CELLULAR MANUFACTURING

- Grouping Machines logically so that material handling (move time, wait time for moves and using smaller batch sizes) and setup (part family tooling and sequencing) can be minimized.
- Application of Group Technology in Manufacturing.
- The basis of cellular layout is part family formation based on production parts/ their manufacturing features.
- For production flow analysis, all parts in a family must require similar routings.
  - Results in Efficient work flow.
  - Reduce tooling, machines
  - Easier automation
- The next slide shows the benefits of functional layout over Cellular (group-technology) layout.

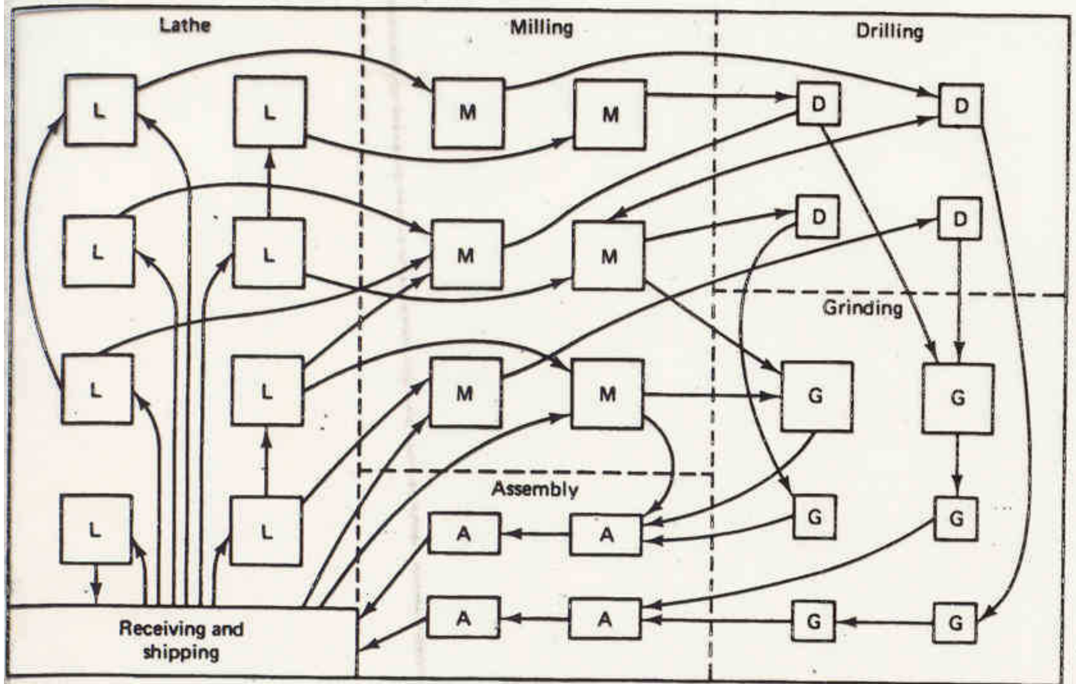


Figure 12.16 Functional (process-type) layout.

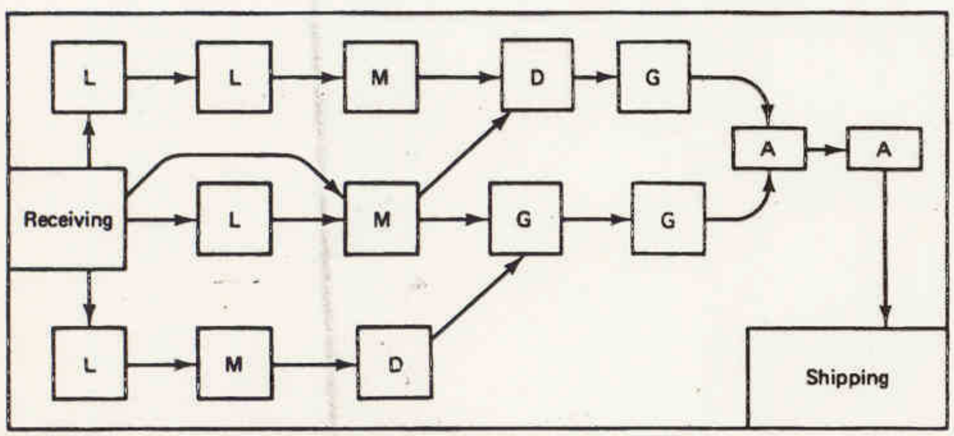


Figure 12.17 Cellular (group-technology) layout.

Cell Formation Approaches

- Machine component group analysis
  1. Family-formation for cell design
     - Production Flow analysis (PFA) introduced by J.L.Burbridge (1971) in which a PFA matrix is constructed, in which each row represents an OP (operation Plan) code, and each column in the matrix represents a component.
  2. Using an algorithm to sort the matrix into blocks, where the each final block represents a cell

     Ex: Rank-order clustering algorithm

     Direct clustering technique

- Similarity Coefficient- Based Approaches
  - Find/Define a measure of similarity between 2 machines, tools, design features, etc. Use this data to form part families and machine groups.

    Ex: Single-Linkage Cluster Analysis

    Cluster Identification algorithm

Process plan for 6 parts using 4 Machines

- Part 1 (P1) – M3(Machine 1), M4
- P2 – M1, M2
- P3 – M3, M4
- P4 – M1, M2
- P5 – M3, M4
- P6 – M1, M2

TABLE 12.1 **Part–Machine Data for Production Flow Analysis**

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

12.8.1.2 Rank Order Clustering Algorithm

Rank order clustering (ROC) (King, 1980) is a simple algorithm used to form

TABLE 12.1 **Part–Machine Data for Production Flow Analysis**

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

TABLE 12.2 **The Cells Formed after Matrix Manipulation Using PFA**

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

12.8.1.2 Rank Order Clustering Algorithm

Rank order clustering (ROC) (King, 1980) is a simple algorithm used to form

DIRECT CLUSTERING ALGORITHM (DCA)

(a) Count the # of positive cells

PARTS

		1	2	3	4	5	6	7	
	1		1		1			1	3
M	2			1		1			2
/	3	1	1		1			1	4
C	4	1		1			1		3
	5			1	1	1	1		4
		2	2	3	3	2	2	2	

(b) Rank rows in **descending** order and columns in **ascending** order

PARTS

		7	6	5	2	1	4	3	
	5		1	1			1	1	4
M	3	1			1	1	1		4
/	4		1			1		1	3
C	1	1			1		1		3
	2			1				1	2
		2	2	2	2	2	3	3	

(c) Conduct column interchanges based on the **First** row

		PARTS						
		6	**5**	**4**	**3**	7	2	1
	5	**1**	**1**	**1**	**1**			
M	3			1		1	1	1
/	4	1			1			1
C	1			1		1	1	
	2		1		1			

Freeze previous changes, continue the column interchanges based on the remaining **rows** until no further change occurs.

(d) Conduct row interchanges, based on the **First** column

		PARTS						
		6	5	4	3	7	2	1
	5	**1**	1	1	1			
M	**4**	**1**			1			1
/	3			1		1	1	1
C	1			1		1	1	
	2		1		1			

Rank-Order Clustering Algorithm

- King (1979,80) presented this simple technique to form machine-parts group.
- Based on sorting rows and column of machine part incidence matrix (PFA matrix).
- Step 1: Assign binary weight and determine decimal weight for each row and column say *"Wi"* and *"Wj"*

  $W_i = \Sigma^m_{p=1} b_{ip} 2^{m-p}$

  where,

  m is the total number of columns

  i is the number of row

  b_{ip} is either 0 or 1 depending upon the matrix.
- Step 2: Rearrange the rows to make *"Wi"* fall in descending order.
- Step 3: Repeat steps 1 and 2 for each column, then go to step 1 again.
- Step 4: Repeat above steps until there is no further change in position of each element in each row and column.

RANK ORDER CLUSTERING (ROC) EXAMPLE

(a) Calculate the binary values of each row

		PARTS								
BINARY VALUE		$2^6 =$ 64	$2^5 =$ 32	$2^4 =$ 16	$2^3 =$ 8	$2^2 =$ 4	$2^1 =$ 2	$2^0 =$ 1		
		1	2	3	4	5	6	7	BV	RANK
	1		1		1			1	41	3
M	2			1		1			20	5
/	3	1	1		1			1	105	1
C	4	1		1			1		82	2
	5			1	1	1	1		30	4

(b) Sort the rows in **descending** order

		PARTS						
		1	2	3	4	5	6	7
	3	1	1		1			1
M	4	1		1			1	
/	1		1		1			1
C	5			1	1	1	1	
	2			1		1		

(c) Calculate the binary values for each column

	BINARY VALUE		PARTS 1	2	3	4	5	6	7
	$2^4 = 16$	3	1	1		1			1
M	$2^3 = 8$	4	1		1			1	
/	$2^2 = 4$	1		1		1			1
C	$2^1 = 2$	5			1	1	1	1	
	$2^0 = 1$	2			1		1		
	BV		24	20	11	22	3	10	20
	RANK		1	3	5	2	7	6	4

(d) Sort the columns in **descending** order

Exceptional Elements

Voids

		PARTS 1	4	2	7	3	6	5
	3	1	1	1	1			
M	4	1				1	1	
/	1		1	1	1			
C	5		1			1	1	1
	2					1		1

(e) **Repeat the row and then column interchanges until no change happen.**

Exceptional Parts and bottle neck machines

- Not always to get neat cells
- Some parts are processed in more than one cell
  - Exceptional parts
  - Machine processing them are called bottleneck machines

Solutions for overcoming this problem?

- Duplicate machines
- Alternate process plans
- Subcontract these operations

TABLE 12.3 **Machine–Component Matrix**

Machines	*Components* 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		

Solution

Use the steps of the ROC algorithm:

Step 1: For each row of the machine–component matrix, assign binary weights and calculate decimal equivalents as given in the following matrix (Table 12.4).

Step 2: Arranging rows by sorting the decimal weights in decreasing order results in the matrix given in Table 12.5.

Step 3: Repeating steps 2 and 3 for columns results in the matrix given in Table 12.6.

Step 4: There is no change in the row and column positions with further iterations.

TABLE 12.4 **Decimal Equivalents for Each Row**

	Components 1	2	3	4	5	6	7	8	9	10	
Machines	*Binary weight* 2^9	2^8	2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0	*decimal equivalent*
M_1	1	1	1	1	1		1	1	1	1	1007
M_2		1	1	1					1	1	451
M_3	1				1	1	1				568
M_4		1	1	1				1	1	1	455
M_5	1	1	1	1	1	1	1	1			1020

TABLE 12.4 **Decimal Equivalents for Each Row**

	Components										
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	
	Binary weight										*decimal*
Machines	2^9	2^8	2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0	*equivalent*
M_1	1	1	1	1	1		1	1	1	1	1007
M_2		1	1	1					1	1	451
M_3	1				1	1	1				568
M_4		1	1	1				1	1	1	455
M_5	1	1	1	1	1	1	1	1			1020

TABLE 12.5 **Row Arrangement in Decreasing Order of the Decimal Weights**

		Components									
		1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
	Binary	Binary weight									
Machines	*weight*	2^9	2^8	2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0
M_5	2^4	1	1	1	1	1	1	1	1		
M_1	2^3	1	1	1	1	1		1	1	1	1
M_3	2^2	1				1	1	1			
M_4	2^1		1	1	1				1	1	1
M_2	2^0		1	1	1					1	1
Column decimal equivalent		28	27	27	27	28	20	28	26	11	11

Similarity Coefficient-Based Approach

- Start with a very small separation, gradually increase it and observe how the clusters merge together until every object has merged into one large cluster. This process is called *agglomerative hierarchical clustering* and the process of merging can be represented by a *hierarchical tree*.
- Hierarchical cluster analysis is an agglomerative methodology that finds clusters of observations within a data set.
- Three of the better known algorithms for clustering are average linkage, complete linkage and **single linkage**.
- The different algorithms differ in how the distance between two clusters is computed.
- Average linkage clustering uses the average similarity of observations between two groups as the measure between the two groups.
- Complete linkage clustering uses the farthest pair of observations between two groups to determine the similarity of the two groups.

Single-Linkage Cluster Analysis

- SLCA : Hierarchical machine grouping method using similarity coefficients between machines
- Single linkage clustering computes the similarity between two groups as the similarity of the closest pair of observations between the two groups.
- Similarity coefficients are used to construct a tree called a dendrogram, *hierarchical tree.*
- Similarity coefficient between two machines is defined as the ratio of number of parts visiting both machines and the number of parts visiting one of the 2 machines:

$$S_{ij} = \frac{\sum_{K=1}^{N} X_{ijk}}{\sum_{K=1}^{N} (Y_{ik} + Z_{jk} - X_{ijk})}$$

X_{ijk}= operation on part k performed both on machine i and j.

Y_{ik} = operation on part k performed both on machine i.

Z_{jk}= operation on part k performed both on machine j.

SLCA Algorithm

- A dendogram is the final representation of the bonds of similarity between machines as measured by the similarity coefficients.
- The branches represents machines in the machine cell.
- Horizontal lines connecting branches represents threshold values at which machine cells are formed. The steps are as follows:
- Step 1: Compute similarity coefficients for all possible pairs of machines.
- Step 2: Select 2 most similar machines to form the first machine cell.
- Step 3: Lower the similarity level (threshold) and form new machine cells by including all the machines with similarity coefficients not less than the threshold value.
- Step 4: Continue step 3 unstill all the machines are grouped into a single cell.

TABLE 12.3 **Machine–Component Matrix**

	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		

Consider the matrix of 5 machines and 10 components given in Table 12.3 in Example 12.4. Develop a dendrogram and discuss the resulting cell structures.

Solution

Step 1: Determine similarity coefficients between all pairs of machines. The similarity coefficient between machine 1 and machine 2 is determined as follows:

$$SC_{12} = \frac{5}{9 + 5 - 5} = 0.556$$

Similarly, other similarity coefficients are calculated and are given in Table 12.7.

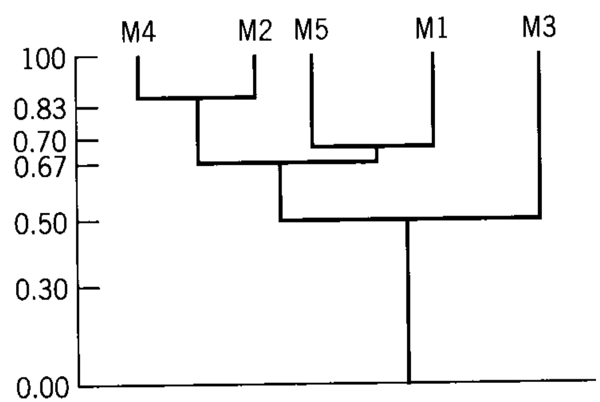
Step 2: Select machines M2 and M4, having the highest similarity coefficient of 0.83, to form the first cell.

TABLE 12.7 **Similarity Coefficients for the Problem Data Given in Table 12.3**

Machine pair:	*M1 M2*	*M1 M3*	*M1 M4*	*M1 M5*	*M2 M3*	*M2 M4*	*M2 M5*	*M3 M4*	*M3 M5*	*M4 M5*
Similarity coefficient:	0.55	0.30	0.67	0.70	0.00	0.83	0.30	0.00	0.50	0.40

Step 3: The next lower coefficient of similarity is between machines M1 and M5. Use these to form the second cell.

Step 4: The next lower coefficient of similarity is now 0.67 between machines M1 and M4. At this threshold value machines M1, M2, M4, and M5 will form one machine group. The next lower coefficient of similarity is 0.55 between machines M1 and M2, which is dominated by the similarity coefficient of 0.67 (for example, see Figure 12.5). The lowest nondominated similarity coefficient is 0.50 between machines M3 and M5, at which all the machines belong to one cell.



Evaluation of cell formation

$$\Gamma = \frac{1 - \psi}{1 + \phi} \tag{12.3}$$

where $\psi = \dfrac{\text{number of exceptional elements}}{\text{total number of operations}}$

$$\phi = \frac{\text{number of voids in the diagonal blocks}}{\text{total number of operations}}$$

12.8.3 Exceptional Parts and Bottleneck Machines

The creation of mutually independent machine cells with no intercell movement is one of the important goals of cell design. However, it may not always be economical or practical to achieve mutually independent cells. In practice, therefore, some parts need to be processed in more than one cell. These are known as "exceptional" parts and the machines processing them are known as "bottleneck" machines. Bottleneck machines are the source of intercellular moves that can be eliminated by duplicating a sufficient number of bottleneck machines in the appropriate cells. The decision to duplicate machines should be traded off against long-term savings resulting from reduced intercell material-handling cost.

The problem of exceptional elements can possibly be eliminated by

- Generating alternative process plans
- Duplication of machines
- Subcontracting these operations

However, a solution will depend very much on the nature of the operations involved. A number of analytical methods have been suggested in the literature (Vannelli and Kumar, 1986; Seifoddini, 1989) to help resolve the problem of exceptional elements and bottleneck machines.

12.8.4 Evaluation of Cell Designs

In Example 12.5, we notice from the dendrogram that four, three, two, and one cells are formed at similarity coefficients of 0.83, 0.70, 0.67, and 0.55, respectively. Also, five cells will be formed if each machine is treated as an independent cell resulting in a similarity coefficient of 1. These cell configurations are shown in Table 12.8. The question now arises, which cell configuration is the best and what are the factors that influence such a cell design decision?

A number of criteria can be used to decide on the optimal cell configuration, as mentioned in Section 12.6. However, to choose a cell design from a set of alternatives, a criterion of minimizing the total material-handling cost of intercell (between cells) and intracell (within cell) movements of parts is particularly relevant if parts have a number of operations visiting a number of machines. However, the following factors influence these costs of inter- and intracell moves:

1. The layout of machines in a group
2. The layout of machine groups
3. The sequences of parts through machines and machine groups

The total distances moved by a component visiting a number of components in a cell has to be determined. Analytical expressions for the total expected distances moved can be determined if machines in a cell are laid out in (1) a straight line, (2) a rectangle, or (3) a square.

The following reasonable assumptions are made to compute the expected distances:

1. In the absence of real data on the sequences in which the components visit the machines, it is assumed that the machines are laid out in a random manner.
2. There is one unit distance between each machine in a group of N machines.
3. A part has to visit two machines in a group of N machines.

TABLE 12.8 **Alternative Cell Configurations**

Similarity coefficient	*Number of cells formed*	*Cell configuration*
1.00	5	(M1), (M2)*, (M3), (M4), (M3)
0.83	4	(M2, M4), (M5), (M1), (M3)
0.70	3	(M2, M4), (M1, M5), (M3)
0.67	2	(M1, M2, M4, M5), (M3)
0.50	1	(M1, M2, M3, M4, M5)

* Each set of parentheses (,) designates a cell.

The expected distance a part moves between two machines in a cell having a group of N machines can be shown to be:

$$\text{Expected distance for a straight-line layout} = \frac{N+1}{3}$$

$$\text{Expected distance for a rectangle layout with } M \text{ rows of } L \text{ machines} = \frac{M+L}{3}$$

$$\text{Expected distance for a square layout} = 2\,\frac{\sqrt{N}}{3}$$

$$\text{Total distance moved in } j\text{th cell for the } i\text{th configuration} = \sum_{j}^{m} d_{ij} k_{ij}$$

where d_{ij} = expected distance moved between two machines for ith configuration in jth cell

k_{ij} = number of moves between two machines by all parts for ith configuration in jth cell

The total cost of inter- and intracellular movements (TC_i) for the ith configuration:

$$TC_i = C_1 N_i + C_2 \sum_{j}^{m} d_{ij} k_{ij}$$

where C_1 = cost of an intercell movement

C_2 = cost per unit distance of an intracell movement

N_i = number of intercell movements for ith configuration

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

could be to allocate parts to a machine group in which the maximum number of operations can be performed.

The number of moves passing through two machines by all the parts in a cell (M_1, M_5) is seven. In cell (M_2, M_4) there are five moves (two for parts 9 and 10 within the cell and three for parts 2, 3, and 4 outside the cell but processed within the cell). In cell (M_3), there are zero moves, since there is only one machine.

$$\text{Total distance for all intracell moves} = \left(\frac{2+1}{3}\right)7 + \left(\frac{2+1}{3}\right)5 + 0 = 12$$

The number of intercell moves is 10 for this cell configuration. Assuming $C_1 = \$2.00$ and $C_2 = \$1.00$, the total cost of intercell and intracell moves for all the solutions is given in Table 12.10. The third configuration is the optimal solution as given in Table 12.9.

In this approach, the cell layout and the cost of inter- and intracell material handling are assumed to be known. There may, however, be situations in which such information is not available. Next, we present an evaluation approach for the cell configuration that does not require all this information.

12.8.5 An Alternative Approach to Evaluating Goodness of Heuristic Solutions

The heuristic algorithms used for forming part families and machine cells essentially try to rearrange the rows and columns of the matrix to get a block diagonal form. The

TABLE 12.10 **Cell Configurations and Their Analysis of Intercell Moves, Intracell Moves, and Total Cost**

	Cell Configuration	*Number of Intercell Moves*	*Total Distance of Intracell Moves*	*Total Cost of Intercell and Intracell Moves*
5-cells	(M1), (M2)*, (M3), (M4), (M5)	22	0	$2 \cdot 22 + 1 \cdot 0 = 44$
4-cells	(M2, M4), (M5), (M1), (M3)	18	5	$2 \cdot 18 + 1 \cdot 5 = 41$
3-cells	(M2, M4), (M1, M5), (M3)	10	12	$2 \cdot 10 + 1 \cdot 12 = 32$
2-cells	(M1, M2, M4, M5), (M3)	4	30	$2 \cdot 4 + 1 \cdot 30 = 38$
1-cell	(M1, M2, M3, M4, M5)	0	44	$2 \cdot 0 + 1 \cdot 44 = 44$