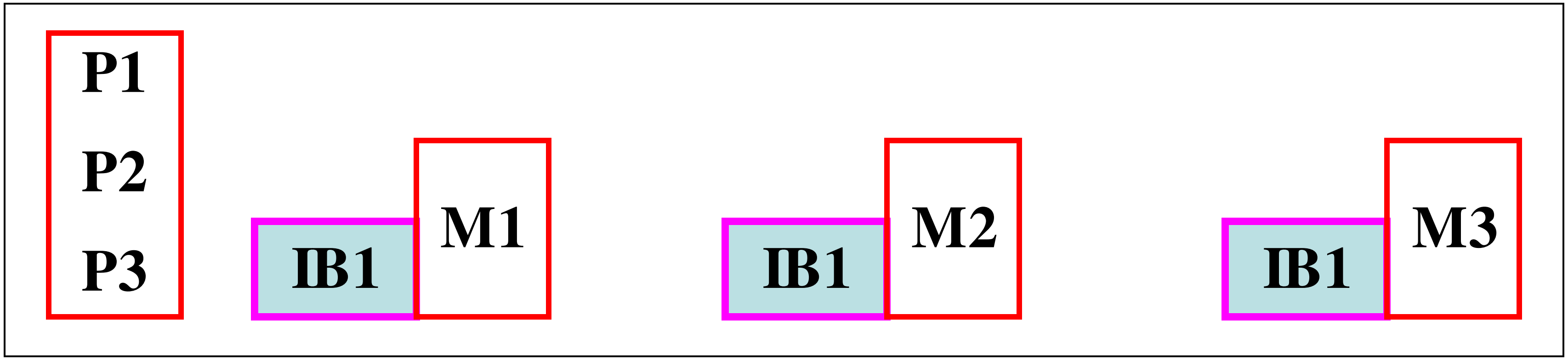
Components of a Discrete Events Model

- **System State:** Combination of state variable at a time.
- **Simulation Clock:** A variable giving the current value of simulated time.
- **Event List:** A list containing the next time that each event will occur.
- **Statistical Counters:** Variables used for storing statistical information about system performance.
- **Timing Routine:** A sub program that determines the next event from the event list and advances clock.

Components of a Discrete Events Model

- **Initialization Routine:** A subprogram to initialize model at “t = 0”
- **Event Routine:** A sub program that updates system status at each event.
- **Report generator--** A subroutine, which computes estimates (from the statistical counters) of the desired measures of performance and prints a report when the simulation ends.
- **Main program--** A subprogram which calls the timing routine to determine the next event and then transfers control to the corresponding event routine to update the system state appropriately.

Example: A System Focused Model

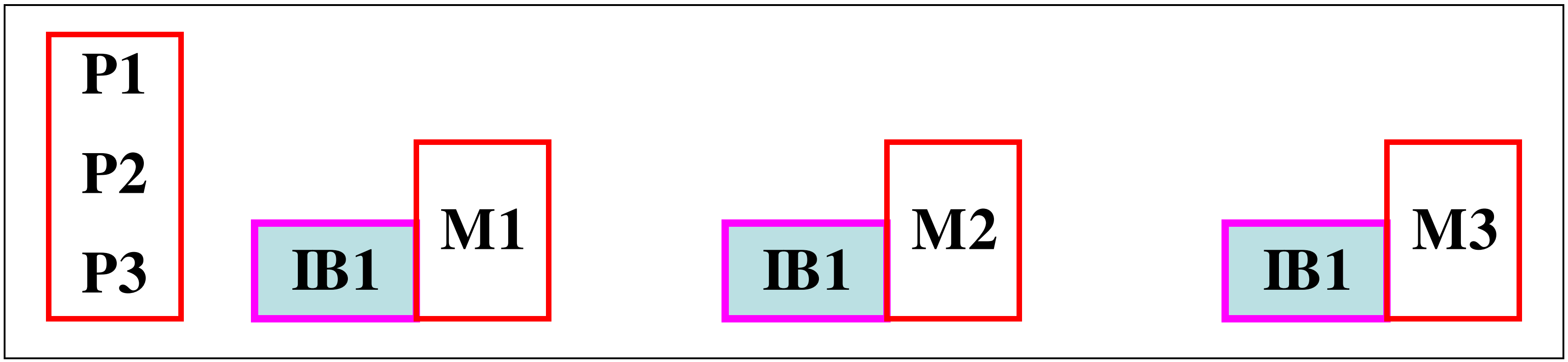


Process Time Matrix Model

	P1	*P2*	*P3*
M1	5	10	8
M2	18	6	15
M3	10	20	12
Total	33	36	35

Total Time for One Batch of P1, P2 and P3 = ? 104 units ?

System Focused Model



Mathematical Model Showing Total Processing Time

A = Total Time needed to Process P1 = Σ t(P1,$M_{j=1 \text{ to } 3}$)

B = Total Time needed to Process P2 = Σ t(P2,$M_{j=1 \text{ to } 3}$)

C = Total Time needed to Process P3 = Σ t(P3,$M_{j=1 \text{ to } 3}$)

Total time for one batch of P1, P2 and P3 = A + B + C

State Transition Representation : Discrete Event Simulation

Time	*Status*						
	IB 1	M 1	IB 2	M 2	IB 3	M 3	Total
t = 0	P3, P2, P1	--	--	--	--	--	--
t = 0 +	P3, P2	P1(5)	--	--	--	--	--
t = 5	P3	P2(10)	P1	--	--	--	--
t = 5 +	P3	P2(10)	--	P1(18)	--	--	--
t = 15	--	P3(8)	P2	P1(8)	--	--	--
t = 23	P3, P2, P1	--	P3, P2	--	P1	--	--
t = 23 +	P3, P2	P1(5)	P3	P2(6)	--	P1(10)	--
t = 28	P3	P2(10)	P1, P3	P2(1)	--	P1(5)	--
t = 29	P3	P2(9)	P1	P3(15)	P2	P1(4)	--

State Transition Representation : Discrete Event Simulation

Time	*Status*						
	IB 1	M 1	IB 2	M 2	IB 3	M 3	Total
t = 33	P3	P2(5)	P1	P3(11)	--	P2(20)	P1
t = 38	P3, P2, P1	P3(8)	P2P1	P3(6)	--	P2(15)	P1
t = 44	P3 ,P2, P1	P3(2)	P2	P1(18)	P3	P2(9)	P1
t = 46	P3, P2	P1(5)	P3P2	P1(16)	P3	P2(7)	P1
t = 51	P3	P2(10)	P1P3P2	P1(11)	P3	P2(2)	P1
t = 53	P3	P2(8)	P1.P3, P2	P1(9)		P3(12)	P2P1
t = 61	P3, P2,P1	P3(8)	P2,P1,P3,P2	P1(1)		P3(4)	P2,P1
t = 65	P3,P2,P1	P3(3)	P2,P1, P3	P2(2)		P1(10)	P3P2P1

System Understanding

- Productivity Improvement Alternatives

- Invest Rs. X on M1 (Increase in Input)
- Expected Impact on Output ? (What Increase in Output ?)
- Total Productivity Improvement ?

- Invest Rs. Y on M2 (Increase in Input)
- Expected Impact on Output ? (What Increase in Output ?)
- Total Productivity Improvement ?

ARENA SIMULATION SOFTWARE

ARENA SIMULATION TOOL

- **ARENA** is a simulation environment consisting of **MODULE TEMPLATES**, built around **SIMAN** language.

- **SIMAN** consists of two classes of objects: BLOCKS and ELEMENTS.

- **BLOCKS** are basic logic constructs that represent operations; for example, a **SEIZE** block models are used for seizing the facility by a entity, while a **RELEASE** block releases the facility for use by other entity.

- **ELEMENTS** are objects that represent facilities, such as **RESOURCES** and **QUEUES**, or other components, such as **DSTATS** and **TALLIES**, used for statistics collection.

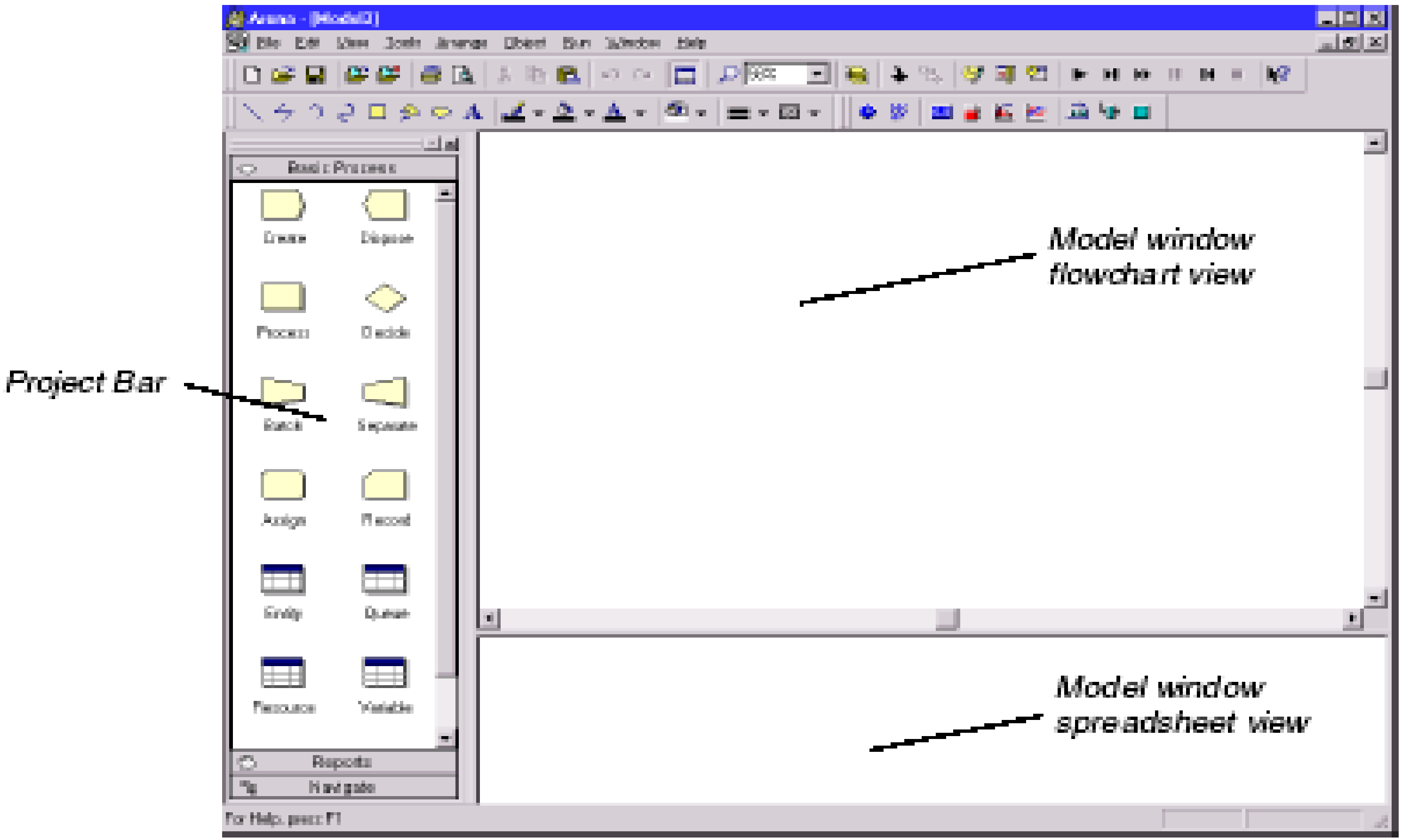
442

- Further more, while the modeler constructs a model interactively in both graphical and textual modes, ARENA is busy in the background transcribing the whole model into SIMAN.

- Since ARENA generates correct SIMAN code and checks the model for syntactic errors (graphical and textual), a large amount of initial debugging takes place automatically.

443

ARENA WINDOW



444

- The **ARENA** home screen has the following components:
- **MENU BAR**
  - The ARENA Menu bar consists of a number of general menus:
  - File, Edit, View, Window, and Help—which support quite generic functionality.

  - **ARENA**-specific menus:
  - **Tools** menu provides access to simulation related tools and ARENA parameters;
  - **Arrange** menu supports flowcharting and drawing operations
  - **Object** menu supports module connections and sub model creation
  - **Run** menu provides simulation run control

445

- **PROJECT BAR**
- The Project bar lets the user access AREANA template panels, where Arena modules and SIMAN blocks.
- Template panels can be attached to the Project bar by clicking the Attach button on the Standard toolbar.
- Choosing a .tpo file will attach its template panel to the Project bar.
- The Arena template panels available to users are as follows:

The Basic Process template panel consists of a set of basic modules, such as Create, Dispose, Process, Decide, Batch, Separate, Assign, and Record.

- **The Advanced Process** template panel provides additional basic modules as well as more advanced ones, such as Pickup, Dropoff, and Match.

446

- **The Advanced Transfer** template panel consists of modules that support entity transfers in the model. These may be ordinary transfers or transfers using material-handling equipment.

- **The Reports** template panel supports report generation related to various components in a model, such as entities, resources, queues, and so on.

- **The Blocks** template panel contains the entire set of SIMAN blocks.

- **The Elements** template panel contains elements needed to declare model resources, queues, variables, attributes, and some statistics collection.

447

- **STANDARD TOOLBAR**
  - The ARENA Standard toolbar contains buttons that support model building.
  - An important button in this bar is the Connect button, which supports visual programming.
  - This button is used to connect ARENA modules as well as SIMAN blocks, and the resulting diagram describes the flow of logical control.

DRAW AND VIEW BARS

- Draw toolbar supports static drawing and coloring of Arena models.
- View toolbar assists the user in viewing a model.
- Its buttons include Zoom In, Zoom Out, View All, and View Previous.

448

- **ANIMATE AND ANIMATE TRANSFER BARS**
  - Animate toolbar is used for animation of ARENA model objects during simulation runs.
  - Animated objects include the simulation clock, queues, monitoring windows for variables, dynamic plots, and histogram functions.
  - The Animate Transfer toolbar is used to animate entity transfer activities, including materials handling.
- **RUN INTERACTION BAR**
  - Run Interaction toolbar supports run control functions to monitor simulation runs, such as access to SIMAN code and model debugging facilities.
  - It also supports model visualization, such as the Animate Connectors button that switches on and off entity traffic animation over module connections.

449

- **INTEGRATION BAR**
- The Integration toolbar supports data transfer (import and export) to other applications.
- It also permits Visual Basic programming and design.

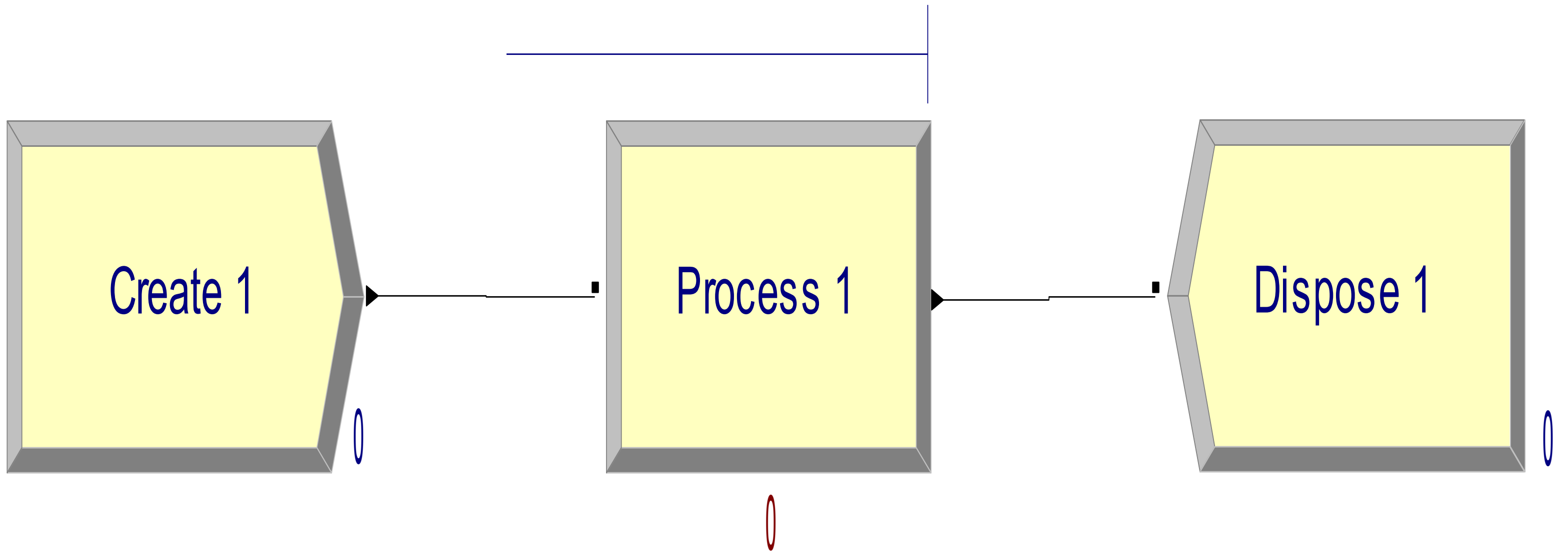
450

EXAMPLE: A SIMPLE WORKSTATION

- Consider a simple workstation consisting of a single machine with an infinite buffer in front of it.
- Jobs arrive randomly and wait in the buffer while the machine is busy. Eventually they are processed by the machine and leave the system.
- Job inter-arrival times are exponentially distributed with a mean of 30 minutes, while job processing times are exponentially distributed with a mean of 24 minutes.
- This example will compare the simulation statistics to their theoretical counterparts to gauge the accuracy of simulation results.
- Specifically, we shall estimate by an ARENA simulation the average job delay in the buffer, the average number of jobs in the buffer, and machine utilization.

451

EXAMPLE: A SIMPLE WORKSTATION



452

ARENA DATA STORAGE OBJECTS

- An important part of the model building is assignment and storage of data supplied by the user (input parameters) or generated by the model during a simulation run (output observations).
- Arena provides three types of data storage objects:
  - **Variables,**
  - **Expressions**
  - **Attributes**

- **Variables**

Variables are user-defined global data storage objects used to store and modify state Information in the course of a run. Such (global) variables are visible everywhere in the mode. For instance, the variable NQ(Machine_Q) stores the current value of the number of entities in the queue called Machine_Q

453

ARENA DATA STORAGE OBJECTS

- **Expressions**

Expressions can be viewed as specialized variables that store the value of an associated formula (expression). They are used as convenient shorthand to compute mathematical expressions that may recur in multiple parts of the model.

- **Attributes**

Attributes are data storage objects associated with entities. Unlike variables, which are global, attributes are local to entities in the sense that each instance of an entity has its own copy of attributes. For example, a customer's arrival time can be stored in a customer attribute to allow the computation of individual waiting times.

454

STATISTICS COLLECTION VIA THE STATISTIC MODULE

- Detailed statistics collection in Arena is typically specified in the Statistic module located in the Advanced Process template panel. Selecting the Statistic module opens a dialog box. The modeler can then define statistics as rows of information in the spreadsheet view that lists all user-defined statistics. For each statistic, the modeler specifies a name in the Name column, and selects the type of statistic from a drop-down list in the Type column.
- The options are as follows:
- **Time-Persistent** statistics are simply time average statistics in Arena terminology. Typical Time-Persistent statistics are average queue lengths, server utilization etc.

455

STATISTICS COLLECTION VIA THE STATISTIC MODULE

- **Tally** statistics are customer averages, and have to be specified in a Record module in order to initiate statistics collection.
- **Counter** statistics are used to keep track of counts, and like the Tally option, have to be specified in a Record module in order to initiate statistics collection.
- **Output** statistics are obtained by evaluating an expression at the end of a simulation run. Expressions may involve Arena variables such as DAVG(S) (time average of the Time-Persistent statistics), TAVG(S) (the average of Tally statistic S), TFIN (simulation completion time), NR(..), NQ(..), or any variable from the Arena Variables Guide.
- **Frequency** statistics are used to produce frequency distributions of (random) expressions, such as Arena variables or resource states.

456

Note that all statistics defined in the Statistic module are reported automatically in the User Specified section of the Arena output report.

STATISTICS COLLECTION VIA THE RECORD MODULE

- Record module is used to collect various statistics. Any statistics related to customer averages or customer observations, such as Tally and Counter, have to be specified in a Record module.
- These options are as follows:
  - The Count option maintains a count with a prescribed increment (positive or negative).
  - The Entity Statistics option provides information on entities, such as time and costing/duration information.
  - The Time Interval option tallies the difference between the current time and the time stored in a prescribed attribute of the entering entity.
  - The Time Between options tallies the time interval between consecutive entries of entities in the Record module. These intervals correspond to inter departure times from the module.
  - Finally, the Expression option tallies an expression whose value is recomputed whenever an entity enters the Record module.

458

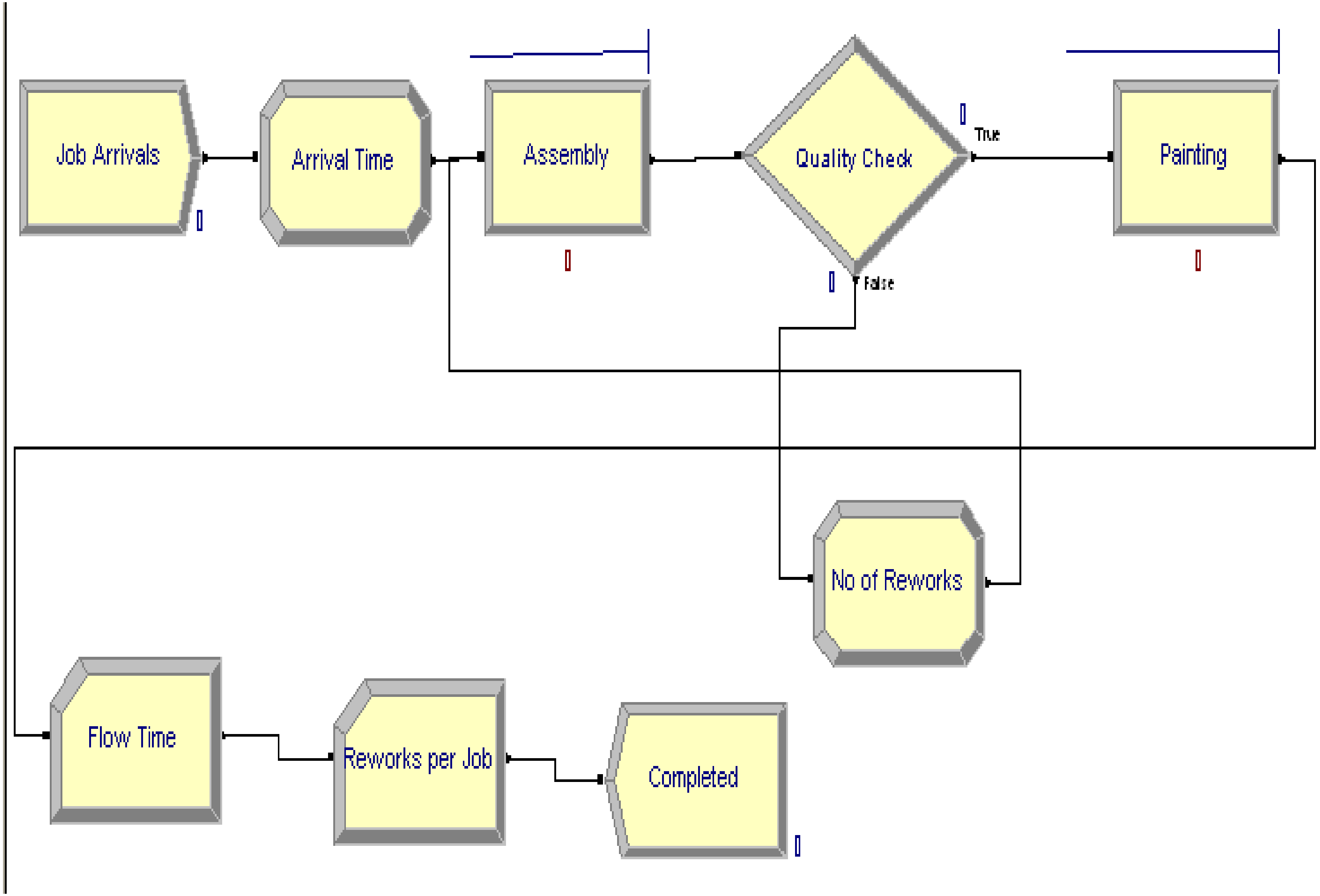
EXAMPLE: TWO PROCESSES IN SERIES

- This example presents a two-stage manufacturing model with two processes in series.
- Jobs arrive at an assembly workstation with exponentially distributed inter arrival times of mean 5 hours.
- The assembly time is uniformly distributed between 2 and 6 hours.
- After the process is completed, a quality control inspection is performed, and past data reveal that 15% of the jobs fail any given inspection and go back to the assembly operation for rework (jobs may end up going through multiple reworks until they pass inspection).

459

- Jobs that pass inspection go to the next stage, which is a painting operation that takes 3 hours per job.
- We are interested in simulating the system for 100,000 hours to obtain process utilizations, average number of reworks per job, average job waiting times, and average job flow times (elapsed times experienced by job entities).

EXAMPLE: TWO PROCESSES IN SERIES



EXAMPLE: AN ELECTRONIC ASSEMBLY AND TEST SYSTEM

- This system represents two different sealed electronic units.
- The first unit called Part A, are produced in an adjacent department with inter-arrival time being exponentially distributed with a mean of 5 minutes. Upon arrival they are transferred to the Part A Prep area, where the mating faces of the cases are machined to assure a good seal, and the part is then deburred and cleaned; the process time for the combined operation at the Part A Prep area follows a TRAI (1, 4, 8) distribution.
- The part is then transferred to the sealer.

462

- The second unit called Part B, are produced in a different department where they are held until a batch of four units is available; the batch is then sent to the final production area. The time between the arrivals of successive batches of Part B is exponentially distributed with a mean of 30 minutes. Upon arrival they are transferred to the Part B Prep area, where the batches is separated into four individual units, which are processed individually from here on, and the individual parts proceed to the Part B Prep area. The processing at the Part B Prep area has the same three steps as at the Part A Prep area, except that the process time for the combined operation follows a TRAI (3, 5, 10) distribution.

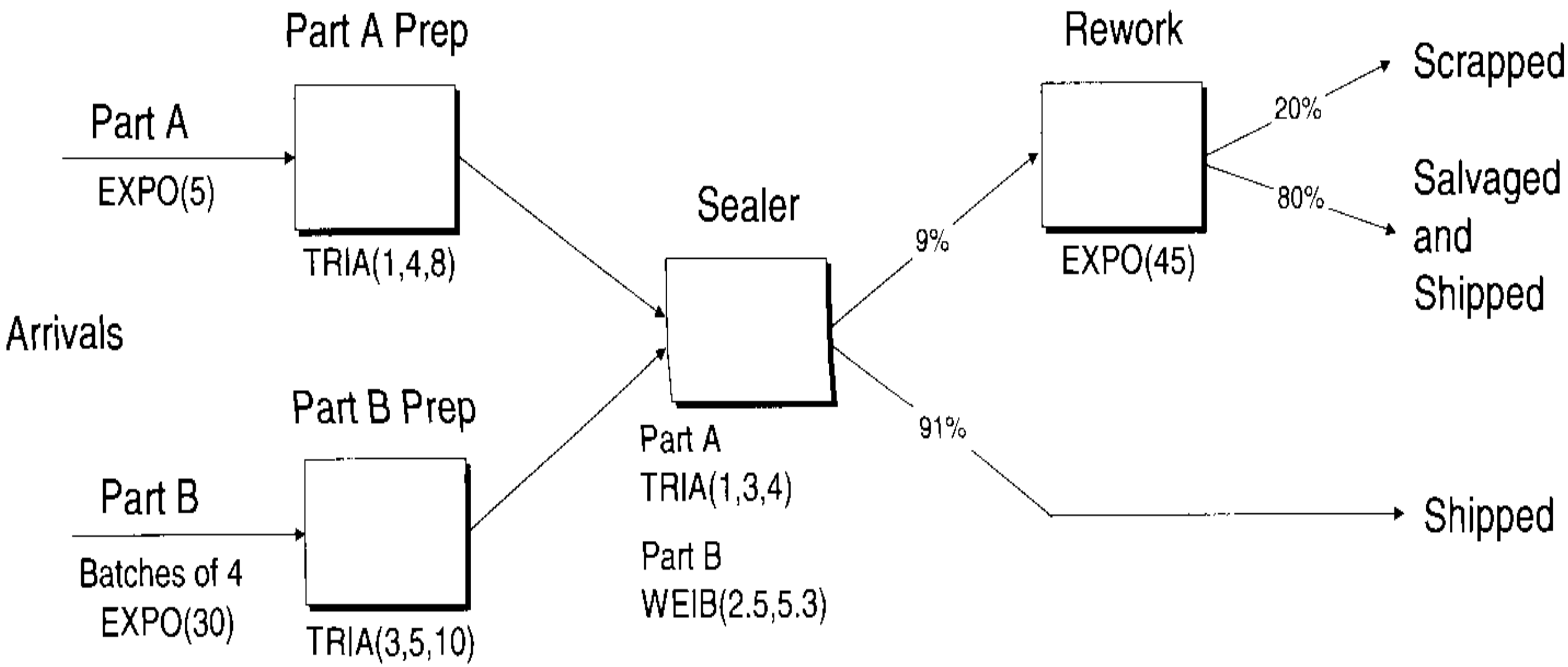
- The part is then transferred to the sealer. At the sealer operation, the electronic components are inserted, the case is assembled and sealed, and sealed unit is tested. The total process time for these operations depends on the part type: TRAI (1,3,4) for Part and WEIB (2.5,5.3) for Part B.
- Ninety one percent of the parts pass the inspection and are transferred immediately to the shipping department ; whether a part pass is independent of whether any other parts pass.
- The remaining parts are transferred instantly to the rework area where they are dissembled, repaired, cleaned, assembled, and re-tested.

- Eighty percent of the parts processed at the rework area are salvaged and transferred instantly to the shipping department as reworked parts, and the rest are transferred instantly to the scrap area.
- The time to rework a part follows an exponential distribution with mean of 45 minutes and is independent of part type and the ultimate disposition.

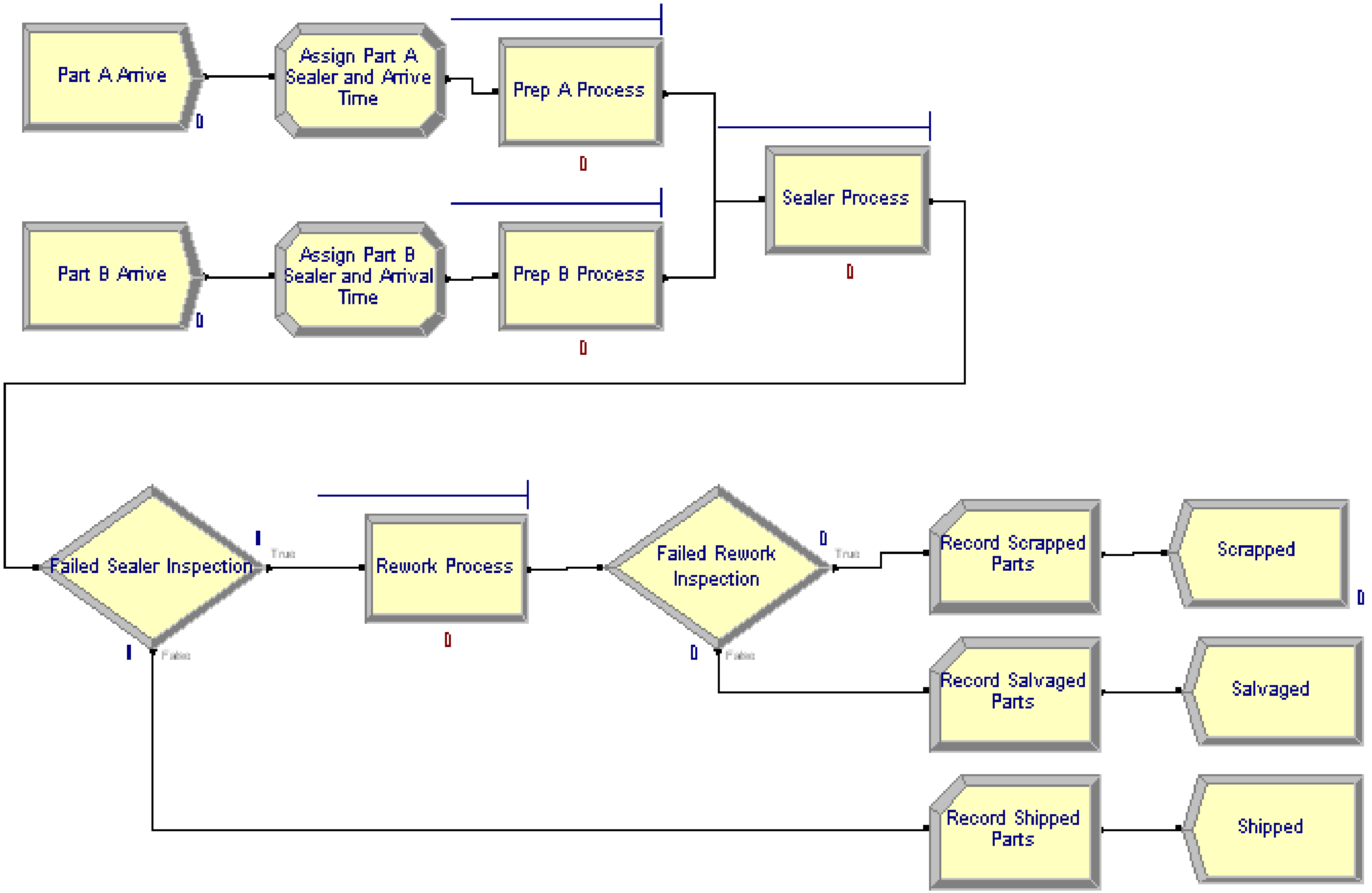
- We want to collect statistics in each area on resource utilization, number in queue, time in queue and cycle time (or total time in system) by shipped parts, salvaged parts or scrapped parts.

- We will run the simulation for four 8 hour shifts or 1920 minutes.

Electronic Assembly and Test System



EXAMPLE: ELECTRONIC ASSEMBLY AND TEST SYSTEM



END OF THE COURSE