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NPTEL ONLINE CERTIFICATION COURSES

NPTEL

AUTOMATION IN PRODUCTION SYSTEMS AND MANAGEMENT

Flexible Manufacturing Systems-II

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Flexible Manufacturing Systems-II

- **Lecture-1:** Operational Problems in FMS: Tools and Techniques-1, Problem Formulation
- **Lecture-2:** Operational Problems in FMS: Tools and Techniques-2, Numerical Examples
- **Lecture-3:** Tool Allocation Policies in FMS, Numerical Examples
- **Lecture-4:** Fixture and Pallet Selection Problems: Numerical Examples
- **Lecture-5:** Types of FMS Layout, Main Benefits of FMS

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Flexible Manufacturing Systems-II

- ✓ **Operational Problems in FMS: Tools and Techniques-1,**
- ✓ **Problem Formulation**

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Operational Problems in FMS

The operational problems in FMS concern detailed decision making on a short-term planning horizon.

- Part selection and tool management
- Fixture and pallet selection
- Machine grouping and loading, considering part and tool assignments

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Part Type Selection and Tool Management Problems

- This problem concerns the determination of a subset of part types from a set of part types for processing.
- A number of criteria can be used for selecting a set of part types for immediate processing.
- For example, due date is an important consideration.

Part Type Selection and Tool Management Problems

- Limited availability of tools on the tool magazine and different requirements of tools by part types complicate the process of part type selection in FMSs.

- A number of mathematical programming models and heuristics for part type selection have been developed.

- Two basic approaches for part type selection have been proposed:
  a. the batching approach and
  b. the flexible approach

The Batching Approach

- Part types are partitioned into separate sets called batches.
- The selected part types in a particular batch are manufactured continuously until all the production requirements are completed.
- Then for processing the next batch, the system setup and the tool changeover time consists of removing all the tools not required by the current batch and loading new tools required to perform all the operations for all the part types of the next scheduled batch.
- Most FMS users and researchers have followed a batching approach, because it results in lower frequency of tool changeovers and is easier to implement in real systems.

The Flexible Approach

- The flexible approach works as follows.
- When the production requirements of some part types are finished, space becomes available in the tool magazine. New part types may be introduced into the system for immediate and simultaneous processing if this input can help increase utilization of the system.
- This approach, however, requires more frequent tool changes.
- Stecke and Kim have reported a simulation study comparing a number of batching approaches and the flexible approach to part type selection.
- The major finding was that the flexible approach tends to make the system more highly utilized.

Hwang's Integer Programming Model

The following notation is used:

$i = 1, 2, \dots, N$ = part types
$c = 1, 2, \dots, C$ = cutting tool types
t = tool magazine capacity

$$b_{ic} = \begin{cases} 1, & \text{if part type } i \text{ requires tool } c \\ 0, & \text{otherwise} \end{cases}$$

d_c =number of tool slots required to hold cutting tool c in a tool magazine of each machine.

Hwang's Integer Programming Model

$$z_i = \begin{cases} 1, & \text{if part type } i \text{ is selected in the batch} \\ 0, & \text{otherwise} \end{cases}$$

$$y_c = \begin{cases} 1, & \text{if cutting tool } c \text{ is is loaded on a machine} \\ 0, & \text{otherwise} \end{cases}$$

In this model, z_i and y_c are the decision variables. We consider a system of identical machines (all of the same type). In that case,

Hwang's Integer Programming Model

$$\text{Maximize} \sum_i z_i$$

subject to

$$\sum_c d_c y_c \leqslant t$$

$$b_{ic} z_i \leqslant y_c \ \forall i, c$$

$$z_i = \{0, 1\} \ \forall i$$

$$y_c = \{0, 1\} \ \forall c$$

Hwang's Integer Programming Model

- The objective function maximizes the number of part types in a batch.
- Subsequent batches, if any, are formed by repeatedly solving the problem after deleting already selected part types from the model.
- Tool magazine capacity is considered for each machine type by constraint.
- Constraint ensures that if a part type is selected, all cutting tools required for all operations of the selected part types are loaded into the tool magazine on each machine.
- Last two constraints define zero - one variables.

Stecke and Kim Extension of Hwang’s Model

- Stecke and Kim (1988) modified the objective function of Hwang’s model by incorporating the number of tool slots required for all operations for each part type as a coefficient.
- With this modification, the objective function aims to select early the part types with the largest number of required tools.
- The modified model is:

Stecke and Kim Extension of Hwang's Model

$$\text{Maximize} \sum_i \left(\sum_c b_{ic} d_c \right) z_i$$

subject to

$$\sum_c d_c y_c \leqslant t$$

$$b_{ic} z_i \leqslant y_c \ \forall i, c$$

$$z_i = \{0, 1\} \ \forall i$$

$$y_{ck} = \{0, 1\} \ \forall c$$

Flexible Manufacturing Systems-II

- ✓ **Operational Problems in FMS: Tools and Techniques-2,**
- ✓ **Numerical Examples**

Numerical Example-1

- Consider the simple example of eight part types and the corresponding required tools given in Table 13.1 for processing on a flexible manufacturing module. The number of slots required by each tool is given in Table 13.2. The tool magazine capacity is limited to 5 tool slots. Determine the batches of part types selected.

Numerical Example-1

TABLE 13.1 **Part Types and Required Tools**

Part types	*P1*	*P2*	*P3*	*P4*	*P5*	*P6*	*P7*	*P8*
Types of tools required	t1	t2	t3	t4	t1, t2	t3, t5	t6	t1, t2, t7

TABLE 13.2 **Tool Types and Required Slots**

Tool types	*t1*	*t2*	*t3*	*t4*	*t5*	*t6*	*t7*
Number of slots required	1	1	1	1	1	2	2

Numerical Example-1

Solution:

$$Maximize\ f = z_1 + z_2 + \cdots + z_8$$

subject to

$$y_1 + y_2 + y_3 + y_4 + y_5 + 2y_6 + 2y_7 \le 5 \cdots\cdots\cdots (1)$$
$$z_1 - y_1 \le 0 \cdots\cdots\cdots (2)$$
$$z_2 - y_2 \le 0 \cdots\cdots\cdots (3)$$
$$z_3 - y_3 \le 0 \cdots\cdots\cdots (4)$$
$$z_4 - y_4 \le 0 \cdots\cdots\cdots (5)$$
$$z_5 - y_1 \le 0 \cdots\cdots\cdots (6)$$

Numerical Example-1

$$z_5 - y_2 \leq 0 \cdots\cdots\cdots (7)$$
$$z_6 - y_3 \leq 0 \cdots\cdots\cdots (8)$$
$$z_6 - y_5 \leq 0 \cdots\cdots\cdots (9)$$
$$z_7 - y_6 \leq 0 \cdots\cdots\cdots (10)$$
$$z_8 - y_1 \leq 0 \cdots\cdots\cdots (11)$$
$$z_8 - y_2 \leq 0 \cdots\cdots\cdots (12)$$
$$z_8 - y_7 \leq 0 \cdots\cdots\cdots (13)$$

Numerical Example-1

- The solution of this integer programming model yields the following batches of part types selected:

  a) Batch 1: P1, P2, P3, P4, P5, P6
  b) Batch 2: P7
  c) Batch 3: P8

- This model is myopic and ignores the potential for more tool sharing among parts.

Numerical Example-1

- Although the first batch has more part types, this can lead to a larger than necessary total number of batches to produce all part types.
- For example, part type 8, which requires all the tools required by part types 1, 2, and 5, should be grouped with them.

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Numerical Example-2

- Using the data in Example 13.1, solve the Stecke and Kim model and determine the optimal number of batches of part types selected.

- **Solution:**

$$Maximize\ f = z_1 + z_2 + z_3 + z_4 + 2z_5 + 2z_6 + 2z_7 + 4z_8$$

- Subject to the constraints (1) to (13) of the previous problem

Numerical Example-2

- This model differs from that of Hwang's model only in the objective function.
- The model yields two batches as follows:

  a) Batch 1: P1, P2, P3, P5, P8
  b) Batch 2: P4, P6, P7

- The number of batches is now reduced to two, compared with three obtained with Hwang's model. This reduction in batches has a tremendous influence on the performance of an FMS, because it will lead to a considerable reduction in setup time.

Flexible Manufacturing Systems-II

- ✓ **Tool Allocation Policies in FMS,**
- ✓ **Numerical Examples**

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Tool Allocation Policies

- Tooling is estimated to account for about 20 percent of the cost of new manufacturing systems and it may be much higher in the case of an FMS.
- Increased numbers of tooling components and their application requirements hinder the productivity of FMSs.
- Therefore, it is important to design a tool management and control system so that the proper tools are available at the right machines at the desired times for processing of the scheduled parts.

Tool Allocation Policies

- The tool magazine capacity, which is typically 30, 60, or 120 slots in commercial flexible manufacturing systems, constraints the number of tools mounted on a machine.
- A number of tool allocation strategies have been investigated to improve FMS productivity:
  1. Bulk exchange policy
  2. Tool migration policy
  3. Resident tooling policy
  4. Tool sharing policy

Tool Allocation Policies

❑ **Bulk Exchange Policy**

- In this tool allocation policy, for each planning period, a new set of tools is mounted on the tool magazine to process the parts in that planning period.
- Every tool allocation policy also determine the batch sizes of parts.
- For example, in the bulk exchange tooling policy, each time a part is assigned to a machine the tools required by that part are assigned to the tool magazine. The assignment of tools continues for other parts until the tool magazine is full.

Tool Allocation Policies

- The assigned part types thus form the batch to be processed for that period.
- The number of tools should be sufficient to process the parts, as no replacement of tools occurs during the production window.

Tool Allocation Policies

❑ Tool Migration Policy

- In terms of part routing, this policy is quite similar to the bulk exchange policy.
- However, the tools are replaced once the parts are processed to make room for tools for processing other parts.
- In this system, tool changing and shuttling are accomplished by the material-handling robot that is used to remove and place parts within the machining centers.

Tool Allocation Policies

- **Example 13.3**

Illustration of Tool Resident Policy

- Consider the matrix of tools required to process parts as given in Table 13.3. Only two machining centers are available. Develop a resident tooling policy consisting of two groups of tools to be mounted on two machining centers. Use the concepts of production flow analysis.

Tool Allocation Policies

TABLE 13.3 **Tool Type and Part Type Matrix**

	Part types														
Tools	*p1*	*p2*	*p3*	*p4*	*p5*	*p6*	*p7*	*p8*	*p9*	*p10*	*p11*	*p12*	*p13*	*p14*	*p15*
t1	1		1		1	1				1	1		1		1
t2	1		1		1	1				1	1		1		1
t3		1		1			1	1	1			1		1	
t4		1					1		1			1		1	
t5	1		1			1				1	1		1		1
t6	1		1		1	1				1	1		1		1
t7		1		1			1	1	1			1		1	
t8		1					1	1				1		1	
t9		1		1			1	1	1			1		1	

Tool Allocation Policies

❑**Solution**

The solution process is similar to the part machine cell formation approach as given in Week-7. Using similarity coefficients between the tools and the single-linkage cluster analysis approach, we obtain two groups of tools that can be permanently mounted on two machining centers to process the parts as follows:

Tool Allocation Policies

Machining Centers	Tools	Parts
First	(t1, t2, t5, t6)	(P1, P3, P5, P6, P10, P11, P13, P15)
Second	(t3, t4, t7, t8, t9)	(P2, P4, P7, P8, P9, P12, P14)

Tool Allocation Policies

❑ Tool-Sharing Policy

- The tool-sharing policy is a kind of hybrid of the bulk exchange and resident tooling policies. Tools are resident on machines based on tool clustering.
- Whenever a new part enters the system, it is identified with a part family and then, based on its routing and tooling requirements, the tool-sharing arrangement is made on the machines.
- Assignment of parts to machine is done randomly in the bulk exchange and migration policies, whereas the specific parts are assigned to specific machines based on the availability of tooling of those groups.

Comparison of Various Tooling Strategies

Five measures of performance were used in the study:

1. Mean flow time of parts representing the average time a part spends in the system.
2. Mean tardiness of parts representing the average lateness of all late jobs
3. Percentage of jobs that are tardy
4. Average utilization of machines
5. Average utilization of the robotic system.

Comparison of Various Tooling Strategies

The following three part-type selection heuristics were used:

1. LNT heuristic

- This part-type selection rule, is based on assigning higher priority to the part types requiring the largest number of tools (LNT) for processing.
- The rationale of the rule is that starting with the part that requires the largest number of tools ensure the minimum number of tool changes on the machine. Minimization of tool changes means improvements in machine utilization.

Comparison of Various Tooling Strategies

2. SNT heuristic

- This part-type selection rule, is based on assigning higher priority to the parts requiring the smallest number of tools (SNT) for processing.
- This rule permits the selection of a large number of part types into one batch, thus minimizing the number of batches.
- Minimizing the number of batches reduces the idle time, leading to higher utilization of the machines.

Comparison of Various Tooling Strategies

3. EDD rule

- This part-type selection rule is based on assigning higher priority to parts with the earliest due date. In a survey of 22 FMS users in the United States it is observed that due date considerations in the selection of parts are important from the customer satisfaction point of view.

Flexible Manufacturing Systems-II

✓ **Fixture and Pallet Selection Problems: Numerical Examples**

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Comparison of Various Tooling Strategies

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Fixture and Pallet Selection Problem

- The use of palletized parts in FMSs is one of the most important factors in the integration of machines, material-handling equipment, and in-process facilities.

- A fixture provides a fixed orientation of the part and can be configured for a part or family of parts.

- The geometry of parts governs the type of fixture suitable for the part types.

Fixture and Pallet Selection Problem

- For example, rotational and prismatic parts would require different fixturing considerations.
- Because the pallets moving the fixtured parts interface with the machine tools, material-handling equipment, in-process storage facilities, and load-unload stations, the selection of fixtures and pallets must be compatible with these systems.
- The fixture and pallet selection problem can be considered as a subset of the part selection problem.

Fixture and Pallet Selection Problem

- The approximate number of pallets required can be estimated using the following equation:

$$\text{Number of Pallets} = \frac{(\text{parts required per shift}) \times (\text{average pallet cycle time})}{(\text{planned production time per shift}) \times (\text{number of parts per pallet})}$$

Fixture and Pallet Selection Problem

TABLE 13.4 **Comparison of Four Tooling Strategies**

Measures of performance	*Part-type selection rules* Largest number of tools (LNT)	Smallest number of tools (SNT)	Earliest due date (EDD)
Mean flow time (MFT)	B-M-S-R*	B-M-S-R	B-M-S-R
Mean tardiness (TD)	B-M-S-R	B-M-S-R	B-M-S-R
Percent jobs tardy (PJT)	B-S-M-R	B-S-M-R	B-S-M-R
Average machine utilization (AMU)	M-B-R-S	M-B-S-R	M-B-R-S
Robot utilization (RU)	R-M-B-S	R-M-B-S	R-M-B-S

* B represents bulk, M migration, S sharing, and R resident tooling policies. The order B-M-S-R represents the order of decreasing performance.

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Fixture and Pallet Selection Problem

- The pallet cycle time is the time span from the entry of a part into a loading station until the part leaves an unloading station.
- This cycle time depends on a number of operational issues such as scheduling rules and processing times.
- If the number of pallets obtained from this equation is a fractional number, the next higher integer number may be selected.

Flexible Manufacturing Systems-II

- ✓ **Types of FMS Layout,**
- ✓ **Main Benefits of FMS**

Layout Considerations

- One of the important design characteristics of manufacturing systems is layout.
- For example, a job shop is characterized by a large variety of parts, general-purpose machines, and a functional layout (also known as process layout).
- In functional layout the machines are collected by function that is, all mining machines together, all grinding machines together, and so forth.
- A manufacturing system with large lots, less variety, special-purpose machines, and more mechanization is known as a flow shop.

Layout Considerations

- In a flow shop the machines are laid out in a line, so the layout is known as a product (or line) layout. A transfer line producing a gearbox is a typical example. The GT layout combines both product and process layouts.

- In an FMS the principles of GT are used to form part families.

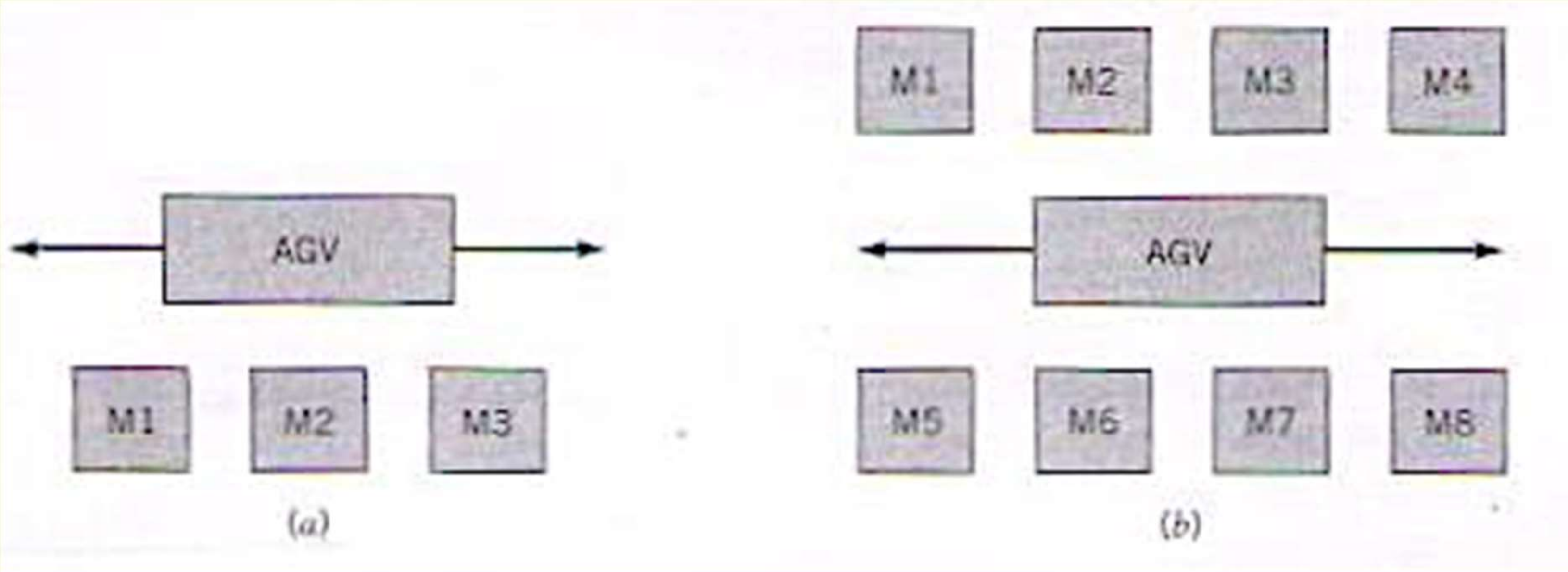
- An analysis of over 50 flexible manufacturing systems shows that the layout of machines to process part families in an FMS is determined by the type of material-handling equipment used.

Five Types of Layouts

❑ **Linear Single and Double-row Machine Layout**

- Automated guided vehicle systems are becoming common material-handling systems. An AGV is most efficient when the movement is in a straight line. Accordingly, the machines are arranged in straight lines along the AGV path as shown in Figure (a) and (b).

Five Types of Layouts

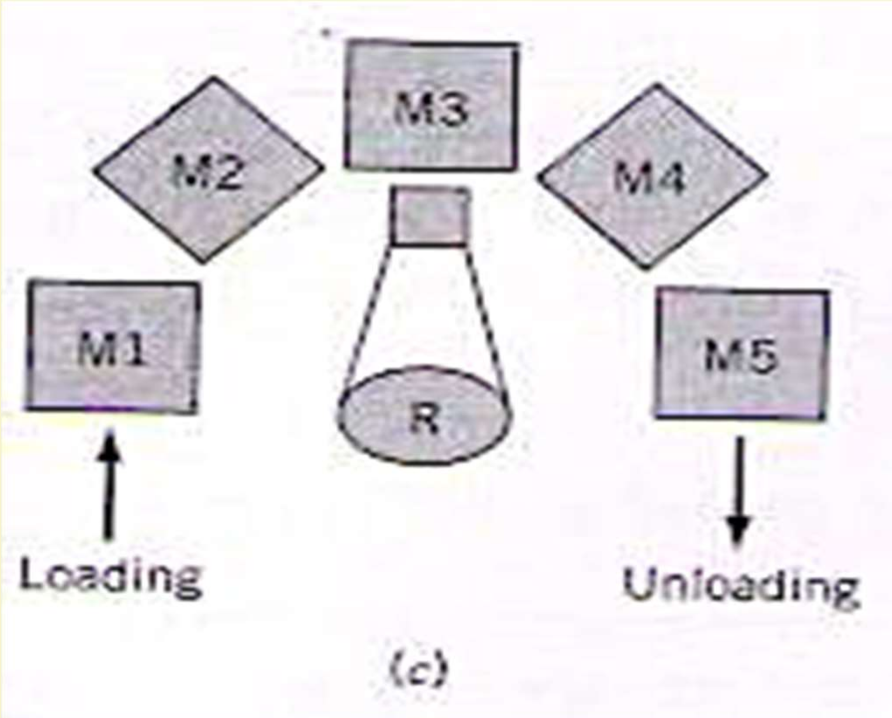


Five Types of Layouts

- **Circular Machine Layout**

If a handling robot is used in an FMS cell, the machines are laid out in a circle. The robot envelope essentially determines the arrangement of machines (Browne et al., 1984) as shown in Figure ‘c’.

Five Types of Layouts

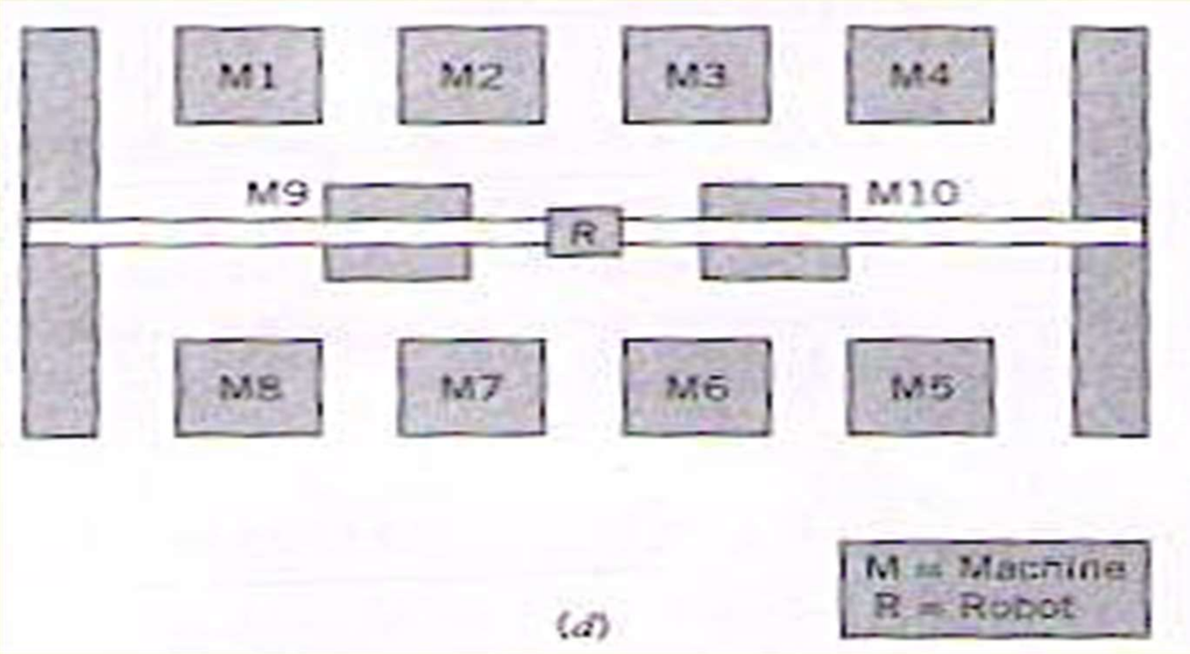


Five Types of Layouts

❑ Cluster Machine Layout

The cluster type of layout, shown in Figure (d), uses gantry robots to transfer parts among the machines. The layout considerations are the size of the machines, the working envelope of the gantry robot, and the access of the robot arm to the machines.

Five Types of Layouts

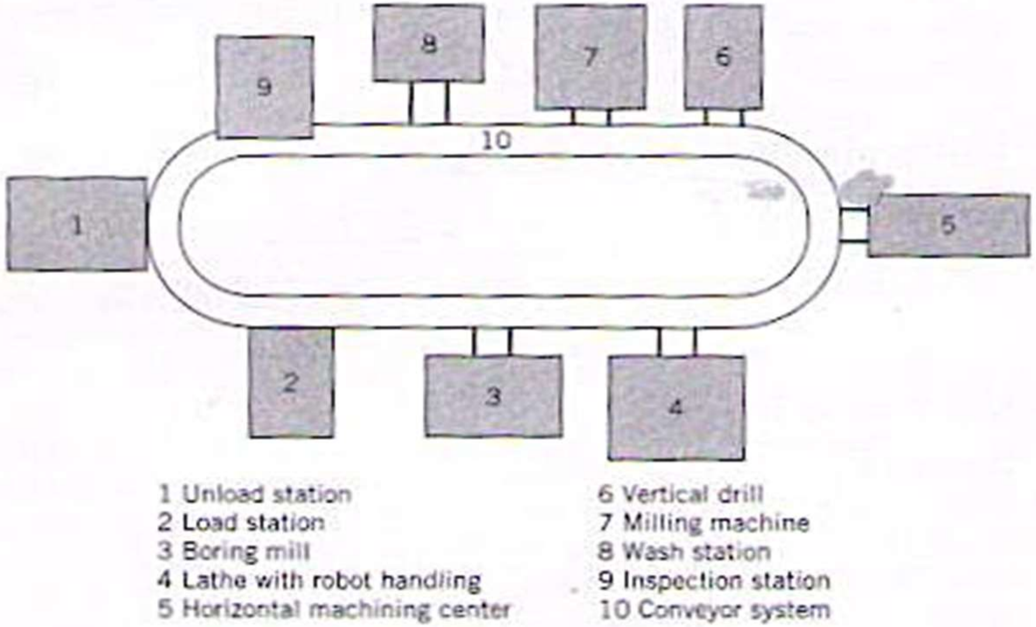


Five Types of Layouts

❑ Loop Layout

The loop layout uses a conveyor system that allows only unidirectional flow of parts around the loop. A secondary material-handling system is provided at each workstation and permits the flow of parts without any obstruction. Many other variations of the loop layout are possible. For example, a ladder layout contains rungs on which workstations are located; an open-field layout consists loops, ladders and sidings.

Five Types of Layouts



(*e*)

FIGURE 13.5 FMS layouts: (*a*) linear single-row machine layout; (*b*) double-row machine layout; (*c*) circular machine layout; (*d*) cluster machine layout; (*e*) loop machine layout.

Fixture and Pallet Selection Problem

❑ **Example 13.4**

Consider the following data available from a simulation study:

- Parts required per shift = 20
- Average pallet cycle time = 120 min
- Planned production time per shift = 480 min
- Number of parts per pallet = 1

❑ **Solution**

Using the formula given in previous slides, the number of pallets required = (20 x 120) / 480 = 5

Thank You!!