Syllabus for Unit- 1

UNIT -I:

Introduction to Automation

Definition and fundamentals of automation, reasons for Automating, basic elements of an automated system: Power, Program and control system, safety, maintenance & repair diagnosis, error detection and recovery, Automation principles and strategies: USA principle, strategies of automation and production system, automation migration strategy

Learning Outcomes:

At the end of the unit, students will be able to:

- To understand the fundamental concepts of automation and its basic elements
- To understand system safety requirements
- To understand about maintenance and repair strategies
- To know about production system automation

Definition of automation:

- The technique of making an apparatus, a process, or a system operate automatically.
- The state of being operated automatically.

Fundamentals of Automation:

- Sensors to detect the system states,
- Actuators to output the control commands,
- Controllers for the program flow and to make decisions.

Reasons for Automation

- Increased labour productivity
- Reduces labour costs
- Mitigates the effects of labor shortages
- Reduces or eliminates routine manual tasks
- Improves worker safety
- Improves product quality
- Reduces manufacturing lead times
- Accomplishes processes that can’t be done manually

Reference link: https://www.inora.com/8-reasons-to-utilize-automation/

Basics elements of an automated system:

- Power
- Program
- Control system
- Safety
- Maintenance
- Repair and diagnosis
- Error detection and recovery

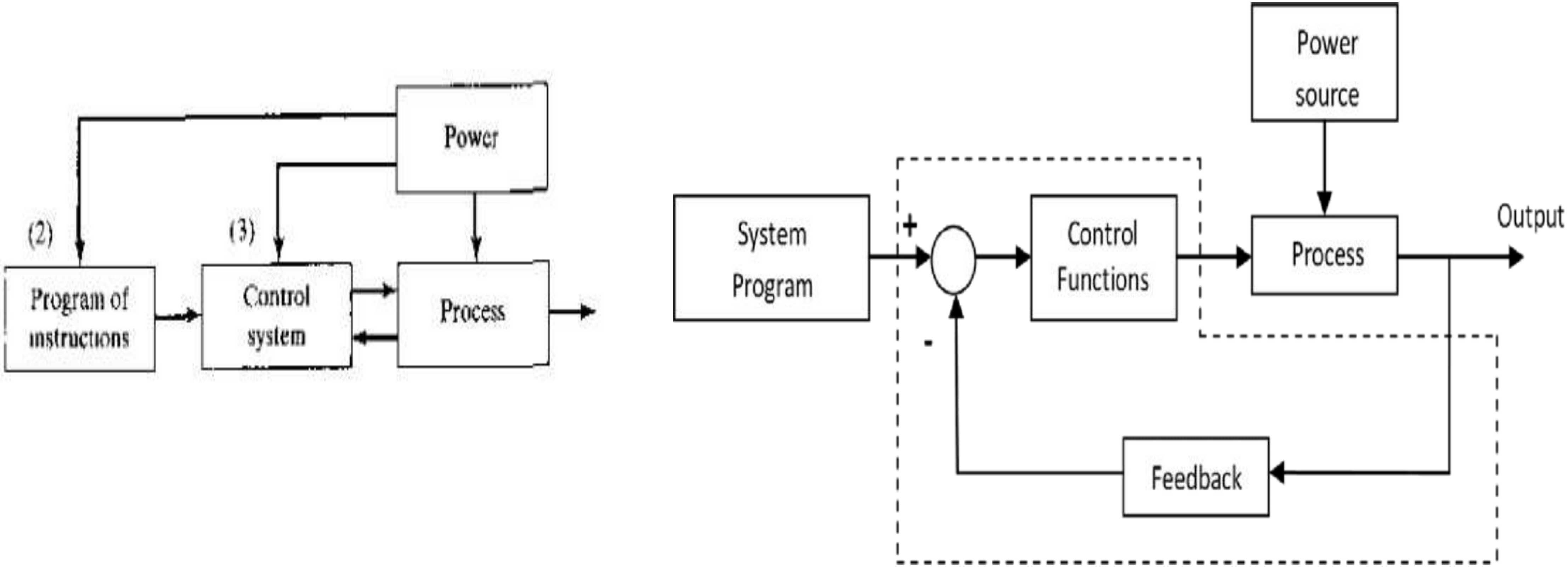


Fig: Basics elements of an automated system

Reference links:

- https://www.brainkart.com/article/Basic-Elements-of-an-Automated-System_6383/#:~:text=An%20automated%20system%20consists%20of,system%20to%20actuate%20the%20instructions.
- https://www.britannica.com/technology/automation/Machine-programming#ref390718

Power in automation

- Power-system automation processes rely on data acquisition; power-system supervision and power-system control all working together in a coordinated automatic fashion. The commands are generated automatically and then transmitted in the same fashion as operator-initiated commands.

Program in automation

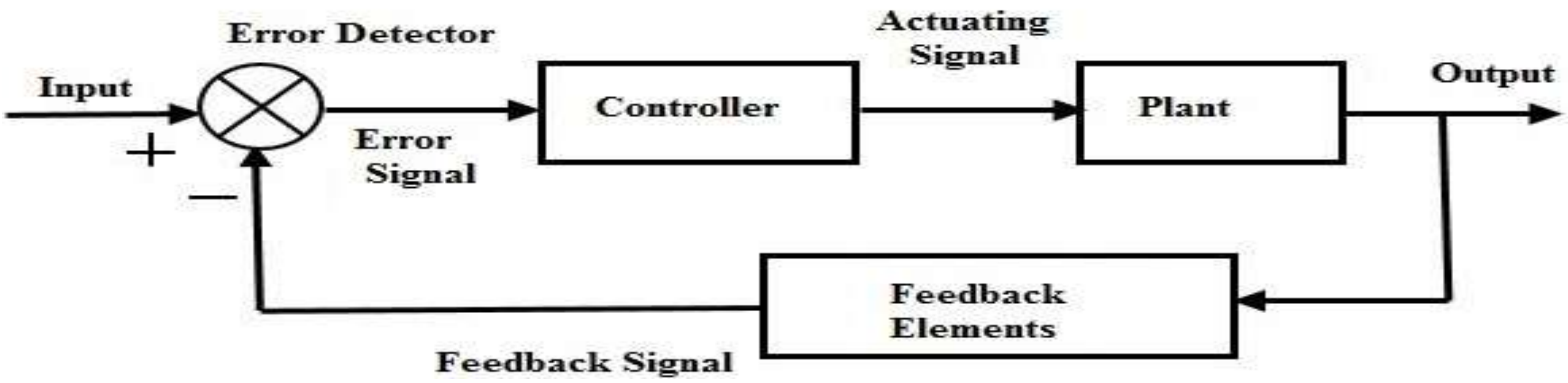
- Automation software are applications that minimize the need for human input and can be used in a variety of ways in almost any industry. At the most basic, automation software is designed to turn repeatable, routine tasks into automated actions.

Control System

- Automation Control System (ACS) is an application of control theories for the regulation of processes without direct human involvement that is used in the various control systems for the operating equipment such as machineries, processes in the productions.

Figure 3.4 An open loop control system.

One type of control system in which the output has no influence or effect on the control action of the input signal is called an Open-loop system. An "open-loop system" is defined by the fact that the output signal or condition is neither measured nor feed back for comparison with the input signal or system set point.



Closed loop system

A closed loop control system is a set of mechanical or electronic devices that automatically regulates a process variable to a desired state or set point without human interaction. Closed loop control systems contrast with open loop control systems, which require manual input.

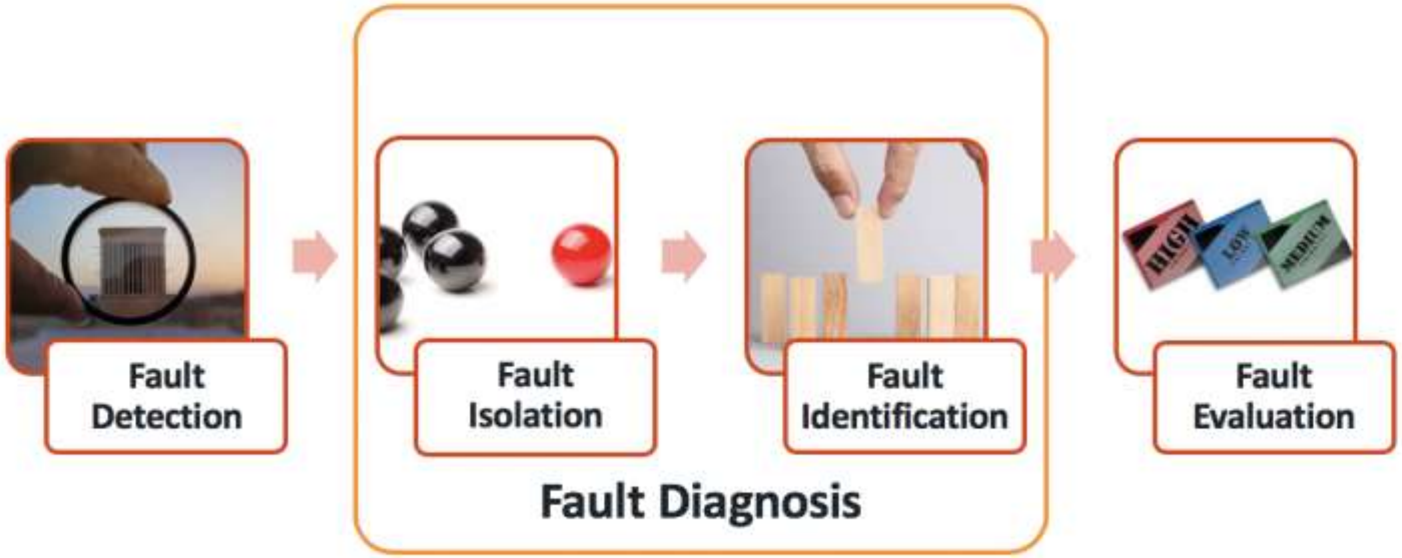
Safety In Automation

- Automation technology can help. Automated systems can reduce the risk of accidents, as well as help avoid and prevent work injuries, resulting in a safer workplace for everyone. By making the workplace safer, uptime and productivity will also increase.

Maintainance In Automation

- Through automation, some maintenance tasks can be either made safer or entirely replaced. This chiefly includes remote inspections, which can be done through robotic methods. Take internal tank inspections, for example. These are not only very hazardous, but time-consuming in prep for safely entrance

Repair and diagnosis



The process of uncovering errors in physical systems while attempting to identify the source of the problem.

Error detection and recovery

- Error detection and recovery is concerned with decisions that must be made by the system in response to undesirable operating conditions. In the operation of any automated system, malfunctions and errors sometimes occur during the normal cycle of operations, for which some form of corrective action must be taken to restore the system. The usual response to a system malfunction has been to call for human assistance. There is a growing trend in automation and robotics to enable the system itself to sense these malfunctions and to correct for them in some manner without human intervention. This sensing and correction is referred to as error detection and recovery, and it requires that a decision-making capability be programmed into the system.

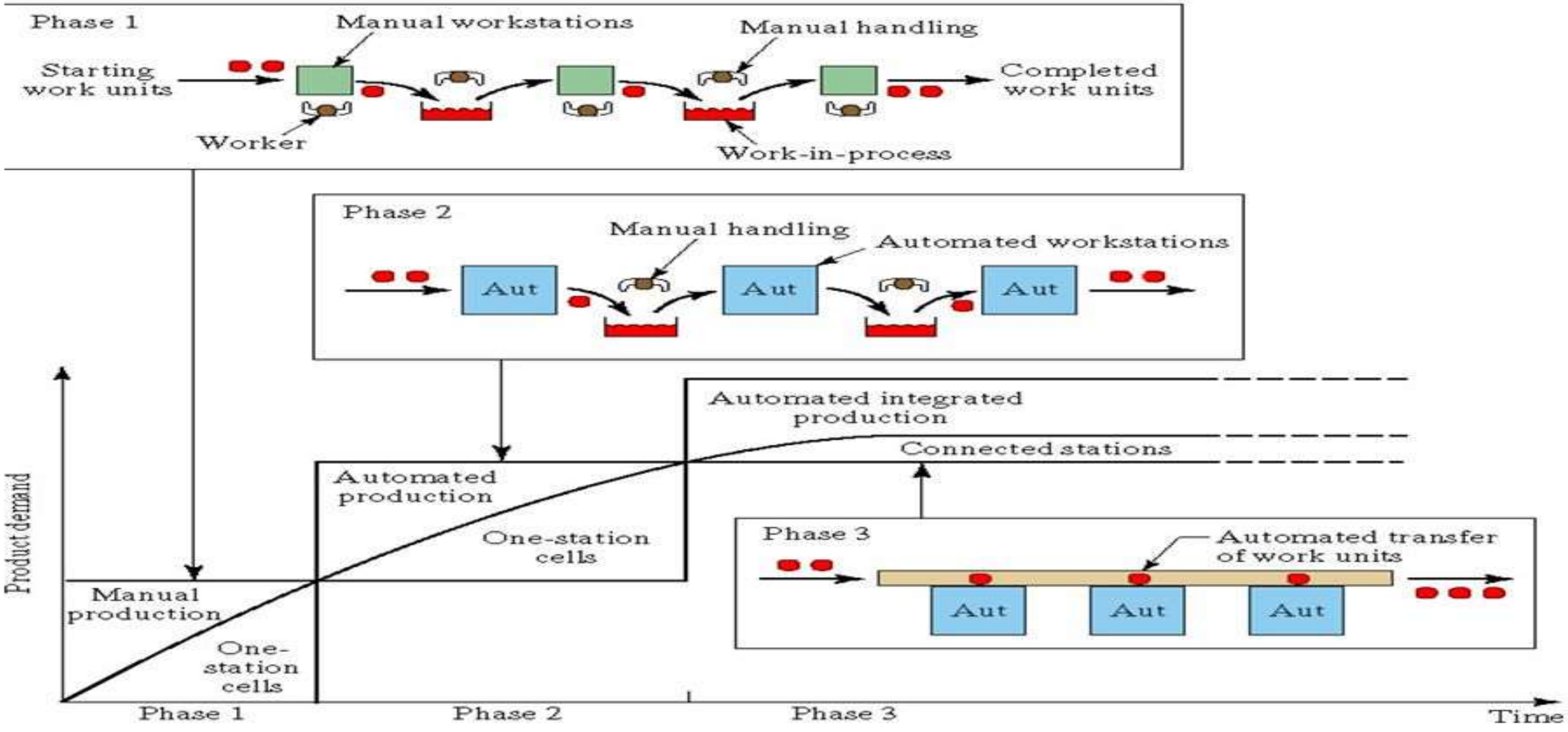
Automation Principles And Strategy

- Specialization of operations
- Combined operations
- Simultaneous operations
- Integration of operations
- Increased flexibility
- Improved material handling and storage
- On-line inspection
- Process control and optimization
- Plant operations control
- Computer-integrated manufacturing (CIM)

Reference Link

- https://faculty.ksu.edu.sa/sites/default/files/10_strategies_for_automation_and_production_systems.pdf
- https://electrical-engineering-portal.com/10-strategies-for-automation-and-production-systems

Automation Migration Strategy



Automation Migration Strategy For Introduction of New Products

1. Phase 1 – Manual production
   - Single-station manned cells working independently
   - Advantages: quick to set up, low-cost tooling
2. Phase 2 – Automated production
   - Single-station automated cells operating independently
   - As demand grows and automation can be justified
3. Phase 3 – Automated integrated production
   - Multi-station system with serial operations and automated transfer of work units between stations

UNIT-II

GROUP TECHNOLOGY

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CONTENTS:-

What is Group Technology (GT)?

- GT is a theory of management based on the principle that similar things should be done similarly
- GT is the realization that many problems are similar, and that by grouping similar problems, a single solution can be found to a set of problems thus saving time and effort
- GT is a manufacturing philosophy in which similar parts are identified and grouped together to take advantage of their similarities in design and production

Implementing GT

Where to implement GT?

- Plants using traditional batch production and process type layout
- If the parts can be grouped into part families

How to implement GT?

- Identify part families
- Rearrange production machines into machine cells

Types of Layout

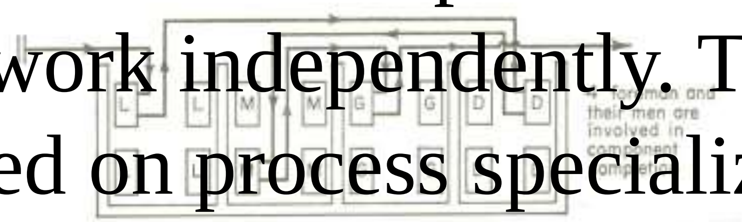
In most of today's factories it is possible to divide all the made components into families and all the machines into groups, in such a way that all the parts in each family can be completely processed in one group only.

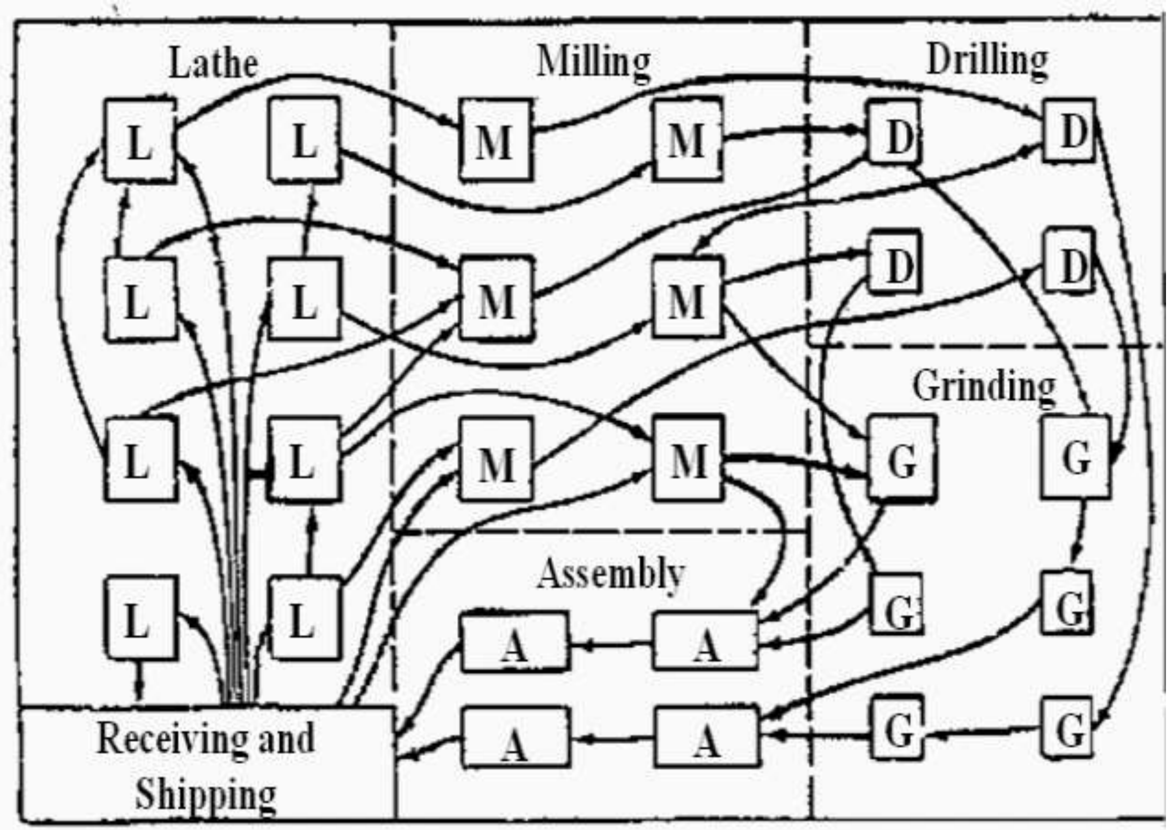
The two main types of layout are:

- Functional Layout
- Group Layout

Functional Layout(or) process layout

• In Functional Layout, all machines of the same type are laid out together in the same section under the same foreman. Each foreman and his team of workers specialize in one process and work independently. This type of layout is based on process specialization.





PROCESS-TYPE LAYOUT

In process lay out all the machine tools of same process are grouped in a single department and placed together.

1. This results in a significant amount of material handling.

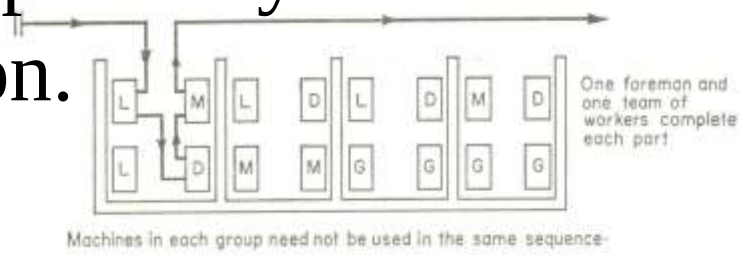
2. A large in process inventory.

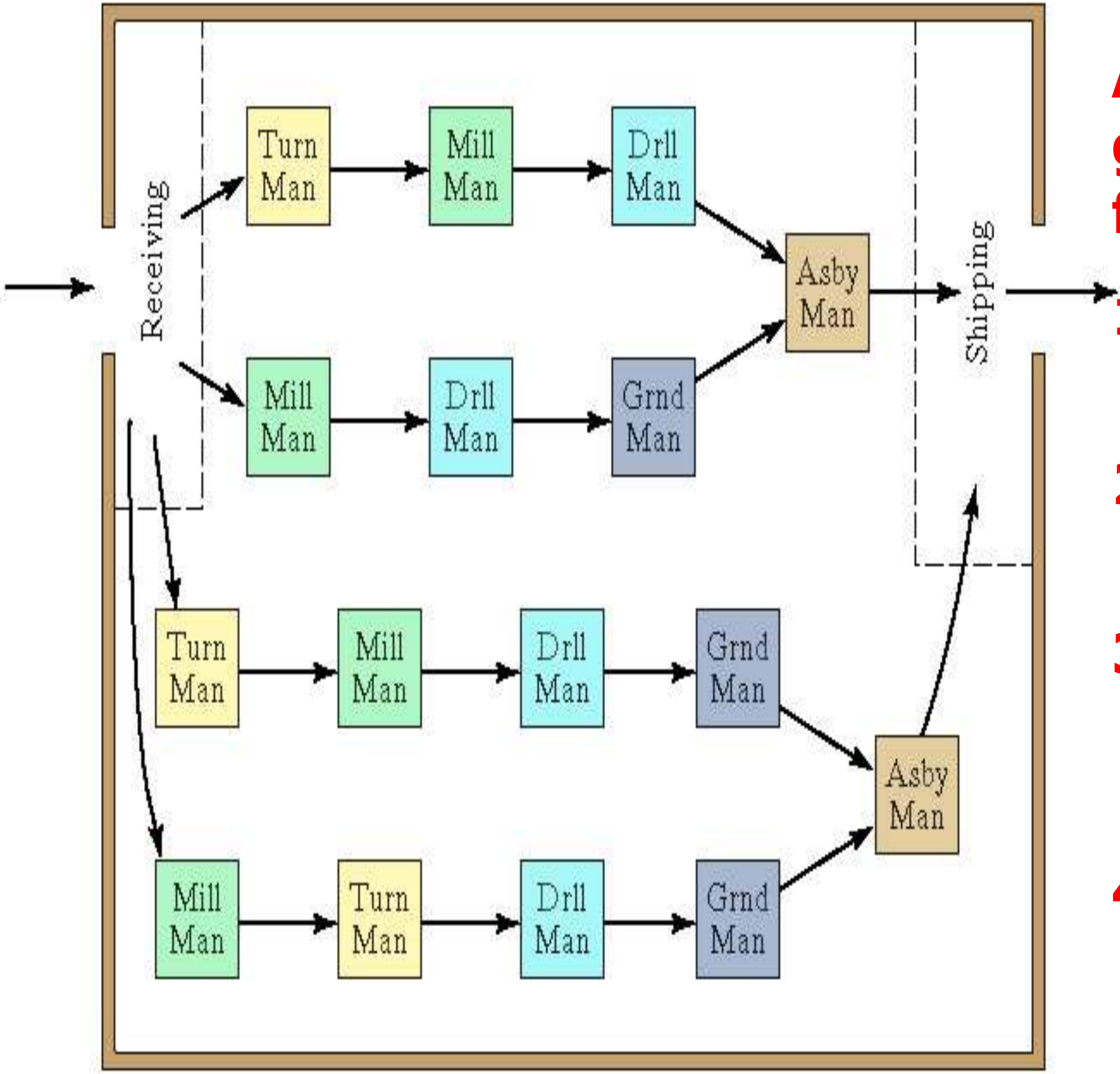
3. Usually more setups than necessary.

4. Long lead times.

Group Layout

- In Group Layout, each foreman and his team specialize in the production of one list of parts and co-operate in the completion of common task. This type of layouts based on component specialization.



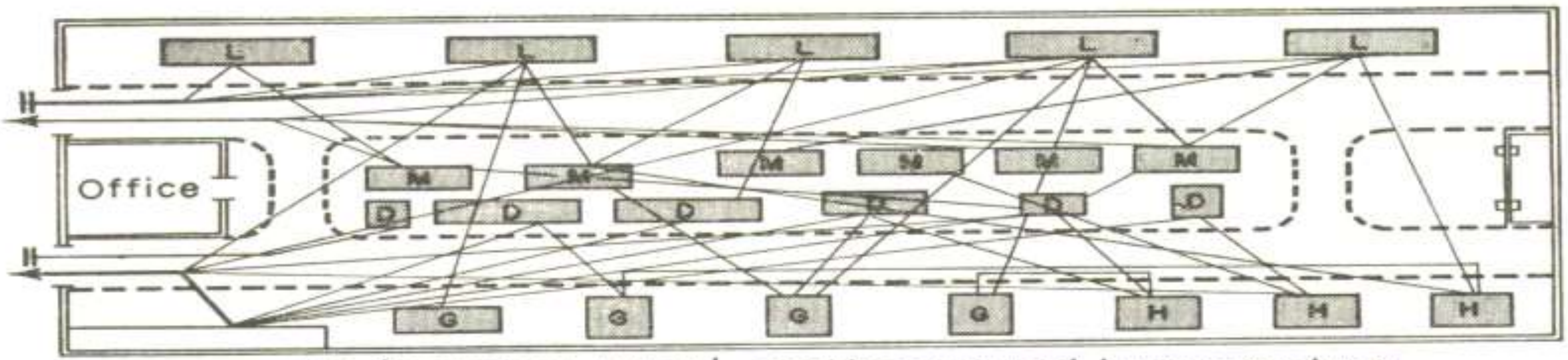


Advantages are gained in the form of reduced

1. **Work piece handling**
2. **Lower setup times**
3. **Less in process inventory**
4. **Less floor space and shorter lead times**

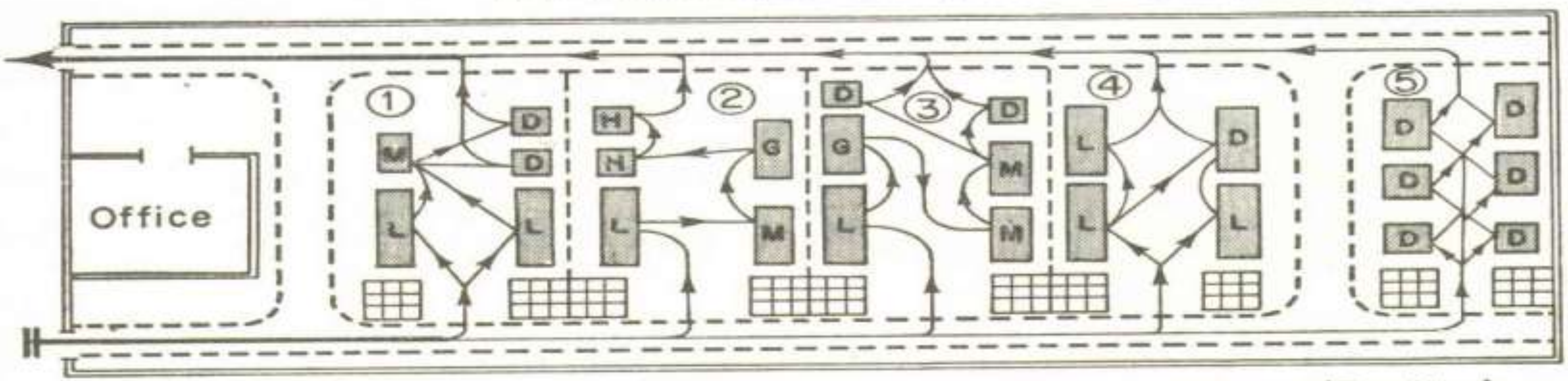
The Difference between group and functional layout:

(i) Complicated



N.B. 'Functional layout' – machines grouped by process type

(ii) Simplified
(By laying out in family machine 'groups')



N.B. 'Group layout' – machines grouped for component 'Families'

The biggest single obstacle in changing over to group technology from a traditional production is the problem of grouping parts into families.

PART FAMILIES:-

A part family is a collection of parts which are similar either because of geometric shape and size or because of similar processing steps are required in their manufacture.

Note:

the parts within a family are different but their similarities are close enough to merit their identification as members of the part family.

Identifying Part Families

Large manufacturing system can be decomposed into smaller subsystems of part families based on similarities in

1. **design attributes** and
2. **manufacturing features**

Identifying Part Families

Design Attributes:

- part configuration *(round or prismatic)*
- dimensional envelope *(length to diameter ratio)*
- surface integrity *(surface roughness, dimensional tolerances)*
- material type
- raw material state *(casting, forging, bar stock, etc.)*

Major dimensions

Basic external shape

Basic internal shape

Length/diameter ratio

Material type

Part function

Tolerances

Surface finish

Identifying Part Families

Part Manufacturing Features:

- operations and operation sequences *(turning, milling, etc.)*
- batch sizes
- machine tools
- cutting tools
- work holding devices
- processing times

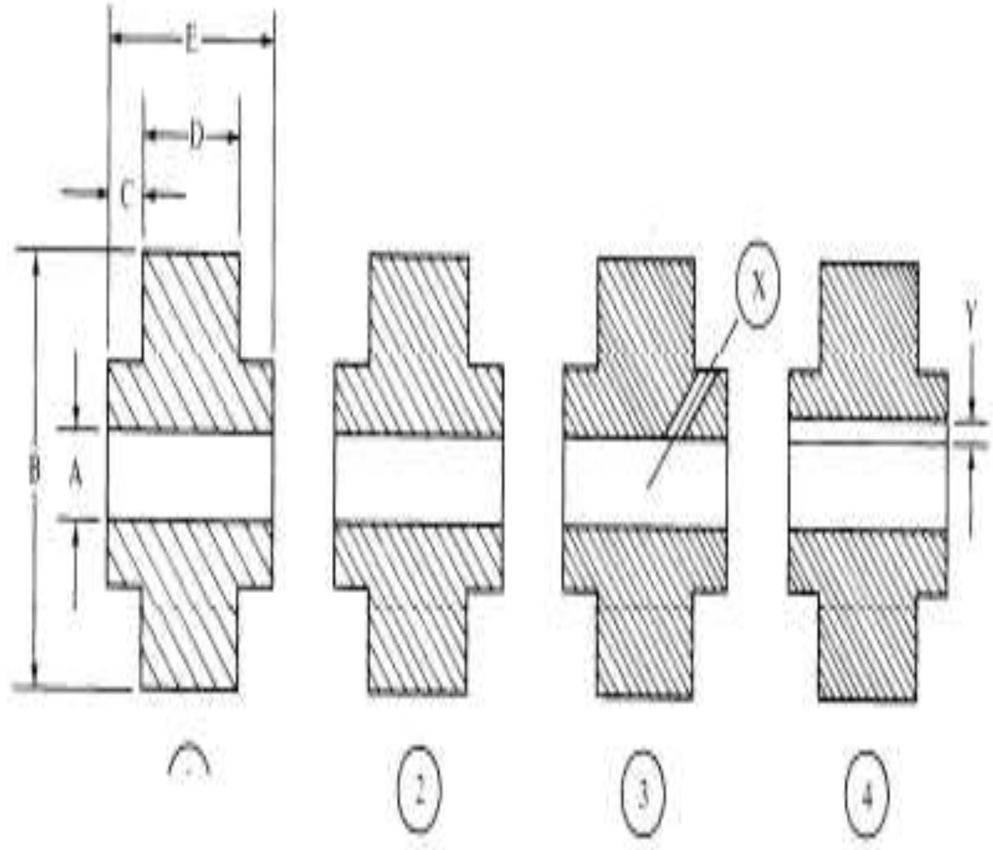
Identifying Part Families

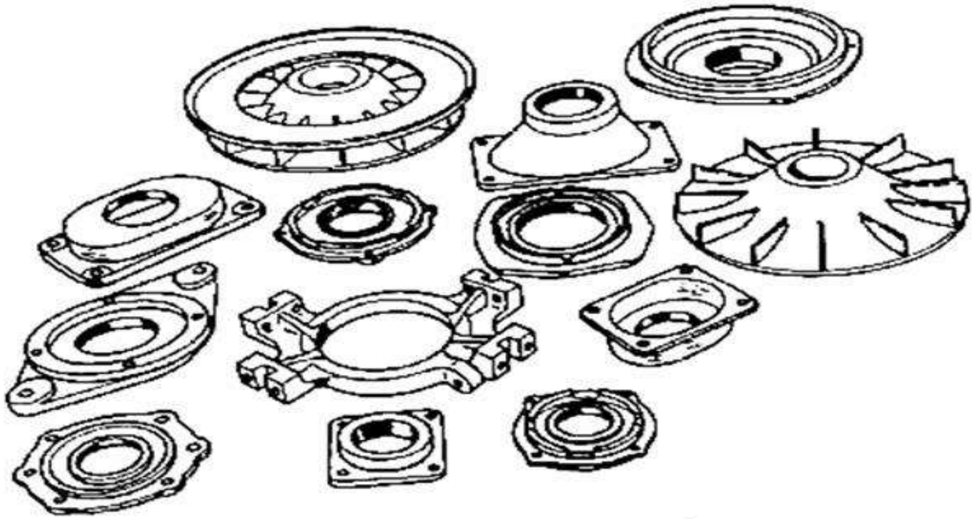
Group technology emphasis on part families based on similarities in design attributes and manufacturing, therefore **GT** contributes to the integration of CAD and CAM.

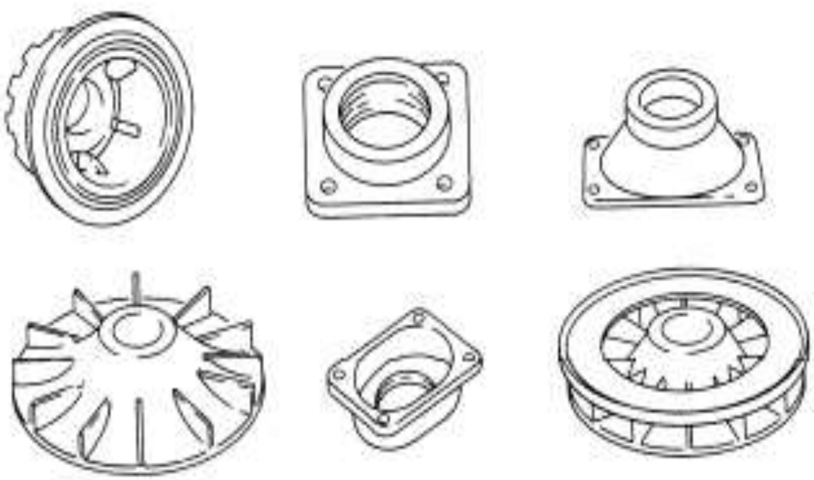
Part Families

A part family is a collection having similar:

Design Characteristics
(Geometrical Features)







Manufacturing Processes
(Process Similarity)

ADVANTAGES OR BENEFITS OF GROUP TECHNOLOGY:-

1. Standardization of tooling, fixtures, and setups is encouraged

2. Material handling is reduced Parts are moved within a machine cell rather than the entire factory

3. Process planning and production scheduling are simplified

4. Work-in-process and manufacturing lead time are reduced

5. Improved worker satisfaction in a GT cell

6. Higher quality work

7. Group technology allows similar designs to be easily modified from the existing designs from the database instead of starting from scratch.

8. Improvement in quality and reduction in scrap results in increase in production.

9. There is improved utilization of machines and as result lesser number of machines are required. This increase the floor space available.

10. There is improved ability to respond to market changes.

REDUCTIONS:-

1. Setup times
2. Inventory
3. Material handling cost
4. Direct and indirect labour cost.

IMPROVEMENTS:-

1. Quality
2. Material flow
3. Machine and operator utilization
4. Space utilization
5. Employee morale

LIMITATIONS:-

1. The cost of implementation is generally high with an outside consultant often being necessary since in house expertise on GT is rarely available. It requires a long setup times and painful debugging.

2. It may not be suitable for a factory with a very large variety of products.

3. There are too many GT codes in use and there is no one GT code that suits all applications.

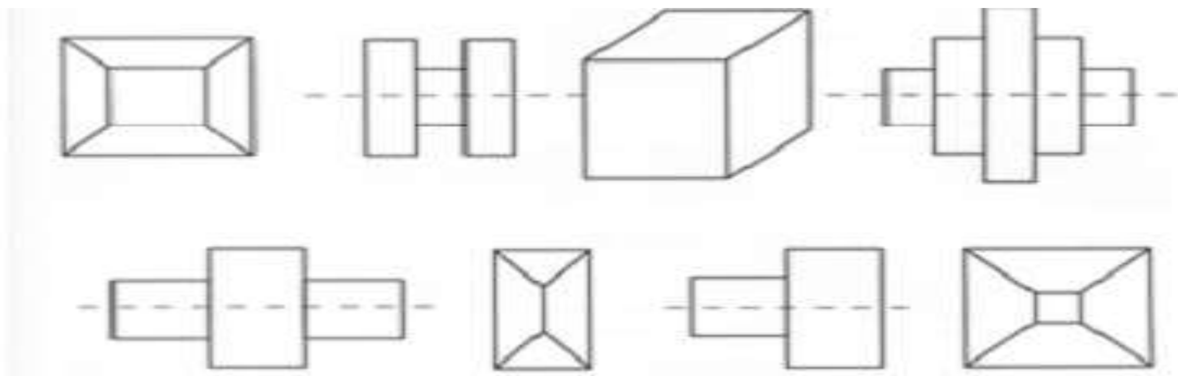
4. The range of product mix in a plant may be under constant change in which case, the GT cells may need constant revision which is impractical.

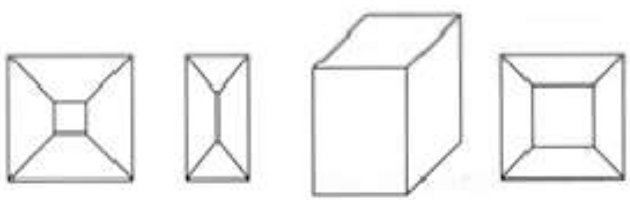
PART FAMILY FORMATION:-

Three methods for identifying parts families

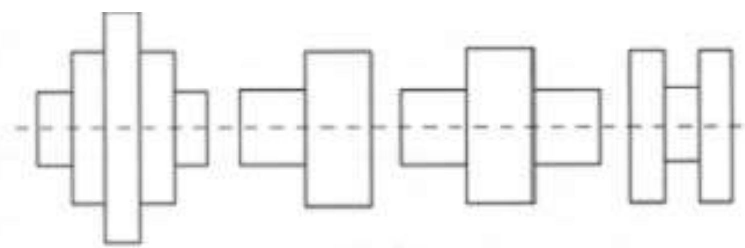
- **Visual inspection**
- **Classification and coding**
- **Production flow analysis**

Forming Part Families – 1. Visual Inspection Method





Prismatic parts



Rotational parts

1. The visual inspection method is the least sophisticated and least expensive method
2. It involves the classification of parts into families by looking at either the physical parts or their photographs and arranging them in to groups having similar features.

Forming Part Families – 1. Visual Inspection Method

- incorrect results
- human error
- different judgment by different people
- inexpensive
- least sophisticated
- good for small companies having smaller number of parts

Forming Part Families – 2. Classification and Coding

Coding:

- The process of assigning symbols to the parts. Where the symbols represent design attributes of parts, manufacturing features of parts, or both

Classification:

- The process of categorization of a set of parts into part families

The OPITZ classification system:

- it is a **mixed** (hybrid) coding system
- developed by **OPTIZ**, Technical University of Aachen, 1970
- it is widely used in industry
- it provides a basic framework for understanding the classification and coding process
- it can be applied to machined parts, non-machined parts (both formed and cast) and purchased parts
- it considers both **design** and **manufacturing** information

Mixed-mode

- Optiz Classification System:

12345	6789	ABCD
Form code	Supplementary code	Secondary code

Form code:

- Focus on part geometry dimensions and features relevant to part design

Supplementary code

- Includes information relevant to manufacturing, such as raw material, tolerance, and surface roughness

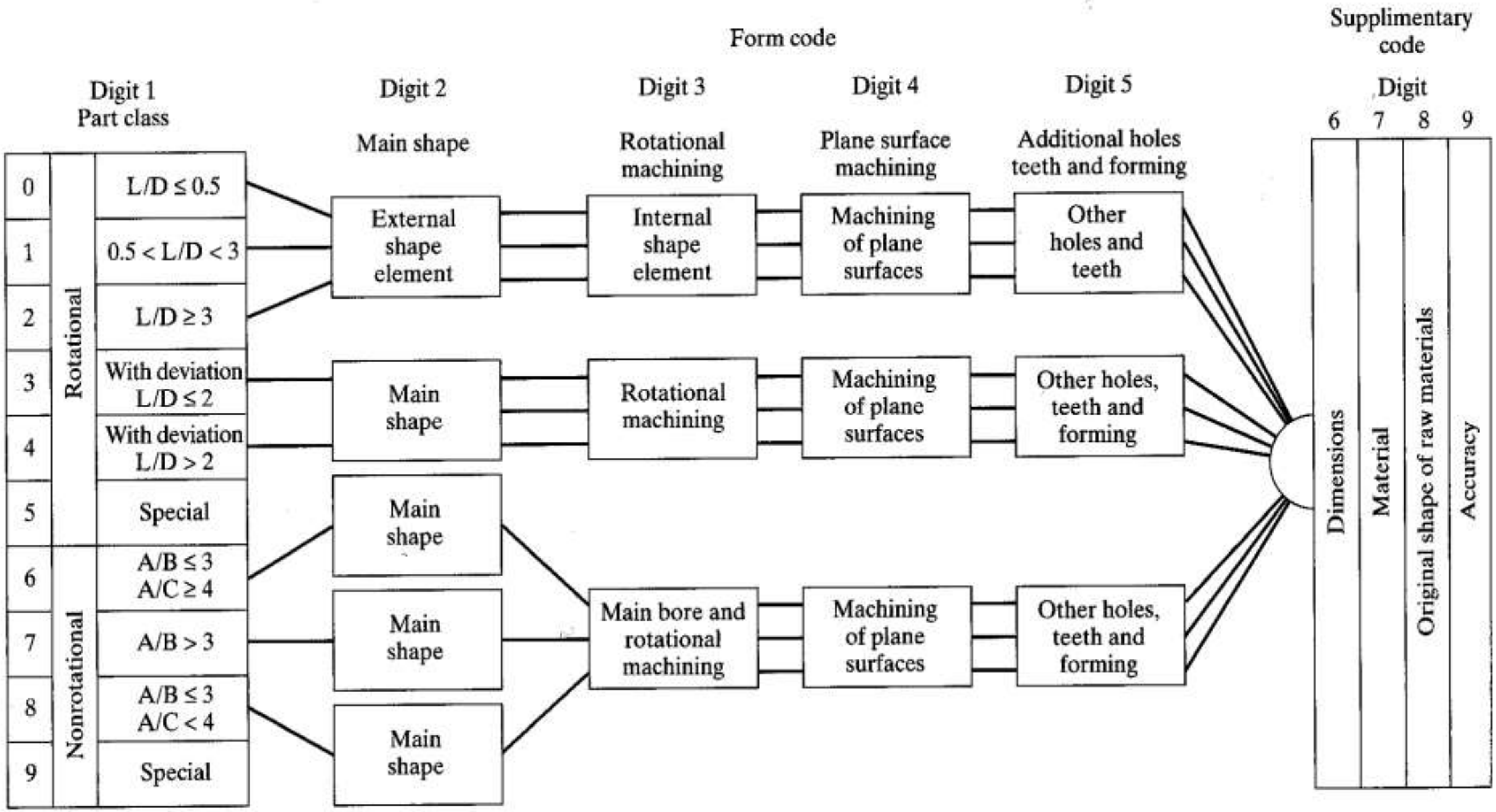
Secondary code

- Intended to identify the production operation type and sequence.
- It can be designed by the user firm to serve its own needs

Basic Structure of the OPTIZ

Digit	Description
1	Part shape class: rotation versus nonrotational (Figure 22.1). Rotational parts are classified by length-to-diameter ratio. Nonrotational parts by length, width, and thickness.
2	External shape features; various types are distinguished.
3	Rotational machining. This digit applies to internal shape features (e.g., holes, threads) on rotational parts, and general rotational shape features for nonrotational parts.
4	Plane machined surfaces (e.g., flats, slots).
5	Auxiliary holes, gear teeth, and other features.
6	Dimensions—overall size.
7	Work material (e.g., steel, cast iron, aluminum).
8	Original shape of raw material.
9	Accuracy requirements.

Basic Structure of the OPTIZ System



Form Code (digits 1 – 5)

Digit 1

Digit 1		Part class
0	Rotational parts	$L/D \le 0.5$
1	Rotational parts	$0.5 < L/D < 3$
2	Rotational parts	$L/D \ge 3$
3	Rotational parts	
4	Rotational parts	
5	Rotational parts	
6	Nonrotational parts	
7	Nonrotational parts	
8	Nonrotational parts	
9	Nonrotational parts	

Digit 2

Digit 2		External shape, external shape elements
0		Smooth, no shape elements
1	Stepped to one end or smooth	No shape elements
2	Stepped to one end or smooth	Thread
3	Stepped to one end or smooth	Functional groove
4	Stepped to both ends	No shape elements
5	Stepped to both ends	Thread
6	Stepped to both ends	Functional groove
7		Functional cone
8		Operating thread
9		All others

Digit 3

Digit 3		Internal shape, internal shape elements
0		No hole, no breakthrough
1	Smooth or stepped to one end	No shape elements
2	Smooth or stepped to one end	Thread
3	Smooth or stepped to one end	Functional groove
4	Stepped to both ends	No shape elements
5	Stepped to both ends	Thread
6	Stepped to both ends	Functional groove
7		Functional cone
8		Operating thread
9		All others

Digit 4

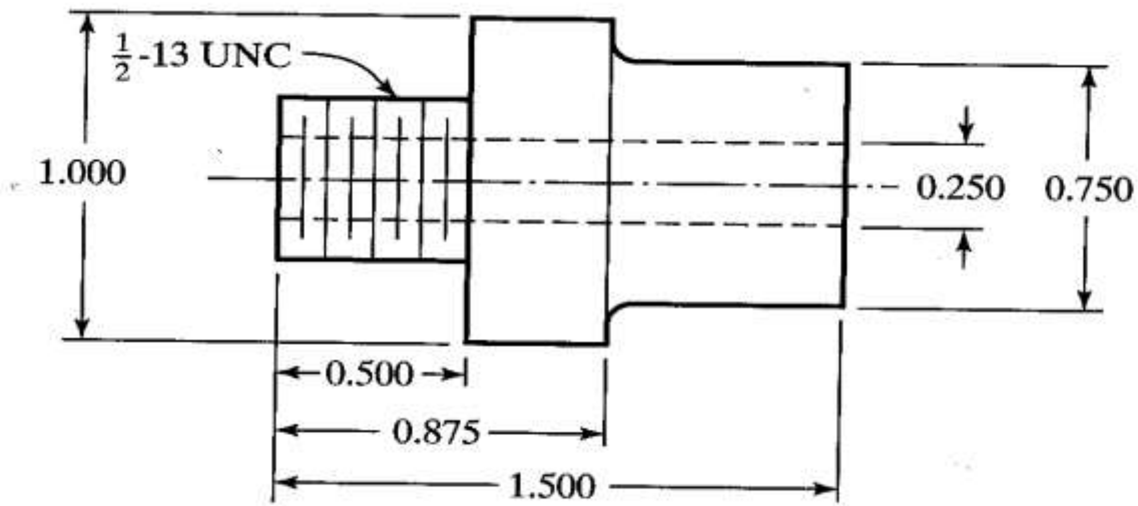
Digit 4	Plane surface machining
0	No surface machining
1	Surface plane and/or curved in one direction, external
2	External plane surface related by graduation around the circle
3	External groove and/or slot
4	External spline (polygon)
5	External plane surface and/or slot, external spline
6	Internal plane surface and/or slot
7	Internal spline (polygon)
8	Internal and external polygon, groove and/or slot
9	All others

Digit 5

Digit 5		Auxiliary holes and gear teeth
0	No gear teeth	No auxiliary hole
1	No gear teeth	Axial, not on pitch circle diameter
2	No gear teeth	Axial on pitch circle diameter
3	No gear teeth	Radial, not on pitch circle diameter
4	No gear teeth	Axial and/or radial and/or other direction
5	No gear teeth	Axial and/or radial on PCD and/or other directions
6	With gear teeth	Spur gear teeth
7	With gear teeth	Bevel gear teeth
8	With gear teeth	Other gear teeth
9	With gear teeth	All others

Example: *Optiz part coding System*

- **Given the rotational part design below, determine the form code in the Optiz parts classification and coding system.**



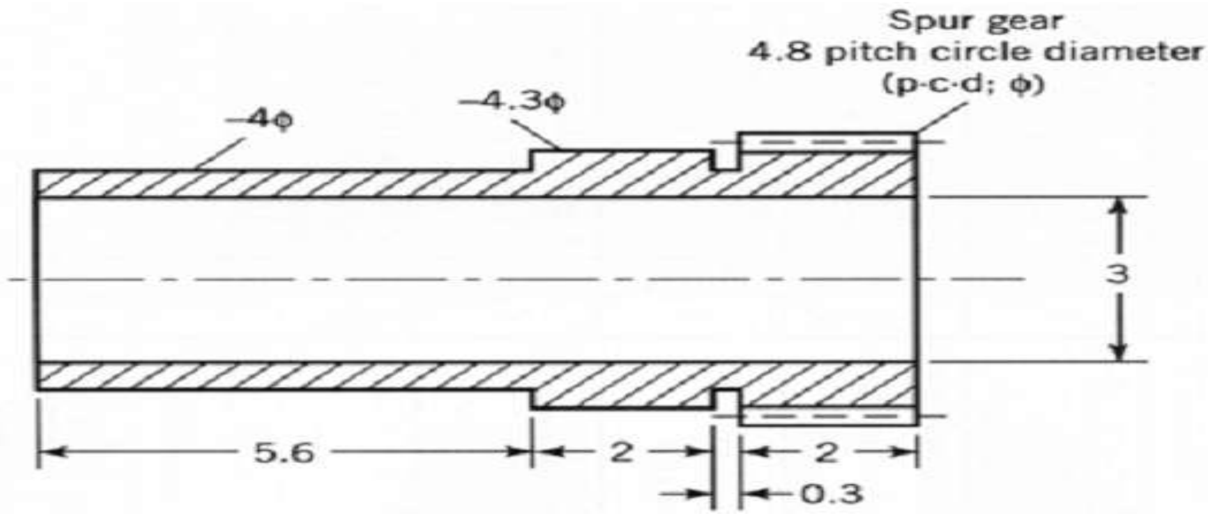
Solution

- *Length-to-diameter ratio*: L/D = 1.5 — Digit 1 = **1**
- *External shape*: both ends stepped with screw thread on one end — Digit 2 = **5**
- *Internal shape:* part contains a through hole — Digit 3 = **1**
- *Plane surface machining*: none — Digit 4 = **0**
- *Auxiliary holes, gear teeth, etc.*: none — Digit 5 = **0**

The form code in the Optiz system is **15100**

Example

Form Code	1	3	1	0	6



- Part class:

Rotational part, L/D = 9.9/4.8 ≈ 2.0 based on the pitch circle diameter of the gear, so the first digit = 1

- External shape:

The part is stepped on one side with a functional groove, so the second digit is 3

- Internal shape:
- The third digit is 1 because of the through hole
- Plain surface machining:
- The fourth digit is 0 because there is no plain surface machining
- Auxiliary holes and gear teeth:
- The fifth digit is 6 because there are spur gear teeth on the part

Forming Part Families – Classification and Coding: 3.Production Flow Analysis (PFA)

Method for identifying part families and associated machine groupings based on production route sheets rather than part design data

- Work parts with identical or similar route sheets are classified into part families
- Advantages of using route sheet data
  - Parts with different geometries may nevertheless require the same or similar processing
  - Parts with nearly the same geometries may nevertheless require different processing

Steps in Production Flow Analysis

1. Data collection – operation sequence and machine routing for each part
2. Sortation of process routings – parts with same sequences and routings are arranged into "packs"
3. PFA chart – each pack is displayed on a PFA chart
   - Also called a *part-machine incidence matrix*
4. Cluster analysis – purpose is to collect packs with similar routings into groups
   - Each machine group = a machine cell

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

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

BENEFITS OF GROUP TECHNOLOGY

It affects all areas of a company, including:

- engineering
- equipment specification
- facilities planning
- process planning
- production control
- quality control
- tool design
- purchasing
- service

BENEFITS OF GROUP TECHNOLOGY

Some of the well-known tangible and intangible benefits of implementing GT :

1. Engineering design

- **Reduction in new parts design**
- **Reduction in the number of drawings through standardization**
- **Reduction of number of similar parts, easy retrieval of similar functional parts, and identification of substitute parts**

BENEFITS OF GROUP TECHNOLOGY

2. Layout planning

- Reduction in production floor space required
- Reduced material-handling effort

BENEFITS OF GROUP TECHNOLOGY

3. Specification of equipment, tools, jigs, and fixtures

- Standardization of equipment
- Implementation of cellular manufacturing systems
- Significant reduction in up-front costs incurred in the release of new parts for manufacture

BENEFITS OF GROUP TECHNOLOGY

4. Manufacturing: *process planning*

- Reduction in setup time and production time
- Alternative routing leading to improved part routing
- Reduction in number of machining operations and numerical control (NC) programming time

BENEFITS OF GROUP TECHNOLOGY

5. Manufacturing: production control

- Reduced work-in-process inventory
- Easy identification of bottlenecks
- Improved material flow and reduced warehousing costs
- Faster response to schedule changes
- Improved usage of jigs, fixtures, pallets, tools, material handling, and manufacturing equipment

BENEFITS OF GROUP TECHNOLOGY

6. Manufacturing: quality control

- Reduction in number of defects leading to reduced inspection effort
- Reduced scrap generation
- Better output quality
- Increased accountability of operators and supervisors responsible for quality production, making it easier to implement total quality control concepts.

BENEFITS OF GROUP TECHNOLOGY

7. Purchasing

- Coding of purchased part leading to standardized rules for purchasing
- Economies in purchasing possible because of accurate knowledge of raw material requirements
- Reduced number of part and raw materials
- Simplified vendor evaluation procedures leading to just-in-time purchasing

BENEFITS OF GROUP TECHNOLOGY

8. Customer service

- Accurate and faster cost estimates
- Efficient spare parts management, leading to better customer service
- Lower lead times

Cellular Manufacturing

Cellular manufacturing

is an application of group technology in manufacturing in which all or a portion of a firm's manufacturing system has been converted into cells

A manufacturing cell

is a cluster of machines or processes located in close proximity and dedicated to the manufacturing of a family of parts

Why cellular manufacturing:

- Reduce setup times: By using part family tooling and sequencing
- Reduce flow times: By reducing setup and move times and wait time for moves and using smaller batch sizes
- Reduce inventories
- Reduce lead time

Cell Design

Design of cellular manufacturing system is a complex exercise with broad implications for an organization.

The **cell design process** involves issues related to both ***system structure*** (Structural Issues) and ***system operation*** (Procedures Issues)

Cell Design

Structural issues include:

- Selection of part families and grouping of parts into families
- Selection of machine and process populations and grouping of these into cells
- Selection of tools, fixtures, and pallets
- Selection of material-handling equipment
- Choice of equipment layout

Cell Design

Procedures Issues include:

- Detailed design of jobs
- Organization of supervisory and support personnel around the cellular structure
- Formulation of maintenance and inspection policies
- Design of procedures *for production planning, scheduling, control*, and *acquisition of related software and hardware*
- Modification of cost control and reward systems
- Outline of procedures for interfacing with the remaining manufacturing system (in terms of work flow and information, whether computer controlled or not)

Evaluation of Cell Design Decisions

The evaluation of design decisions can be categorized as related to either

- ***the system structure***

or

- ***the system operation***.

Evaluation of Cell Design Decisions

Typical considerations related to the ***system structure*** include:

- Equipment and tooling investment (low)
- Equipment relocation cost (low)
- Material-handling costs (low)
- Floor space requirements (low)
- Extent to which parts are completed in a cell (high)
- Flexibility (high)

Evaluation of Cell Design

Evaluations of cell system design are incomplete unless they relate to the ***operation of the system***.

A few typical performance variables related to ***system operation*** are:

- Equipment utilization (high)
- Work-in-process inventory (low)
- Queue lengths at each workstation (short)
- Job throughput time (short)
- Job lateness (low)

Cell Formation Approaches

1. Machine - Component Group Analysis:

Machine - Component Group Analysis is based on ***production flow analysis***

Machine - Component Group Analysis

Production flow analysis involves four stages:

Stage 1: ***Machine classification***.

Machines are classified on the basis of operations that can be performed on them. A machine type number is assigned to machines capable of performing similar operations.

Machine - Component Group Analysis

Production flow analysis involves four stages:

Stage 2: ***Checking parts list and production route information*.**

For each part, information on the operations to be undertaken and the machines required to perform each of these operations is checked thoroughly.

Machine - Component Group Analysis

Production flow analysis involves four stages:

Stage 3: ***Factory flow analysis*.**

This involves a micro-level examination of flow of components through machines. This, in turn, allows the problem to be decomposed into a number of machine-component groups.

Machine - Component Group Analysis

Production flow analysis involves four stages:

Stage 4: ***Machine-component group analysis*.**

An intuitive manual method is suggested to manipulate the matrix to form cells. However, as the problem size becomes large, the manual approach does not work. Therefore, there is a need to develop analytical approaches to handle large problems systematically.

Machine - Component Group Analysis

Example: Consider a problem of 4 machines and 6 parts. Try to group them.

Components

Machines	1	2	3	4	5	6
M1		1		1		1
M2		1		1		1
M3	1		1		1	
M4	1		1		1	

Machine - Component Group Analysis

Solution

Components

Machines	**2**	**4**	**6**	**1**	**3**	**5**
M1	1	1	1			
M2	1	1	1			
M3				1	1	1
M4				1	1	1

Rank Order Clustering Algorithm

Rank Order Clustering Algorithm is a simple algorithm used to form ***machine-part groups.***

Rank Order Clustering Algorithm

Step 1: Assign binary weight and calculate a decimal weight for each row and column using the following formulas:

$$\text{Decimal weight for row } i = \sum_{p=1}^{m} b_{ip} 2^{m-p}$$

$$\text{Decimal weight for column } j = \sum_{p=1}^{n} b_{pj} 2^{n-p}$$

Rank Order Clustering Algorithm

Step 2: Rank the rows in order of decreasing decimal weight values.

Step 3: Repeat steps 1 and 2 for each column.

Step 4: Continue preceding steps until there is no change in the position of each element in the row and the column.

Rank Order Clustering Algorithm

Example:

Consider a problem of 5 machines and 10 parts. Try to group them by using *Rank Order Clustering Algorithm.*

Table 1 **Components**

Machines	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
M1	1	1	1	1	1		1	1	1	1
M2		1	1	1					1	1
M3	1				1	1	1			
M4		1	1	1				1	1	1
M5	1	1	1	1	1	1	1	1		

Rank Order Clustering Algorithm

Table 2 **Binary weight**

	2^9	2^8	2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0

Components

Machines	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Decimal equivalent**
M1	1	1	1	1	1		1	1	1	1	1007
M2		1	1	1					1	1	451
M3	1				1	1	1				568
M4		1	1	1				1	1	1	455
M5	1	1	1	1	1	1	1	1			1020

Rank Order Clustering Algorithm

Table 3 **Binary weight**

		2^9	2^8	2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0

Components

Binary weight	Machines	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
2^4	**M5**	1	1	1	1	1	1	1	1		
2^3	**M1**	1	1	1	1	1		1	1	1	1
2^2	**M3**	1				1	1	1			
2^1	**M4**		1	1	1				1	1	1
2^0	**M2**		1	1	1					1	1
Decimal equivalent		28	27	27	27	28	20	28	26	11	11

Rank Order Clustering Algorithm

Table 4

Binary weight

		2^9	2^8	2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0

Components

Binary weight	Machines	**1**	**5**	**7**	**2**	**3**	**4**	**8**	**6**	**9**	**10**	**Decimal equivalent**
2^4	**M5**	1	1	1	1	1	1	1	1			1020
2^3	**M1**	1	1	1	1	1	1	1		1	1	1019
2^2	**M3**	1	1	1					1			900
2^1	**M4**				1	1	1	1		1	1	123
2^0	**M2**				1	1	1			1	1	115
Decimal equivalent		28	28	28	27	27	27	26	20	11	11	

Rank Order Clustering Algorithm

- R/O clustering oscillations indicating need of machine replication (happens often!)
- Presence of Outliers and/or Voids in the finished clusters
- Outliers indicate the need of machine replication
- Voids indicate ‘skipped’ machines in a cell
- Generally speaking, these clustering algorithms are designed to convert existing routes for facility re-organization
- They require a previous engineering study to be performed to develop a series of routers on a core sample of parts that represent most of the production in the shop

Rank Order Clustering Algorithm

- The ROC provides a simple analytical technique that can be easily computerized
- The ROC has fast convergence and relatively low computation time depending on the matrix size
- The fact that ROC uses binary values will impose restrictions on the size of the matrix that can be solved

Rank Order Clustering Algorithm

- Most computers have a maximum of 2^{48}-1 for integer representation, which means that the maximum number of rows and columns is limited to 47 and columns is limited to 47
- The algorithm results depend on the initial matrix arrangement
- The algorithm collects positive entries (1s) in the top left-hand corner, leaving the rest of the matrix disorganized

Cluster Identification Algorithm (CIA)

- Designed to identify disconnected blocks if they exist
- If there are no disconnected blocks (the matrix is not mutually separable), the entire matrix will form one block
- The algorithm begins by masking all columns that have an entry of 1 in any row (selected randomly), then all rows that have an entry of 1 in these columns are masked. This process is repeated until all intersecting columns and rows are masked.

Cluster Identification Algorithm (CIA)

- These masked columns and rows are placed in a block and removed from the matrix removed from the matrix.
- Then the process of masking starts again and another block is identified.
- This will continue until all the entries in the matrix are assigned in blocks and all separable blocks are identified

Cluster Identification Algorithm (CIA)

Example:

Part Number (columns) / Machine Number (rows)

Machine Number	1	2	3	4	5	6	7	8
1				1				1
2			1		1			
3		1				1	1	
4			1		1			
5	1			1				1
6		1				1	1	
7	1			1				1

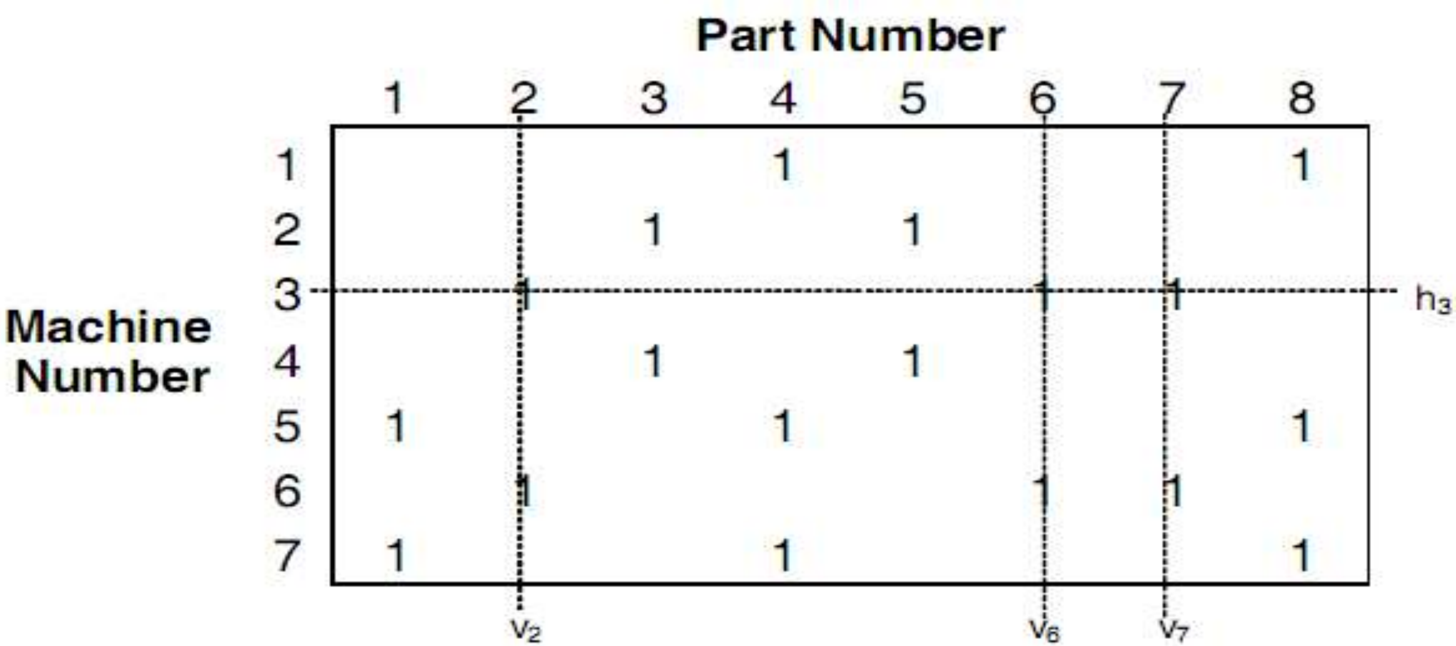
Step 1. Select any row i of the incidence matrix and draw a horizontal line hi through it.

Row 3 of the matrix is selected randomly and a horizontal line h3 is drawn.

Cluster Identification Algorithm (CIA)

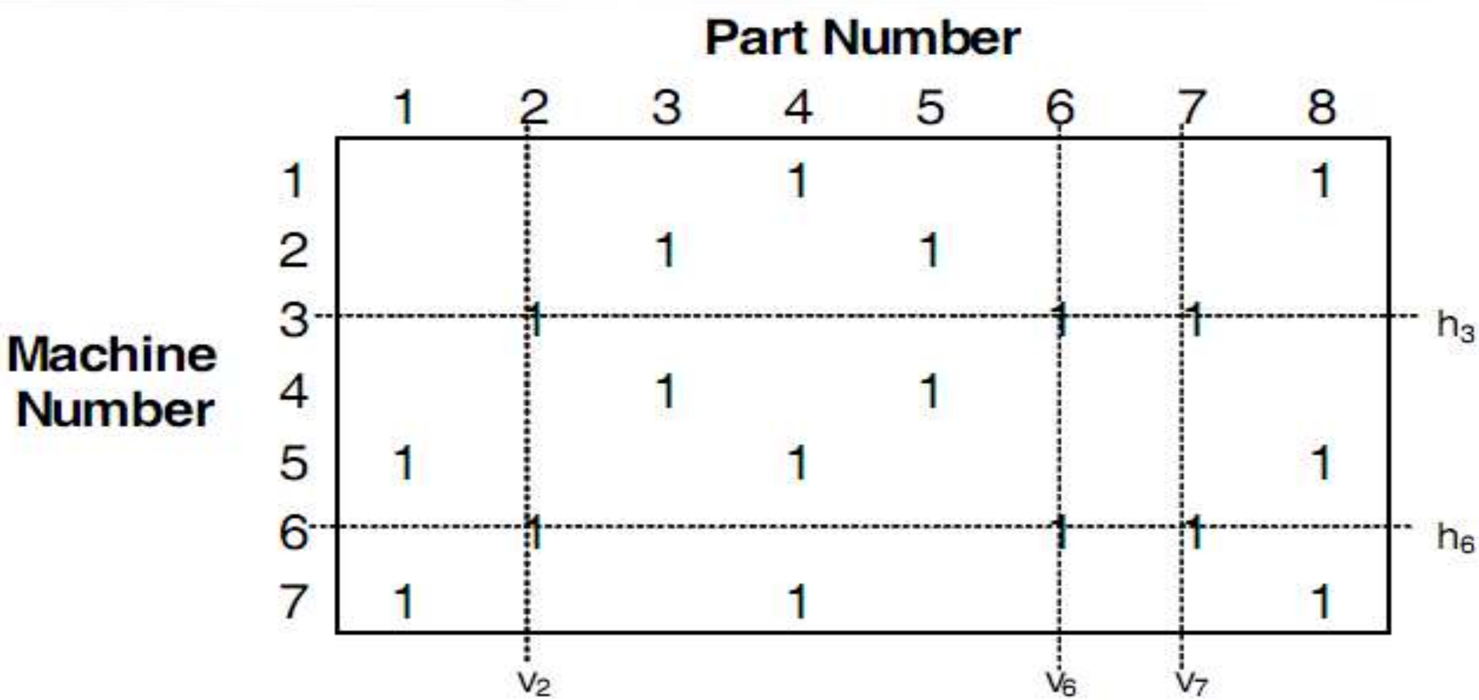
Step 2. For each entry of 1 crossed by the horizontal line h3 draw a vertical line vj.

Three vertical lines v2, v6, and v7 are drawn



Cluster Identification Algorithm (CIA)

Step 3. For each entry of 1 crossed once by a vertical line vj draw a horizontal line. A horizontal line h6 is drawn through all the crossed-once entries of the matrix:



Cluster Identification Algorithm (CIA)

Step 4. The preceding steps are repeated until no more crossed once entries are left.

• All the crossed-twice entries are grouped in a block and removed from the matrix.

•Parts 2, 6, 7 and machines 3, 6 are grouped in one block.

Machine Number \ Part Number	2	6	7	1	3	4	5	8
3	1	1	1					
6	1	1	1					
1						1		1
2					1		1	
4					1		1	
5				1		1		1
7				1		1		1

Cluster Identification Algorithm (CIA)

The grouped parts and machines are removed from the matrix

	2	6	7
3	1	1	1
6	1	1	1

Cluster Identification Algorithm (CIA)

Step 5: The above procedure is repeated for the remaining matrix entries until all entries are grouped

	1	3	4	5	8
1			1		1
2		1		1	
4		1		1	
5	1		1		1
7	1		1		1

Cluster Identification Algorithm (CIA)

The resulting matrix is as follows:

	2	6	7	8	1	4	3	5
3	1	1	1					
6	1	1	1					
5				1	1	1		
1				1		1		
7				1	1	1		
2							1	1
4							1	1

Arranging Machines in a GT Cell

- **After part-machine grouping have been identified by cell formation approaches, the next problem is to organize the machines into the most logical arrangement.**

- **Hollier Method. This method uses the sums of flow "From" and "To" each machine in the cell. The method can be outlined as follows**

1. ***Develop the From-To chart from part routing data.*** **The data contained in the chart indicates numbers of part moves between the machines in the cell.**

2. ***Determine the "From" and "To" sums for each machine.*** **This is accomplished by summing all of the "From" trips and "To" trips for each machine.**

   - **The "From" sum for a machine is determined by adding the entries in the corresponding row.**
   - **The "To" sum is found by adding the entries in the corresponding column.**

Arranging Machines in a GT Cell

3. *Assign machines to the cell based on minimum "From" or "To" sums.* **The machine having the smallest sum is selected.**
   - **If the minimum value is a "To" sum, then the machine is placed at the beginning of the sequence.**
   - **If the minimum value is a "From" sum, then the machine is placed at the end of the sequence.**

   Tie breaker

   - **If a tie occurs between minimum "To" sums or minimum "From" sums, then the machine with the minimum "From/To" ratio is selected.**
   - **If both "To" and "From" sums are equal for a selected machine, it is passed over and the machine with the next lowest sum is selected.**
   - **If a minimum "To" sum is equal to a minimum "From" sum, then both machines are selected and placed at the beginning and end of the sequence, respectively**

4. *Reformat the From-To chart.* **After each machine has been selected, restructure the From-To chart by eliminating the row and column corresponding to the selected machine and recalculate the "From" and "To" sums.**

5. **Repeat steps 3 and 4 until all machines have been assigned**

Example of Arranging Machines in a GT Cell

- **Suppose that four machines, 1, 2, 3, and 4 have been identified as belonging in a GT machine cell. An analysis of 50 parts processed on these machines has been summarized in the From-To chart presented below. Additional information is that 50 parts enter the machine grouping at machine 3, 20 parts leave after processing at machine 1, and 30 parts leave after machine 4. Determine a logical machine arrangement using Hollier method.**

From-To Chart

	To:	1	2	3	4
From:	1	0	5	0	25
	2	30	0	0	15
	3	10	40	0	0
	4	10	0	0	0

Example of Arranging Machines in a GT Cell

- **First iteration**

	To:	1	2	3	4	"From" Sums
From:	1	0	5	0	25	30
	2	30	0	0	15	45
	3	10	40	0	0	50
	4	10	0	0	0	10
"To" sums		50	45	0	40	135

Example of Arranging Machines in a GT Cell

- **Second iteration with machine 3 removed.**

	To:	1	2	4	"From" Sums
From:	1	0	5	25	30
	2	30	0	15	45
	4	10	0	0	10
"To" sums		40	5	40	

Example of Arranging Machines in a GT Cell

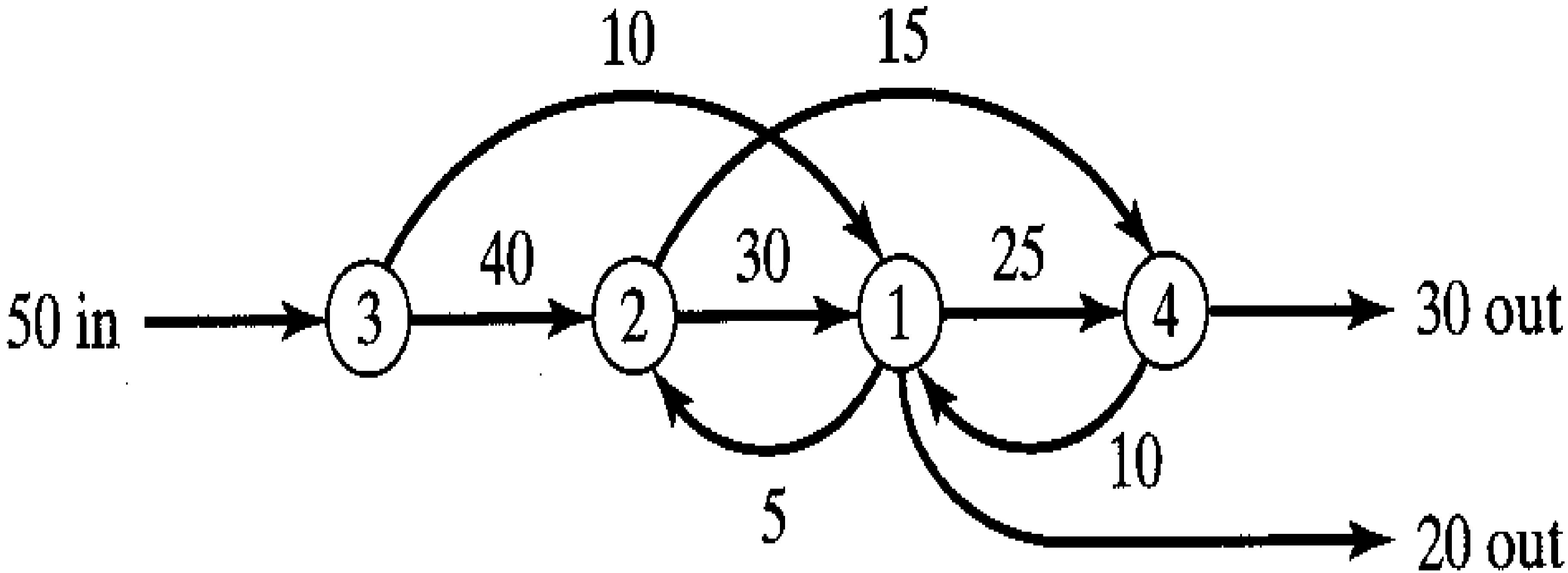
- **Third iteration with machine 2 removed.**

	To:	1	4	"From" Sums
From:	1	0	25	**25**
	4	10	0	**10**
"To" sums		**10**	**25**	

- **The resulting machine sequence 3 → 2 → 1 → 4**

Example of Arranging Machines in a GT Cell

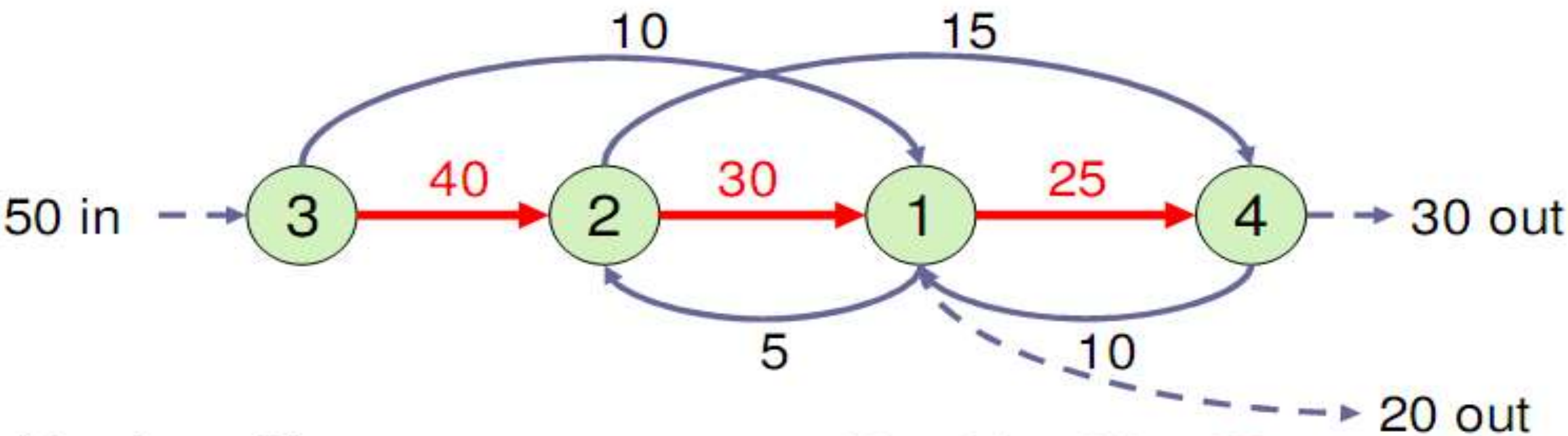
- **The flow diagram for machine cell in the Example is shown below. Flow of parts into and out of the cells has also been included**



Hollier Method

- Percentage of in-sequence moves

(%) which is computed by adding all of the values representing in-sequence moves and dividing by the total number of moves



Number of in-sequence moves = 40 + 30 + 25 = 95

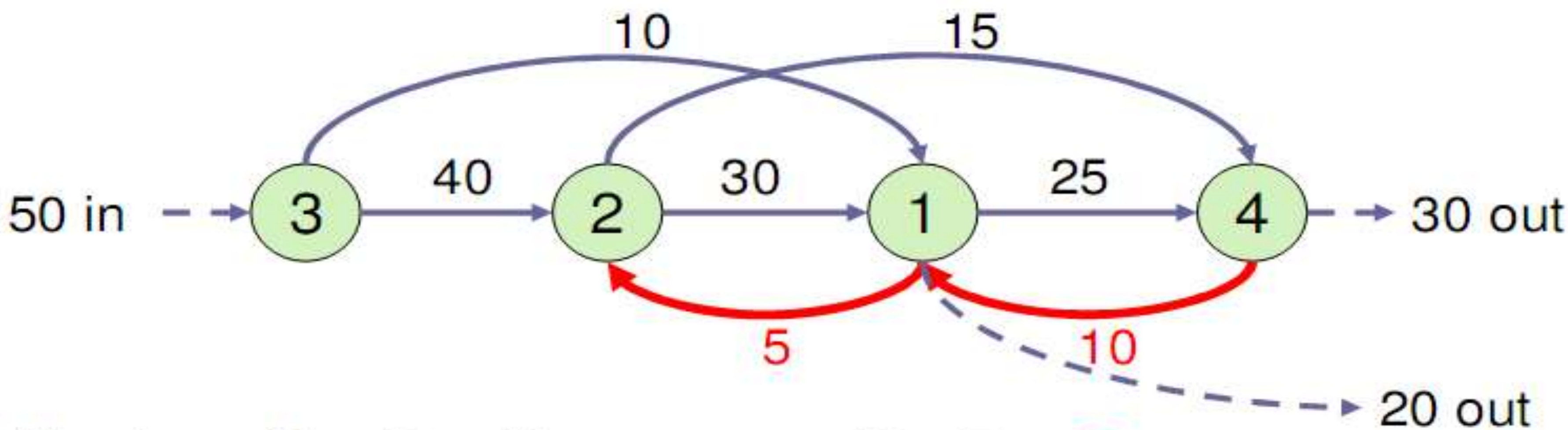
Total number of moves = 95 + 15 + 10 + 10 + 5 = 135

Percentage of in-sequence moves = 95/135 = 0.704 = 70.4%

Hollier Method

- ## Percentage of backtracking moves

(%) which is computed by adding all of the values representing backtracking moves and dividing by the total number of moves



Number of backtracking moves = 10 + 5 = 15

Total number of moves = 95 + 15 + 10 + 10 + 5 = 135

Percentage of backtracking moves = 15/135 = 0.704 = 11.1%

Hollier Method 2 Example

- **From-To sums and From/To ratio**

	To: 1	2	3	4	From sums	From/To ratio
From: 1	0	5	0	25	30	0.60
2	30	0	0	15	45	1.0
3	10	40	0	0	50	∞
4	10	0	0	0	10	0.25
To sums	50	45	0	40	135	

Resulting machine sequence 3 – 2 – 1 – 4

UNIT V

INDUSTRIAL ROBOTICS

ROBOT ANATOMY AND RELATED ATTRIBUTES

- The anatomy of industrial robots deals with the assembling of outer components of a robot such as wrist, arm and body.
- Before jumping into robot configurations, here are some of the key facts about robot anatomy.

(a) Joints and Links

(b) Common Robot Configurations

JOINTS AND LINKS

- The manipulator of an industrial robot consists of a series of joints and links.
- Robot anatomy deals with the study of different joints and links and other aspects of the manipulator's physical construction.
- A robotic joint provides relative motion between two links of the robot.
- Each joint, or axis, provides a certain degree-of-freedom (dof) of motion.
- In most of the cases, only one degree-of-freedom is associated with each joint.
- Robot's complexity can be classified according to the total number of degrees -of-freedom they possess.
- Each joint is connected to two links, an input link and an output link.

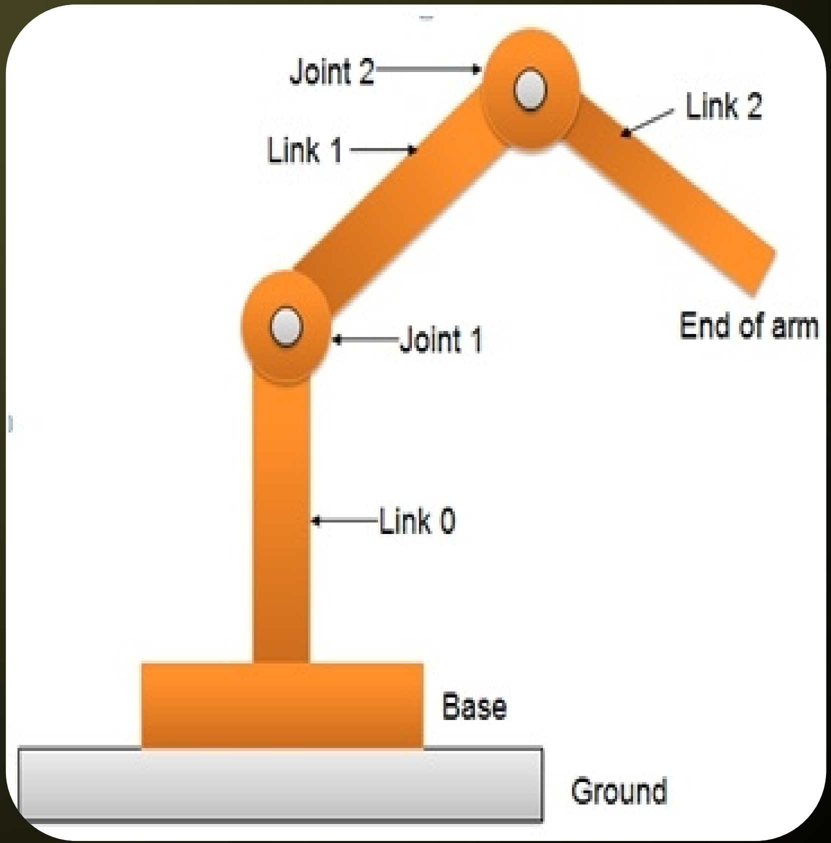
JOINTS AND LINKS

- A Joint provides controlled relative movement between the input link and output link. A robotic link is the rigid component of the robot manipulator.

- Most of the robots are mounted upon a stationary base, such as the floor. From this base, a joint-link numbering scheme may be recognized as shown in Figure.

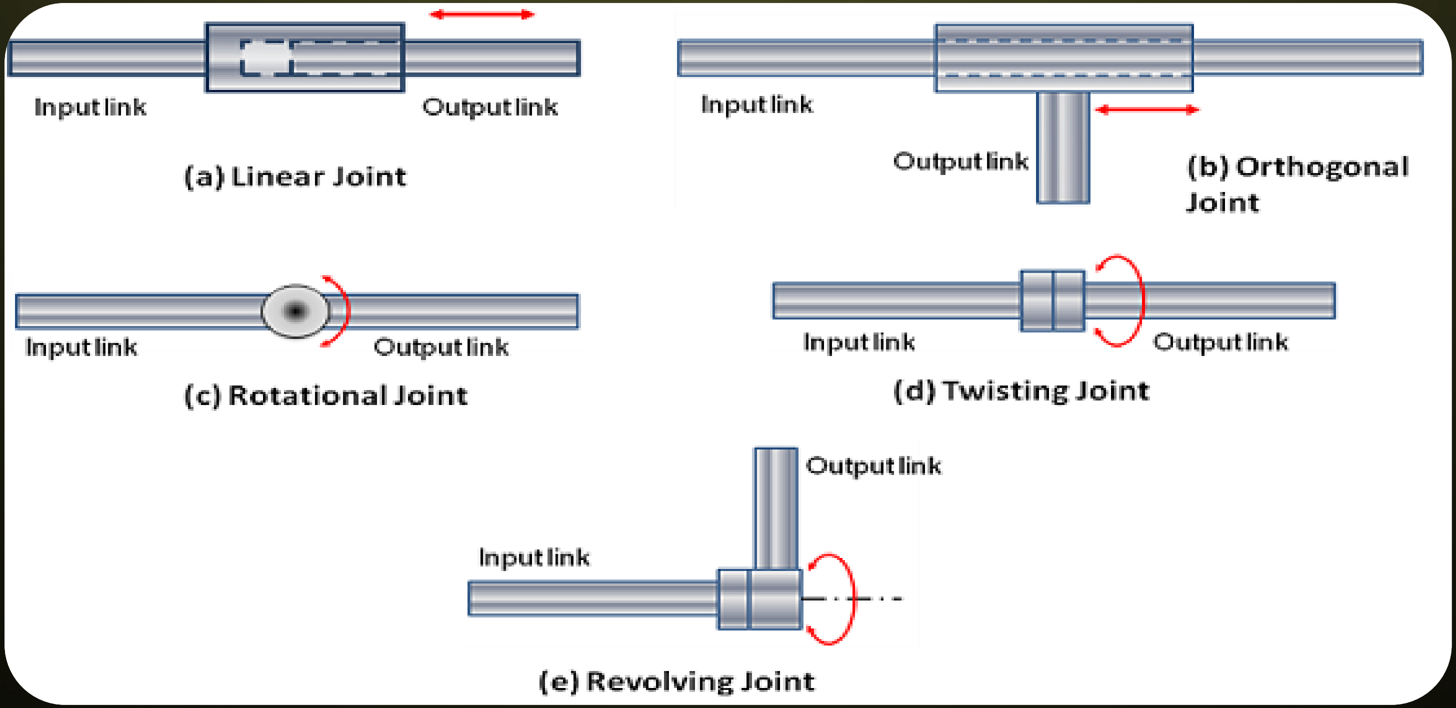
JOINTS AND LINKS

- The robotic base and its connection to the first joint are termed as link-0.
- The first joint in the sequence is joint-1.
- Link-0 is the input link for joint-1, while the output link from joint-1 is link-1 which leads to joint-2.
- Link 1 is the output link for joint-1 and the input link for joint-2.
- This joint-link-numbering scheme is further followed for all joints and links in the robotic systems.



JOINTS AND LINKS

- Nearly all industrial robots have mechanical joints that can be classified into following five types as shown in Figure below.



JOINTS AND LINKS

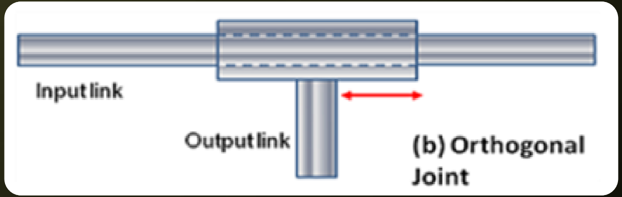
a) Linear joint (type L joint)

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

(a) Linear Joint

b) Orthogonal joint (type U joint)

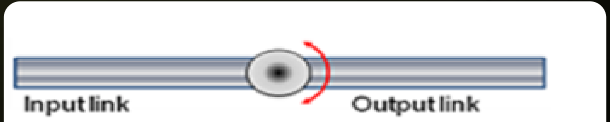
- This also has a translational sliding motion, but the input and output links are perpendicular to each other during the move.



(b) Orthogonal Joint

c) Rotational joint (type R joint)

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

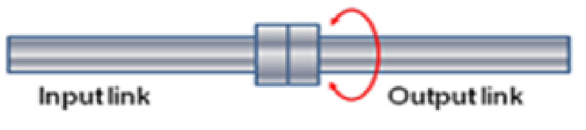


(c) Rotational Joint

JOINTS AND LINKS

d) Twisting joint (type T joint)

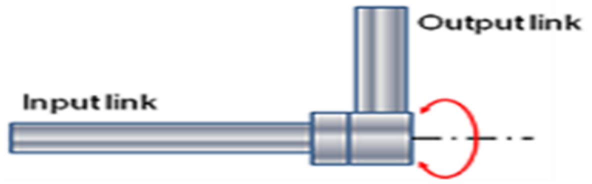
- This joint also involves rotary motion, but the axis or rotation is parallel to the axes of the two links.



(d) Twisting Joint

e) Revolving joint (type V-joint, V from the “v” in revolving)

- In this type, axis of input link is parallel to the axis of rotation of the joint. Axis of the output link is perpendicular to the axis of rotation.



(e) Revolving Joint

COMMON ROBOT CONFIGURATIONS

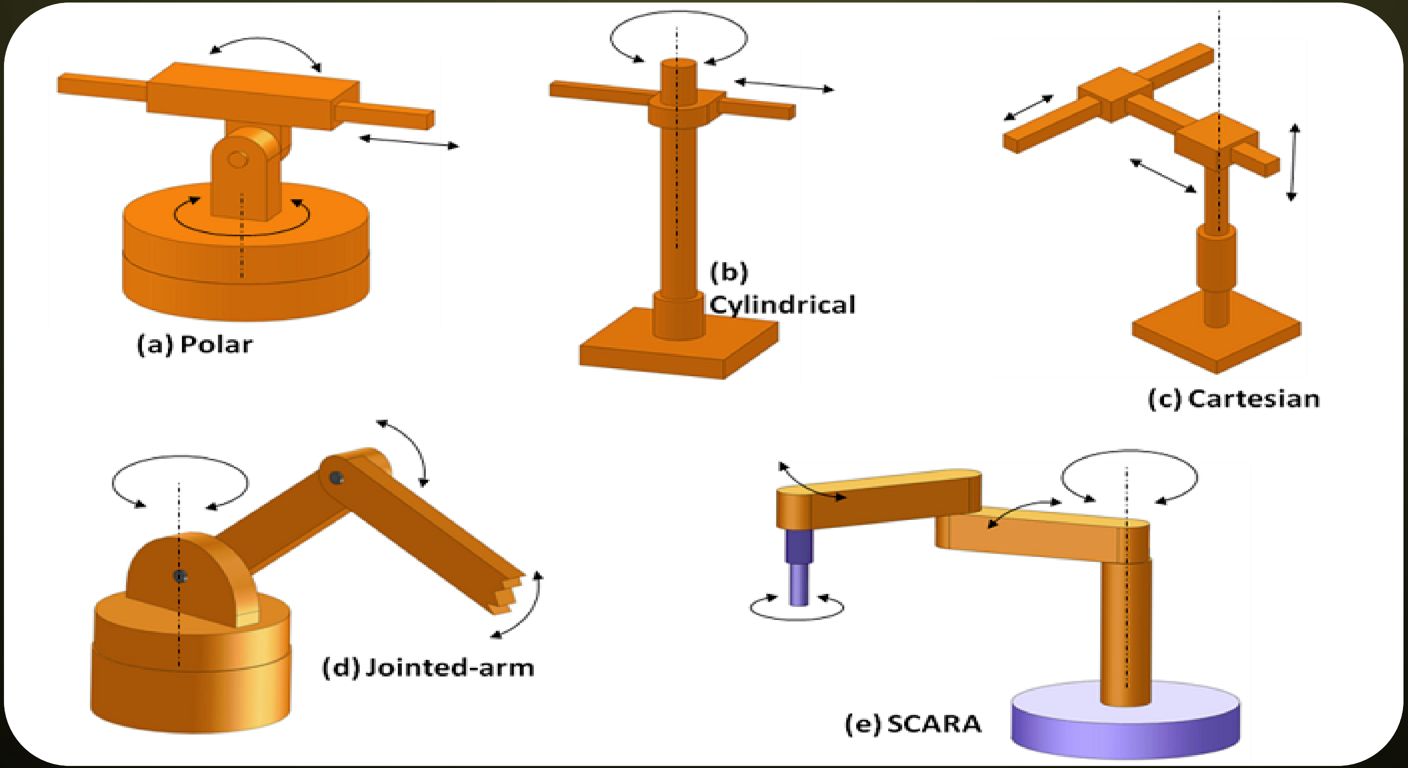
- Basically the robot manipulator has two parts viz.

- A body-and-arm assembly with three degrees-of-freedom and A wrist assembly with two or three degrees-of-freedom.

- For body-and-arm configurations, different combinations of joint types are possible for a three-degree-of-freedom robot manipulator.

COMMON ROBOT CONFIGURATIONS

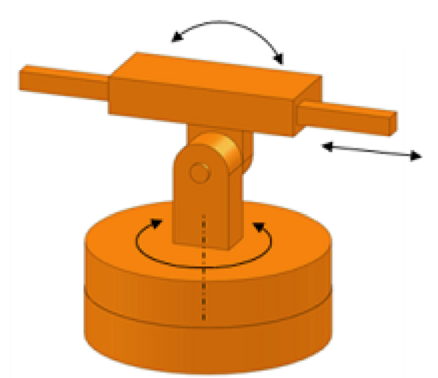
- Five common body-and-arm configurations are outlined below.



COMMON ROBOT CONFIGURATIONS

(i) Polar configuration

- It consists of a sliding arm L-joint, actuated relative to the body, which rotates around both a vertical axis (T-joint)and horizontal axis (R-joint).

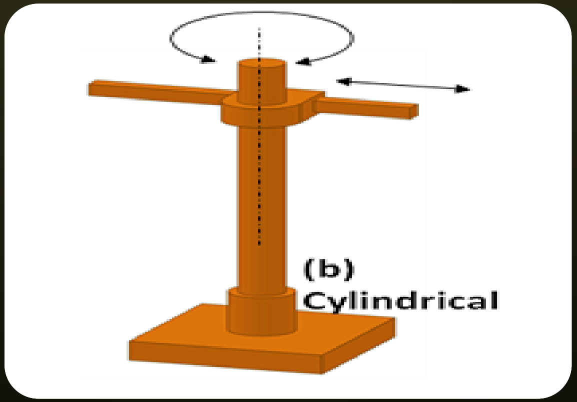


(a) Polar

COMMON ROBOT CONFIGURATIONS

(ii) Cylindrical configuration

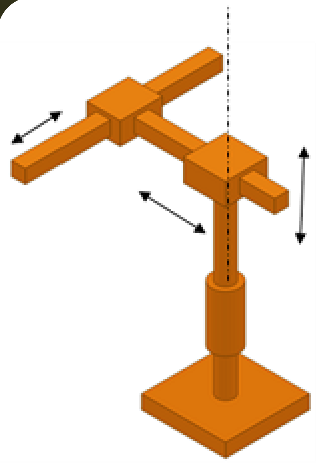
- It consists of a vertical column. An arm assembly is moved up or down relative to the vertical column.
- Arm can be moved in and out relative to the axis of the column. Common configuration is to use a T-joint to rotate the column about its axis.
- An L-joint is used to move the arm assembly vertically along the column, while an O-joint is used to achieve radial movement of the arm.



COMMON ROBOT CONFIGURATIONS

(iii) Cartesian co-ordinate robot

- It is also known as rectilinear robot and x-y-z robot. It consists of three sliding joints, two of which are orthogonal O-joints.

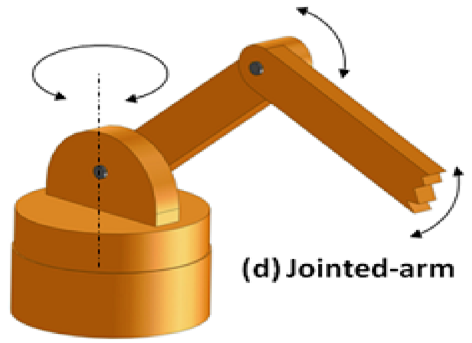


(c) Cartesian

COMMON ROBOT CONFIGURATIONS

(iv) Jointed-arm robot

- It is similar to the configuration of a human arm.
- It consists of a vertical column that swivels about the base using a T-joint. Shoulder joint (R-joint) is located at the top of the column.
- The output link is an elbow joint (another R joint).



(d) Jointed-arm

COMMON ROBOT CONFIGURATIONS

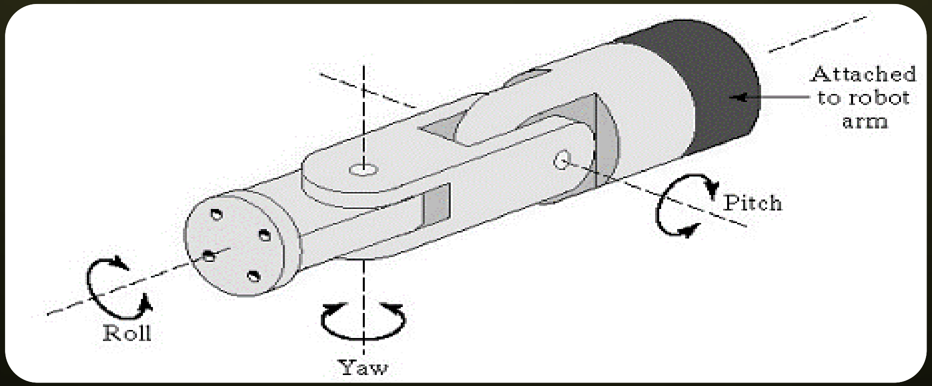
(v) SCARA

- Its full form is 'Selective Compliance Assembly Robot Arm'.
- It is similar in construction to the jointer-arm robot, except the shoulder and elbow rotational axes are vertical.
- The arm is very rigid in the vertical direction, but compliant in the horizontal direction. Robot wrist assemblies consist of either two or three degrees-of-freedom.

COMMON ROBOT CONFIGURATIONS

(v) SCARA

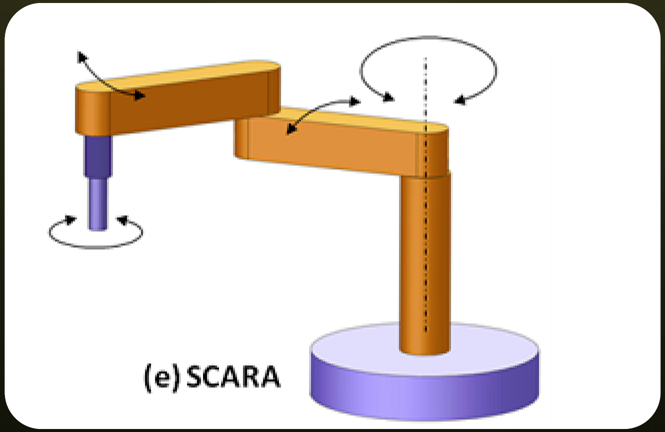
- A typical three-degree-of-freedom wrist joint is depicted in Figure.
- Roll joint is accomplished by use of a T-joint.
- Pitch joint is achieved by recourse to an R-joint. Yaw joint, a right-and-left motion, is gained by deploying a second R-joint.



COMMON ROBOT CONFIGURATIONS

(v) SCARA

- SCARA body and arm configuration does not use a separate wrist assembly.
- Its usual operative environment is for insertion-type assembly operations where wrist joints are unnecessary.
- The other four body and arm configurations more or less follow the wrist-joint configuration by deploying various combinations of rotary joints.



CLASSIFICATION OF ROBOTS

- The three types of drive systems that are generally used for industrial robots are:

(i)Hydraulic drive

(ii)Electric drive

(iii)Pneumatic drive

CLASSIFICATION OF ROBOTS

i) Hydraulic drive

- It gives a robot great speed and strength. They provide high speed and strength, hence they are adopted for large industrial robots.
- This type of drives are preferred in environments in which the use of electric drive robots may cause fire hazards
- Example: In spray painting.

Disadvantages of a hydraulic robot:

- Occupy more floor space for ancillary equipment in addition to that required by the robot.
- There are housekeeping problems such as leaks.

CLASSIFICATION OF ROBOTS

ii) Electric drive

- This provides a robot with less speed and strength. Electric drive systems are adopted for smaller robots.

- Robots supported by electric drive systems are more accurate, exhibit better repeatability and are cleaner to use.

- Electrically driven robots are the most commonly available .

CLASSIFICATION OF ROBOTS

ii) Electric drive

- Electrically driven robots can be classified into two broad categories.

  (i)Stepper motor driven.

  (ii)Direct Current (DC) servo-motor driven.

- Most stepper motor-driven robots are of the open loop type.
- Feedback loops can be incorporated in stepper-driven robots.
- Servo-driven robots have feedback loops from the driven components back to the driver.

CLASSIFICATION OF ROBOTS

iii) Pneumatic drive

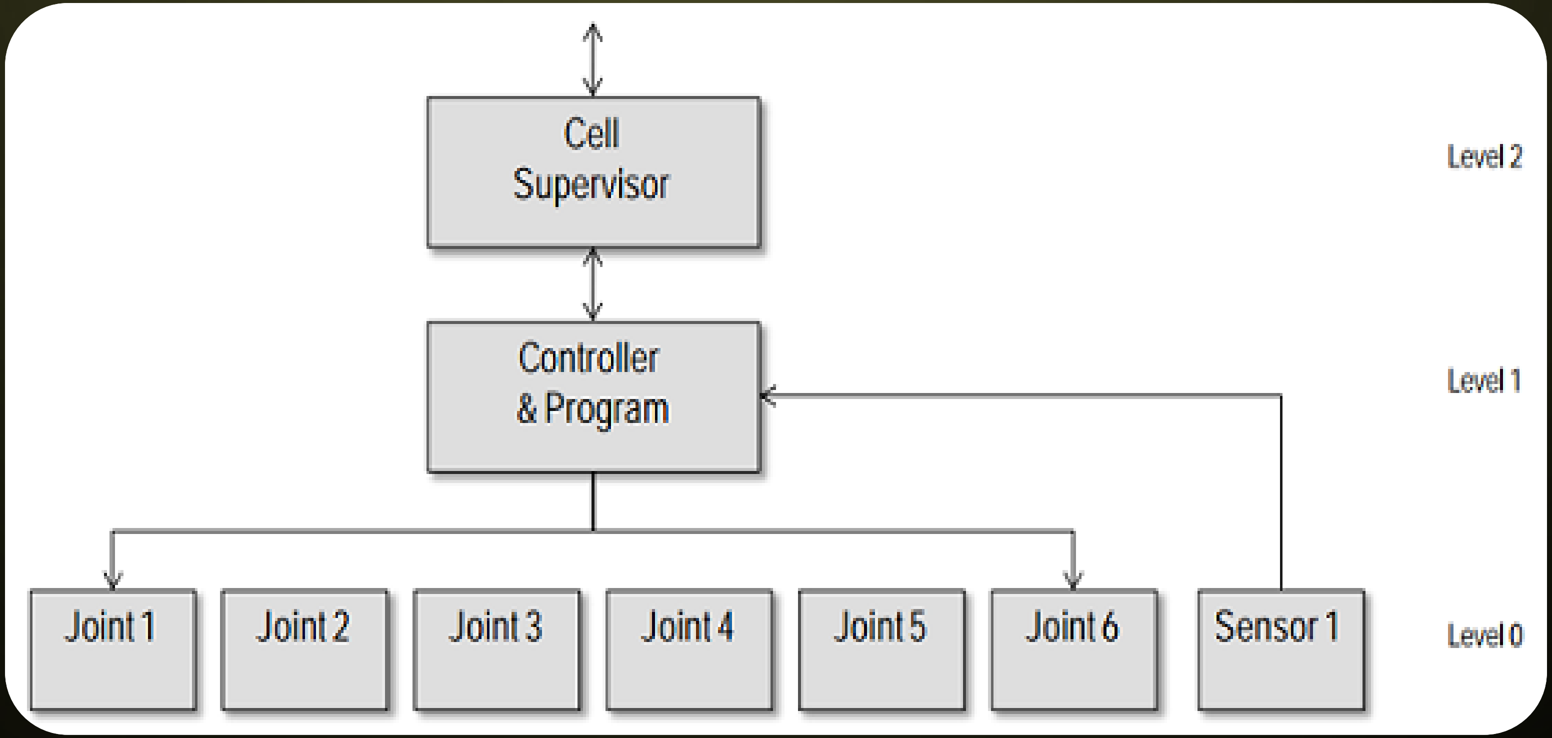
- Generally used for smaller robots.
- Have fewer axes of movement.
- Carry out simple pick-and-place material-handling operations, such as picking up an object at one location and placing it at another location.
- These operations are generally simple and have short cycle times.
- Here pneumatic power can be used for sliding or rotational joints.
- Pneumatic robots are less expensive than electric or hydraulic robots.

ROBOT CONTROL SYSTEMS

- The Joint movements must be controlled if the robot is to perform as desired.
- Micro-processor-based controllers are regularly used to perform this control action.
- Controller is organised in a hierarchical fashion, as illustrated in Figure.
- Each joint can feed back control data individually, with an overarching supervisory controller co-ordinating the combined actuations of the joints according to the sequence of the robot programme.

ROBOT CONTROL SYSTEMS

- Controller is organised in a hierarchical fashion, as illustrated in Figure.



ROBOT CONTROL SYSTEMS

Hierarchical control structure

(a) Limited Sequence Control

- Elementary control type, it is used for simple motion cycles, such as pick and place operations.
- It is implemented by fixing limits or mechanical stops for each joint and sequencing the movement of joints to accomplish operation.
- Feedback loops may be used to inform the controller that the action has been performed, so that the programme can move to the next step.
- No servo-control exists for precise positioning of joint. Many pneumatically driven robots are this type.

ROBOT CONTROL SYSTEMS

Hierarchical control structure

(b) Playback with Point to Point Control

- Playback control uses a controller with memory to record motion sequences in a work cycle, as well as associated locations and other parameters and then plays back the work cycle during programme execution.
- Point to point control means individual robot positions are recorded in the memory.
- These positions include both mechanical stops for each joint and the set of values that represent locations in the range of each joint.
- Feedback control is used to confirm that the individual joints achieve the specified locations in the programme.

ROBOT CONTROL SYSTEMS

Hierarchical control structure

(c) Playback with Continuous Path Control

- Playback is as described above.
- Continuous path control refers to a control system capable of continuous simultaneous control of two or more axes.
- Greater storage capacity—the number of locations that can be stored is greater than in point to point and interpolation calculations may be used, especially linear and circular interpolations.

ROBOT CONTROL SYSTEMS

Hierarchical control structure

(d) Intelligent Control

- An intelligent robot is one that exhibits behaviour that makes it seem intelligent.
- For example, capacities to interact with its ambient surroundings, decision-making capabilities, communication with humans; computational analysis during the work cycle and responsiveness to advanced sensor inputs.
- They may also possess the playback facilities of the above two instances.
- Requires a high level of computer control and an advanced programming language to input the decision-making logic and other ‘intelligence’ into the memory.

END EFFECTORS

- It is commonly known as robot hand.
- It is mounted on the wrist, enables the robot to perform specified tasks.
- Various types of end-effectors are designed for the same robot to make it more flexible and versatile.
- End-effectors are categorised into two major types:

1. Grippers
2. Tools

END EFFECTORS - GRIPPERS

- Grippers grasp and manipulate objects during the work cycle.
- Typically the objects grasped are work parts that need to be loaded or unloaded from one station to another.
- It may be custom-designed to suit the physical specifications of the work parts they have to grasp.

END EFFECTORS - GRIPPERS

- End effectors, grippers are described in detail in table below.

Type	comment
Mechanical gripper	Two or more fingers that can be actuated by robot controller to open and close on a work part.
Vacuum gripper	Suction cups are used to hold flat objects.
Magnetised devices	Making use of the principles of magnetism, these are used for holding ferrous work parts.
Adhesive devices	Deploying adhesive substances these hold flexible materials, such as fabric.
Simple mechanical devices	For example, hooks and scoops.

END EFFECTORS - GRIPPERS

- End effectors, grippers are described in detail in table below.

Type	comment
Dual grippers	Mechanical gripper with two gripping devices in one end effector for machine loading and unloading. Reduces cycle time per part by gripping two work parts at the same time.
Interchangeable fingers	Mechanical gripper whereby, to accommodate different work part sizes, different fingers may be attached.
Sensory feedback fingers	Mechanical gripper with sensory feedback capabilities in the fingers to aid locating the work part and to determine correct grip force to apply (for fragile work parts).

END EFFECTORS - GRIPPERS

- End effectors, grippers are described in detail in table below.

Type	comment
Multiple fingered grippers	Mechanical gripper with the general anatomy of the human hand.
Standard grippers	Mechanical grippers that are commercially available, thus reducing the need to custom-design a gripper for each separate robot application.

END EFFECTORS - TOOLS

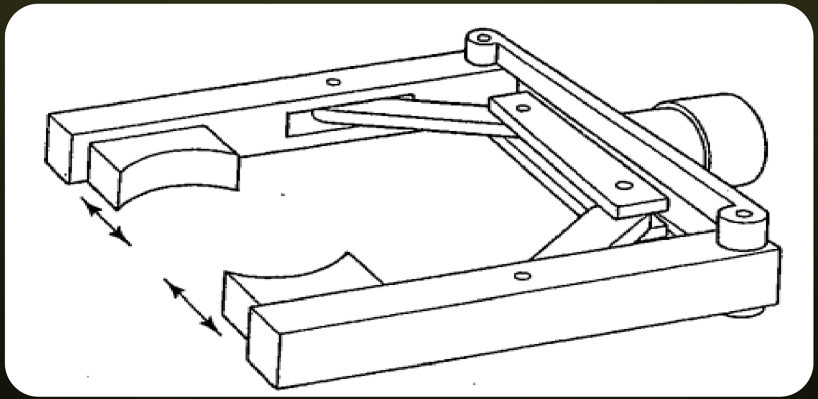
- The robot end effecter may also use tools.
- Tools are used to perform processing operations on the work part.
- Typically the robot uses the tool relative to a stationary or slowly moving object.
- In this way the process is carried out.

END EFFECTORS - TOOLS

- Examples of the tools used as end effectors by roots to perform processing applications include:
  - Spot welding gun
  - Arc welding tool
  - Spray painting gun
  - Rotating spindle for drilling, routing, grinding, etc.
  - Assembly tool (e.g. automatic screwdriver)
  - Heating torch
  - Water-jet cutting tool

END EFFECTORS

- For each instance, the robot controls both the position of the work part and the position of the tool relative to the work part.
- For this purpose, the robot must be able to transmit control signals to the tool for starting, stopping and otherwise regulating the tools actions.
- Figure illustrates a sample gripper and tool.



SENSORS IN ROBOTICS

- Two basic categories of sensors used in industrial robots:

(i)Internal sensors

(ii)External sensors

SENSORS IN ROBOTICS

(i) Internal sensors

- Internal sensors are used to monitor and control the various joints of the robot.
- They form a feedback control loop with the robot controller.
- Examples of internal sensors include potentiometers and optical encoders, while tachometers of various types can be deployed to control the speed of the robot arm.

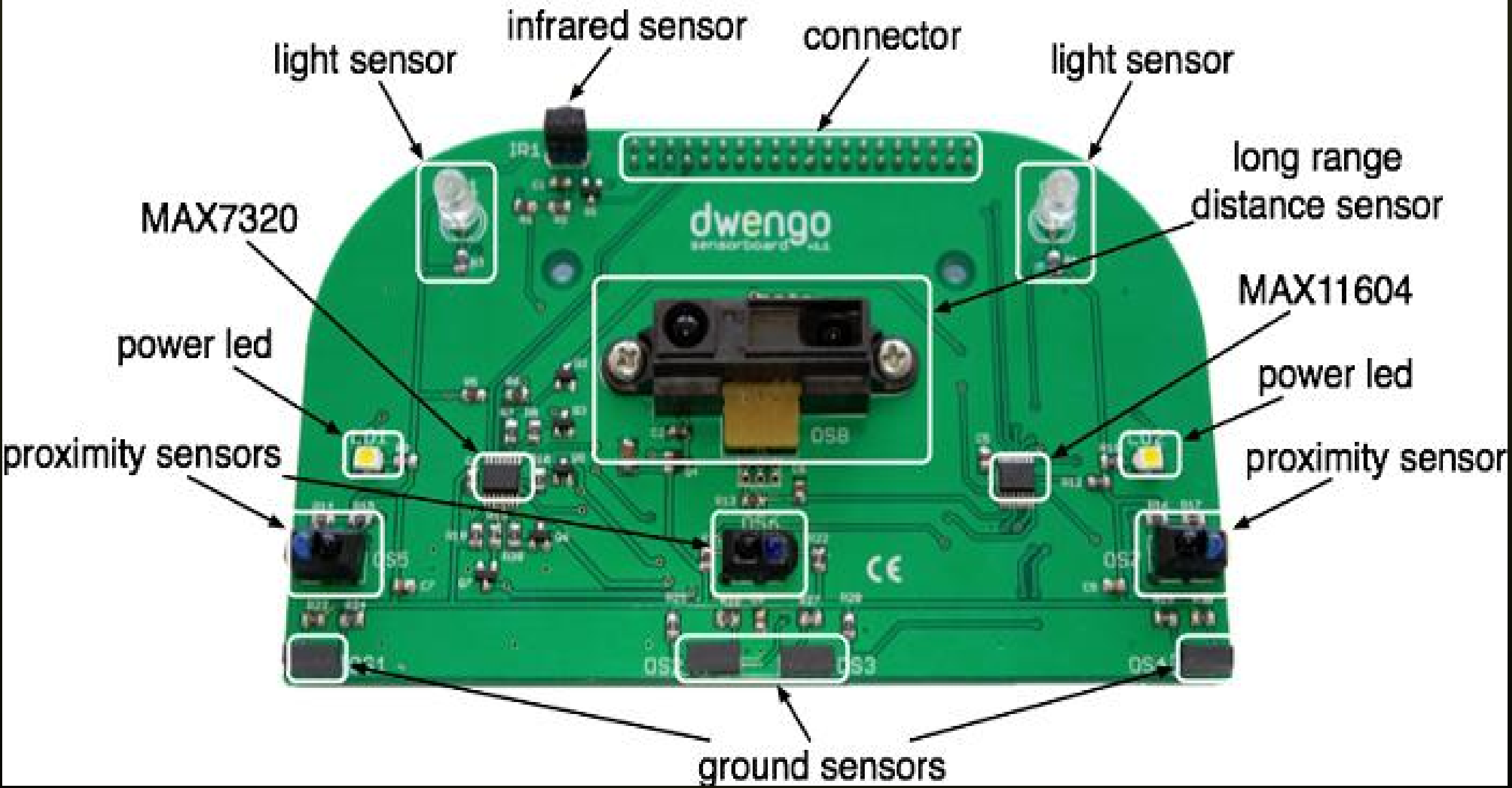
SENSORS IN ROBOTICS

(ii) External sensors

- These are external to the robot itself.
- They are used when we wish to control the operations of the robot with other pieces of equipment in the robotic work cell.
- External sensors can be relatively simple devices, such as limit switches that determine whether a part has been positioned properly or whether a part is ready to be picked up from an unloading bay.

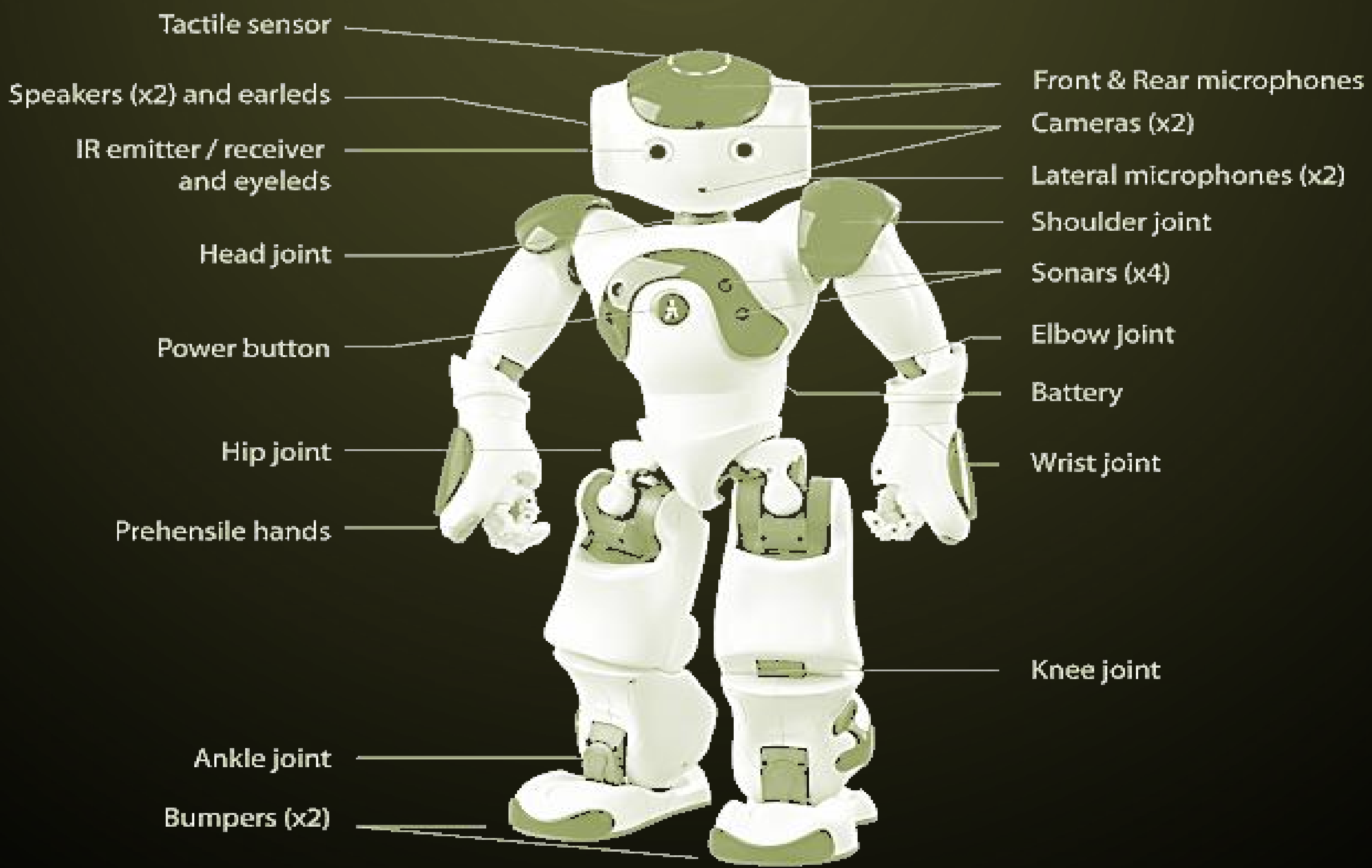
SENSORS IN ROBOTICS

- Micro Sensor board



SENSORS IN ROBOTICS

- Advanced sensor model technologies for robotics



END EFFECTORS - GRIPPERS

- A number of advanced sensor technologies may also be used; these are outlined in Table.

Sensor Type	Description
Tactile sensors	Used to determine whether contact is made between sensor and another object. Two types: touch sensors which indicate when contact is made and force sensors which indicate the magnitude of the force with the object.
Proximity sensors	Used to determine how close an object is to the sensor. Also called a range sensor.
Optical sensors	Photocells and other photometric devices that are used to detect the presence or absence of objects. Often used in conjunction to proximity sensors.

END EFFECTORS - GRIPPERS

- A number of advanced sensor technologies may also be used; these are outlined in Table.

Sensor Type	Description
Machine vision	Used in robotics for inspection, parts identification, guidance and other uses.
Miscellaneous category	temperature, fluid pressure, fluid flow, electrical voltage, current and other physical properties.

ROBOT ACCURACY AND REPEATABILITY

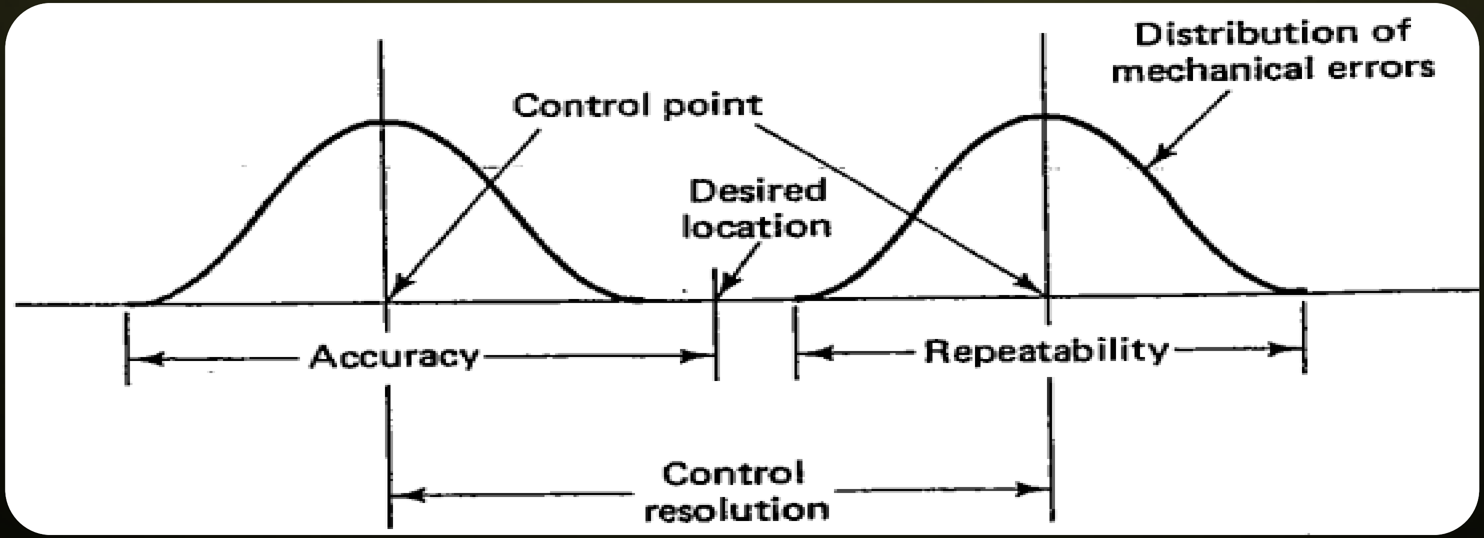
- The capacity of the robot to position and orient the end of its wrist with accuracy and repeatability is an important control attribute in nearly all industrial applications.

- Some assembly applications require that objects be located with a precision of only 0.002 to 0.005 inches.

- Other applications, such as spot welding, usually require accuracies of 0.020 to 0.040 inches.

ROBOT ACCURACY AND REPEATABILITY

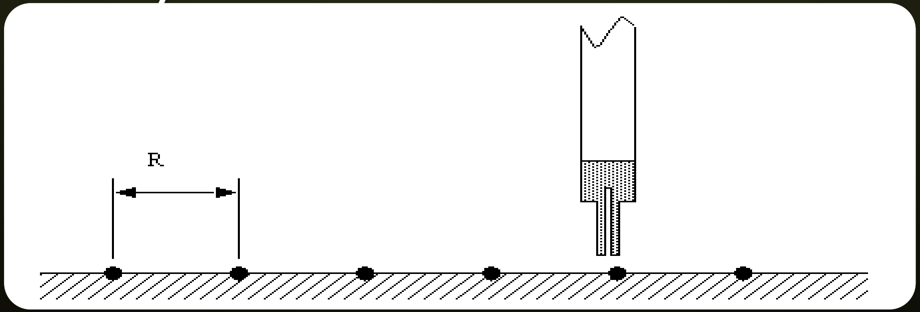
- There are several terms that must defined in the context of this discussion:
  - Control resolution
  - Accuracy
  - Repeatability



ROBOT ACCURACY AND REPEATABILITY

Resolution

- Resolution is based on a limited number of points that the robot can be commanded to reach for, these are shown here as black dots.
- These points are typically separated by a millimetre or less, depending on the type of robot.
- This is further complicated by the fact that the user might ask for a position such as 456.4mm, and the system can only move to the nearest millimetre, 456mm, this is the accuracy error of 0.4mm.



ROBOT ACCURACY AND REPEATABILITY

Accuracy

- "How close does the robot get to the desired point".
- This measures the distance between the specified position, and the actual position of the robot end effector.
- Accuracy is more important when performing off-line programming, because absolute coordinates are used.

ROBOT ACCURACY AND REPEATABILITY

Repeatability

- How close will the robot be to the same position as the same move made before".
- A measure of the error or variability when repeatedly reaching for a single position.
- This is the result of random errors only.
- Repeatability is often smaller than accuracy.

INDUSTRIAL ROBOT APPLICATIONS

- Industrial Robot Applications can be divided into:

(i) Material-handling applications

(ii) Processing Operations

(iii) Assembly Applications

MATERIAL-HANDLING APPLICATIONS

- The robot must have following features to facilitate material handling:

1. The manipulator must be able to lift the parts safely.
2. The robot must have the reach needed.
3. The robot must have cylindrical coordinate type.
4. The robot's controller must have a large enough memory to store all the programmed points so that the robot can move from one location to another.
5. The robot must have the speed necessary for meeting the transfer cycle of the operation.

MATERIAL-HANDLING APPLICATIONS

- This category includes the following:

(1) Part Placement

(2) Palletizing or depalletizing

(3) Machine loading or unloading

(4) Stacking and insertion operations

MATERIAL-HANDLING APPLICATIONS

(1) 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.
- Only two, three or four joints are required for most of the applications.
- Pneumatically powered robots are often utilized.

MATERIAL-HANDLING APPLICATIONS

(2) 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.
- Example: Process of taking parts from the assembly line and stacking them on a pallet or vice versa.

MATERIAL-HANDLING APPLICATIONS

(3) Machine loading and/or unloading:

- Robot transfers parts into and/or from a production machine.

There are three possible cases:

- Machine loading in which the robot loads parts into a production machine, but the parts are unloaded by some other means.

Example: A press working operation, where the robot feeds sheet blanks into the press, but the finished parts drop out of the press by gravity.

MATERIAL-HANDLING APPLICATIONS

- 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 work parts by the robot. The robot loads a raw work part into the process and unloads a finished part.

Example: Machine operation

PROCESSING OPERATIONS

- In processing operations, the robot performs some processing actions such as grinding, milling, etc. on the work part.
- The end effector is equipped with the specialised tool required for the process.
- The tool is moved relative to the surface of the work part.
- 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.

PROCESSING OPERATIONS

- Industrial robot applications in the processing operations include:

  (1) Spot welding

  (2) Continuous arc welding

  (3) Spray painting

  (4) Metal cutting and deburring operations

  (5) Various machining operations like drilling, grinding, laser and waterjet cutting and riveting.

  (6) Rotating and spindle operations

  (7) Adhesives and sealant dispensing

ASSEMBLY OPERATIONS

- The applications involve both material handling and the manipulation of a tool.
- They typically include components to build the product and to perform material handling operations.

These are classified as:

- **Batch assembly:** As many as one million products might be assembled. The assembly operation has long production runs.
- **Low-volume:** In this a sample run of ten thousand or less products might be made. The assembly robot cell should be a modular cell.
- One of the well suited area for robotics assembly is the insertion of odd electronic components.

FUTURE APPLICATIONS

The medical applications of the robot

- Routine examinations
- Surgical procedures

Underwater applications

- Involves prospecting for minerals on the floor of the ocean.
- Salvaging of sunken vessels, repair the ship either at sea or in dry dock.
- Mobile firefighters to be used by air force and navy.

FUTURE APPLICATIONS

Surveillance and Guard duty

- Used in military
- Used in power generating plants, oil refineries and other civilian facilities that are potential targets of terrorist groups.

ROBOT PART PROGRAMMING

- It is a path in space to be followed by the manipulator, combined with peripheral actions that support the work cycle.

- To programme a robot , specific commands are entered into the robot's controller memory and this action may be performed in a number of ways.

- For limited sequence robots ,programming occurs when limit switches and mechanical stops are set to control the endpoints of its motions.

ROBOT PART PROGRAMMING

- A sequencing device controls the occurrence of the motions, which in turn controls the movement of the joints that completes the motion cycle.
- For industrial robots with digital computers as controllers three programming methods can be distinguished.

  (a) Lead-through programming

  (b) Computer-like robot programming languages

  (c) Off-line programming.

- Lead-through methodologies and associated programming methods, are outlined in detail in table

ROBOT PART PROGRAMMING - LEAD-THROUGH PROGRAMMING

- Task is 'taught' to the robot by manually moving the manipulator through the required motion cycle and simultaneously entering the programme into the controller memory for playback.

- Two methods are used for teaching: powered lead-through and manual lead-through.

ROBOT PART PROGRAMMING - MOTION PROGRAMMING

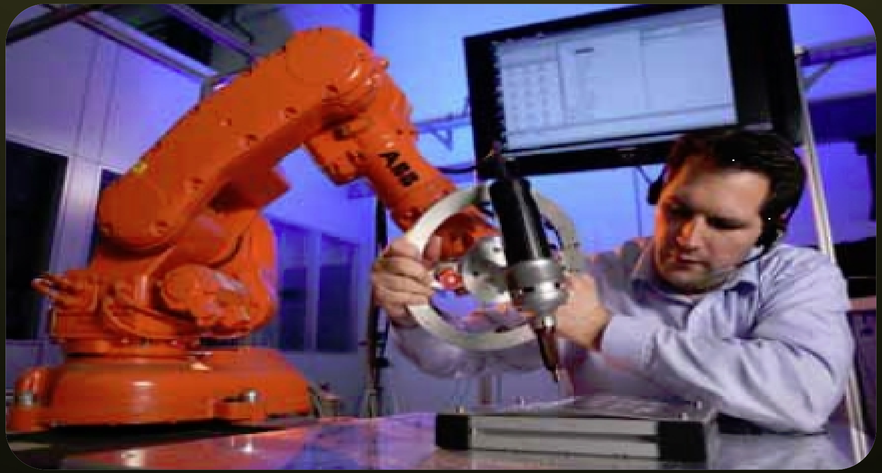
- To overcome difficulties of co-ordinating individual joints associated with lead-through programming, two mechanical methods can be used:
- The world co-ordinate system whereby the origin and axes are defined relative to the robot base and the tool co-ordinate system whereby the alignment of the axis system is defined relative to the orientation of the wrist face plate.
- These methods are typically used with Cartesian co-ordinate robots and not for robots with rotational joints.

ROBOT PART PROGRAMMING - MOTION PROGRAMMING

- The latter robotic types must rely on interpolation processes to gain straight line motion.
- Straight line interpolation where the control computer calculates the necessary points in space that the manipulator must move through to connect two points and Joint interpolation where joints are moved simultaneously at their own constant speed such that all joints start/stop at the same time.

MANUAL LEAD-THROUGH PROGRAMMING

- Manual lead through programming is convenient for programming playback robots with continuous path control where the continuous path is an irregular motion pattern such as in spray painting.
- This programming method requires the operator to physically grasp the end of arm or the tool that is attached to the arm and move it through the motion sequence, recording the path into memory.



MANUAL LEAD-THROUGH PROGRAMMING

- Because the robot arm itself may have significant mass and would therefore be difficult to move, a special programming device often replaces the actual robot for the teaching procedure.

- The programming device has the same joint configuration as the robot and is equipped with a trigger handle (or other control switch) which the operator activates when recording motions into memory.

- The motions are recorded as a series of closely spaced points. During playback the path is recreated by controlling the actual robot arm through the same sequence of points.

ADVANTAGES AND DISADVANTAGES

Advantages

- It can readily be learned by shop personnel.
- It is a logical way to teach a robot.
- It does not require knowledge of computer programming.

Disadvantages

- Downtime regular production must be interrupted to program the robot.
- Limited programming logic capability.
- Not readily compatible with modern computer based technologies.

Manipulator Dynamics 3

Iterative Newton-Euler Equations - Solution Procedure

- **Error Checking -** Check the units of each term in the resulting equations

- **Gravity Effect** - The effect of gravity can be included by setting ${}^{0}\dot{v}_{0} \bullet g$. This is the equivalent to saying that the base of the robot is accelerating upward at 1 g. The result of this accelerating is the same as accelerating all the links individually as gravity does.

Iterative Newton-Euler Equations - Solution Procedure

- **Error Checking -** Check the units of each term in the resulting equations

- **Gravity Effect** - The effect of gravity can be included by setting ${}^0\dot{v}_0 \bullet g$. This is the equivalent to saying that the base of the robot is accelerating upward at 1 g. The result of this accelerating is the same as accelerating all the links individually as gravity does.

Iterative Newton-Euler Equations - Solution Procedure

- **Error Checking -** Check the units of each term in the resulting equations

- **Gravity Effect** - The effect of gravity can be included by setting ${}^{0}\dot{v}_{0} = g$. This is the equivalent to saying that the base of the robot is accelerating upward at 1 g. The result of this accelerating is the same as accelerating all the links individually as gravity does.

Iterative Newton-Euler Equations - 2R Robot Example

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Iterative Newton-Euler Equations - 2R Robot Example

Equation of Motion – Non Rigid Body Effects

$$\tau = M(\Theta)\ddot{\Theta} + V(\Theta,\dot{\Theta}) + G(\Theta) + F(\Theta,\dot{\Theta})$$

- Viscous Friction $\tau_{friction} = v\dot{\theta}$
- Coulomb Friction $\tau_{friction} = c\,\mathrm{sgn}(\dot{\theta})$
- Model of Friction $\tau_{friction} = v\dot{\theta} + c\,\mathrm{sgn}(\dot{\theta}) = f(\theta,\dot{\theta})$

Velocity / Force Transformation - Wrist / Sensor / Tool

Velocity / Force Transformation - Wrist / Sensor / Tool

Velocity / Force Transformation - Wrist / Sensor / Tool

Velocity / Force Transformation - Wrist / Sensor / Tool

Velocity / Force Transformation - Wrist / Sensor / Tool

ROBOT PROGRAMMING

Robot Programming Revisited

- **<u>Robot Programming</u>** is the defining of desired motions so that the robot may perform them without human intervention.
  - identifying and specifying the robot configurations (i.e. the pose of the end-effector, P_e, with respect to the base-frame)

1. **MANUAL METHOD**
2. **WALKTHROUGH METHOD**
3. **LEADTHROUGH METHOD**
4. **OFF-LINE PROGRAMMING**

Type of Robot Programming

- Joint level programming
  - basic actions are positions (and possibly movements) of the individual joints of the robot arm: joint angles in the case of rotational joints and linear positions in the case of linear or prismatic joints.
- Robot-level programming
  - the basic actions are positions and orientations (and perhaps trajectories) of P_e and the frame of reference attached to it.
- High-level programming
  - Object-level programming
  - Task-level programming

Object Level Programming

- basic actions are operations to be performed on the parts, or relationships that must be established between parts

pick-up part-A **by** side-A1 **and** side-A3

move part-A **to** location-2

pick-up part-B **by** side-B1 **and** side-B3

put part-B **on-top-off** part-A

with side-A5 **in-plane-with** side-B6 **and**

with side-A1 **in-plane-with** side-B1 **and**

with side-A2 **in-plane-with** side-B2

Task Level Programming

- basic actions specified by the program are complete tasks or subtasks

paint-the car-body *red*

assemble the gear-box

ROBOT PROGRAMMING

- Typically performed using one of the following
  - On line
    - teach pendant
    - lead through programming
  - Off line
    - robot programming languages
    - task level programming

Robot Programming Methods

- Offline:
  - write a program using a text-based robot programming language
  - does not need access to the robot until its final testing and implementation
- On-line:
  - Use the robot to generate the program
    - Teaching/guiding the robot through a sequence of motions that can them be executed repeatedly
- Combination Programming:
  - Often programming is a combination of on-line and off-line
    - on-line to teach locations in space
    - off-line to define the task or "sequence of operations"

Use of Teach Pendant

- hand held device with switches used to control the robot motions
- End points are recorded in controller memory
- sequentially played back to execute robot actions
- trajectory determined by robot controller
- suited for point to point control applications

Lead Through Programming

- lead the robot physically through the required sequence of motions
- trajectory and endpoints are recorded, using a sampling routine which records points at 60-80 times a second
- when played back results in a smooth continuous motion
- large memory requirements

On-Line/Lead Through

- Advantage:
  - Easy
  - No special programming skills or training
- Disadvantages:
  - not practical for large or heavy robots
  - High accuracy and straight-line movements are difficult to achieve, as are any other kind of geometrically defined trajectory, such as circular arcs, etc.
  - difficult to *edit out* unwanted operator moves
  - difficult to incorporate external sensor data
  - Synchronization with other machines or equipment in the work cell is difficult
  - A large amount of memory is required

On-Line Programming

- Requires access to the robot
- Programs exist only in the memory of robot control system – often difficult to transfer, document, maintain, modify

- Easy to use, no special programming skills required
- Useful when programming robots for wide range of repetitive tasks for long production runs
- RAPID

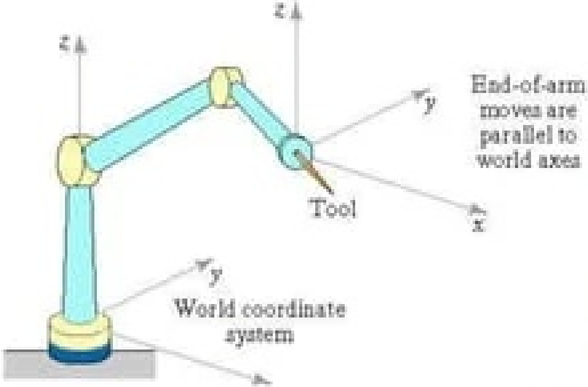
On-Line/Teach Box

- Advantage:
  - Easy
  - No special programming skills or training
  - Can specify other conditions on robot movements (type of trajectory to use – line, arc)
- Disadvantages:
  - Potential dangerous (motors are on)

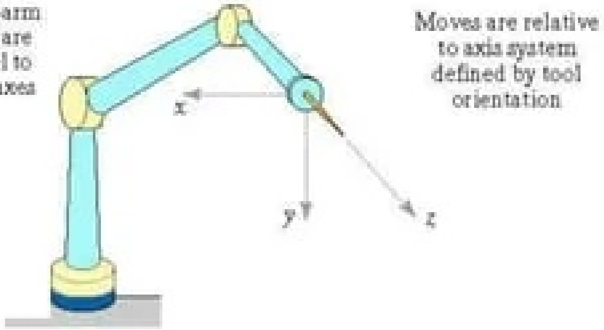
Off-line Programming

- Programs can be developed without needing to use the robot
- The sequence of operations and robot movements can be optimized or easily improved
- Previously developed and tested procedures and subroutines can be used
- External sensor data can be incorporated, though this typically makes the programs more complicated, and so more difficult to modify and maintain
- Existing CAD data can be incorporated-the dimensions of parts and the geometric relationships between them, for example.
- Programs can be tested and evaluated using simulation techniques, though this can never remove the need to do final testing of the program using the real robot
- Programs can more easily be maintained and modified
- Programs can more be easily properly documented and commented.

Coordinate Systems

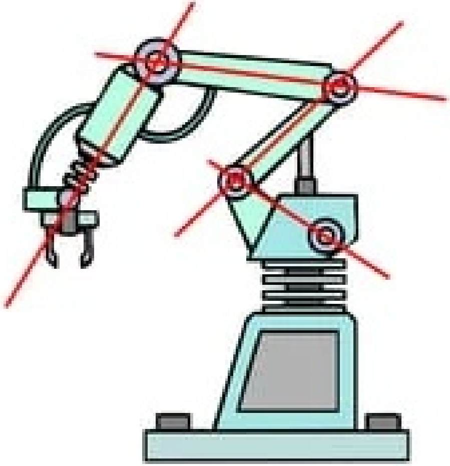


World coordinate system



Tool coordinate system

Configuration: Any particular position and orientation of P_e in space, and so any particular set of joint values, is called a *configuration* of the robot arm.



Motion Commands

MOVE P1

HERE P1 - used during lead through of manipulator

MOVES P1

DMOVE(4, 125)

APPROACH P1, 40 MM

DEPART 40 MM

DEFINE PATH123 = PATH(P1, P2, P3)

MOVE PATH123

SPEED 75

- Robot motion programming commands
-
- MOVE P1
- HERE P1 -used during leadthrough of manipulator
- MOVES P1
- DMOVE(4, 125)
- APPROACH P1, 40 MM
- DEPART 40 MM
- DEFINE PATH123 = PATH(P1, P2, P3)
- MOVE PATH123
- SPEED 75
-
- Input interlock:
- WAIT 20, ON
- Output interlock:
- SIGNAL 10, ON
- SIGNAL 10, 6.0
- Interlock for continuous monitoring:
- REACT 25, SAFESTOP
-
- Gripper
- OPEN
- CLOSE
- Sensor and servo-controlled hands
- CLOSE 25 MM

Interlock and Sensor Commands

Interlock Commands

- WAIT 20, ON
- SIGNAL 10, ON
- SIGNAL 10, 6.0
- REACT 25, SAFESTOP

Gripper Commands

- OPEN
- CLOSE
- CLOSE 25 MM
- CLOSE 2.0 N

Programming Languages

- Motivation
  - need to interface robot control system to external sensors, to provide "real time" changes based on sensory equipment
  - computing based on geometry of environment
  - ability to interface with CAD/CAM systems
  - meaningful task descriptions
  - off-line programming capability

- Large number of robot languages available
  - AML, VAL, AL, RAIL, RobotStudio, etc. (200+)
- Each robot manufacturer has their own robot programming language
- No standards exist
- Portability of programs virtually non-existent

Robot Programming Languages

- The VALTM Language
- The VAL language was developed for PUMA robot
- Monitor command are set of administrative instructions that direct the operation of the
- robot system. Some of the functions of Monitor commands are
- Preparing the system for the user to write programs for PUMA
- Defining points in space
- Commanding the PUMA to execute a program
- Listing program on the CRT
- Examples for monitor commands are: EDIT, EXECUTE, SPEED, HERE etc.

The MCL Language

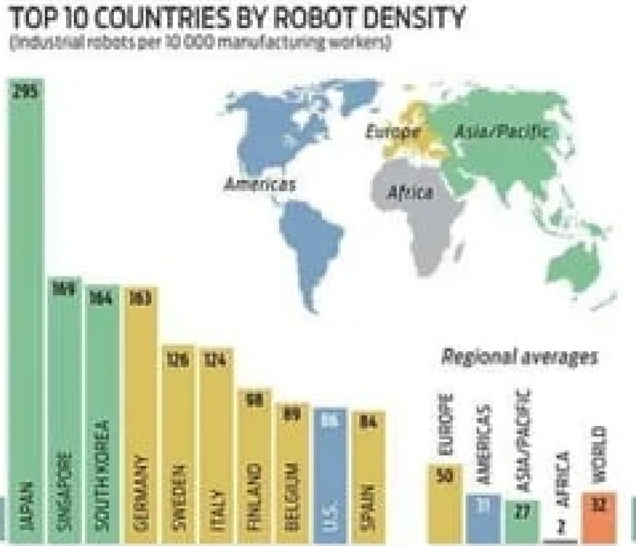
- MCL stands for Machine Control Language developed by Douglas.
- The language is based on the APT and NC language. Designed control complete
- manufacturing cell.
- MCL is enhancement of APT which possesses additional options and features needed
- to do off-line programming of robotic work cell.
- Additional vocabulary words were developed to provide the supplementary
- capabilities intended to be covered by the MCL. These capability include Vision,
- Inspection and Control of signals
- MCL also permits the user to define MACROS like statement that would be
- convenient to use for specialized applications.
- MCL program is needed to compile to produce CLFILE.
- Some commands of MCL programming languages are DEVICE, SEND, RECEIV,
- WORKPT, ABORT, TASK, REGION, LOCATE etc.

INDUSTRIAL ROBOT APPLICATIONS

- Material-handling applications:
  - Involve the movement of material or parts from one location to another.
  - It includes part placement, palletizing and/or de-palletizing, machine loading and unloading.
- Processing Operations:
  - Requires the robot to manipulate a special process tool as the end effectors.
  - The application include spot welding, arc welding, riveting, spray painting, machining, metal cutting, de-burring, polishing.
- Assembly Applications:
  - Involve part-handling manipulations of a special tools and other automatic tasks and operations.
- Inspection Operations:
  - Require the robot to position a work part to an inspection device.
  - Involve the robot to manipulate a device or sensor to perform the inspection.

Industrial Robot Applications

1. Material handling applications
   - Material transfer – pick-and-place, palletizing
   - Machine loading and/or unloading
2. Processing operations
   - Welding
   - Spray coating
   - Cutting and grinding
3. Assembly and inspection



Material Handling Applications

- This category includes the following:
  - Part Placement
  - Palletizing and/or depalletizing
  - Machine loading and/or unloading
  - Stacking and insertion operations

THE GENERAL CONSIDERATIONS IN ROBOT MATERIAL HANDLING

- Part positioning orientation
- Gripper design
- Minimum distance moved
- Robot work volume
- Robot weight capacity
- Accuracy and repeatability
- Robot configuration, Degree of Freedom and Control
- Machine utilization problems

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.
- Only two, three, or four joints are required for most of the applications.
- 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.
- Example: process of taking parts from the assembly line and stacking them on a pallet or vice versa.

Machine loading and/or unloading

- Robot transfers parts into and/or from a production machine.
- There are three possible cases:

Machine loading in which the robot loads parts into a production machine, but the parts are unloaded by some other means.

- Example: a press working 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.

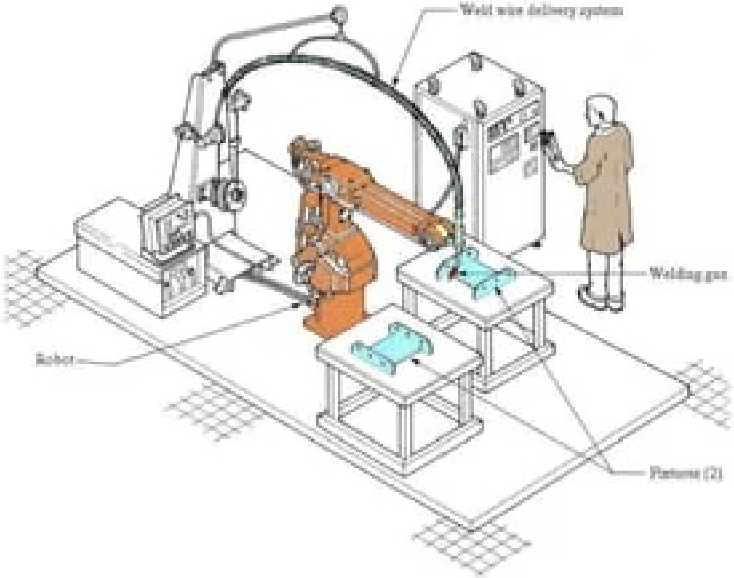
- Example: bin picking, die casting, and plastic moulding.

Machine loading and unloading that involves both loading and unloading of the work parts by the robot. The robot loads a raw work part into the process ad unloads a finished part.

- Example: Machine operation difficulties
- Difference in cycle time between the robot and the production machine. The cycle time of the machine may be

Robotic Arc-Welding Cell

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



STACKING AND INSERTION OPERATION

- In the stacking process the robot places flat parts on top of each other, where the vertical location of the drop-off position is continuously changing with cycle time.
- In the insertion process robot inserts parts into the compartments of a divided carton.
- The robot must have following features to facilitate material handling:
  - The manipulator must be able to lift the parts safely.
  - The robot must have the reach needed.
  - The robot must have cylindrical coordinate type.
  - The robot's controller must have a large enough memory to store all the programmed points so that the robot can move from one location to another.
  - The robot must have the speed necessary for meeting the transfer cycle of the operation.

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 water jet cutting, and riveting.

Rotating and spindle operations

Adhesives and sealant dispensing

Assembly operations

- The applications involve both material-handling and the manipulation of a tool.
- 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.
- These are classified as:

Batch assembly: As many as one million products might be assembled.

The assembly operation has long production runs.

Low-volume: In this a sample run of ten thousand or less products might be made.

The assembly robot cell should be a modular cell.

One of the well suited areas for robotics assembly is the insertion of odd electronic components.

Inspection operation

- Some inspection operation requires parts to be manipulated, and other applications require that an inspection tool be manipulated.
- 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 known as a linear variable differential transformer (LVDT), 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, matrix 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.

- The robot may be in active or passive role.

In active role robot is responsible for determining whether the part is good or bad.

In the passive role the robot feeds a gauging station with the part. While the gauging station is determining whether the part meets the specification, the robot waits for the process to finish.

ADVANTAGES OF ROBOTS

- Robotics and automation can, in many situation, increase productivity, safety, efficiency, quality, and consistency of Products
- Robots can work in hazardous environments
- Robots need no environmental comfort
- Robots work continuously without any humanity needs and illnesses
- Robots have repeatable precision at all times
- Robots can be much more accurate than humans, they may have milli or micro inch accuracy.
- Robots and their sensors can have capabilities beyond that of humans.
- Robots can process multiple stimuli or tasks simultaneously, humans can only one.
- Robots replace human workers who can create economic problems.

Accuracy and Precision

	Accuracy	Precision
Definition:	The degree of closeness to true value.	The degree to which an instrument or process will repeat the same value.
Measurements:	Single factor or measurement	Multiple measurements or factors are needed
About:	A term used in measuring a process or device.	A term used in measuring a process or device.
Uses:	Physics, chemistry, engineering, statistics and so on.	Physics, chemistry, engineering, statistics and so on.

ROBOT APPLICATIONS

- Work environment hazardous for human beings
- Repetitive tasks
- Boring and unpleasant tasks
- Multi shift operations
- Infrequent changeovers
- Performing at a steady pace
- Operating for long hours without rest
- Responding in automated operations
- Minimizing variation

Disadvantages of Robots

- Robots lack capability to respond in emergencies, this can cause:

Inappropriate and wrong responses
A lack of decision-making power
A loss of power
Damage to the robot and other devices
Human injuries

- Robots may have limited capabilities in

Degrees of Freedom
Dexterity
Sensors
Vision systems
Real-time Response

- Robots are costly, due to

Initial cost of equipment
Installation Costs
Need for peripherals
Need for training
Need for Programming

Summary of Robot Applications

- 1. Hazardous work environment for humans
- 2. Repetitive work cycle
- 3. Difficult handling task for humans
- 4. Multi shift operations
- 5. Infrequent changeovers
- 6. Part position and orientation are established in the work cell