Design of Manufacturing Systems – Manufacturing Cells

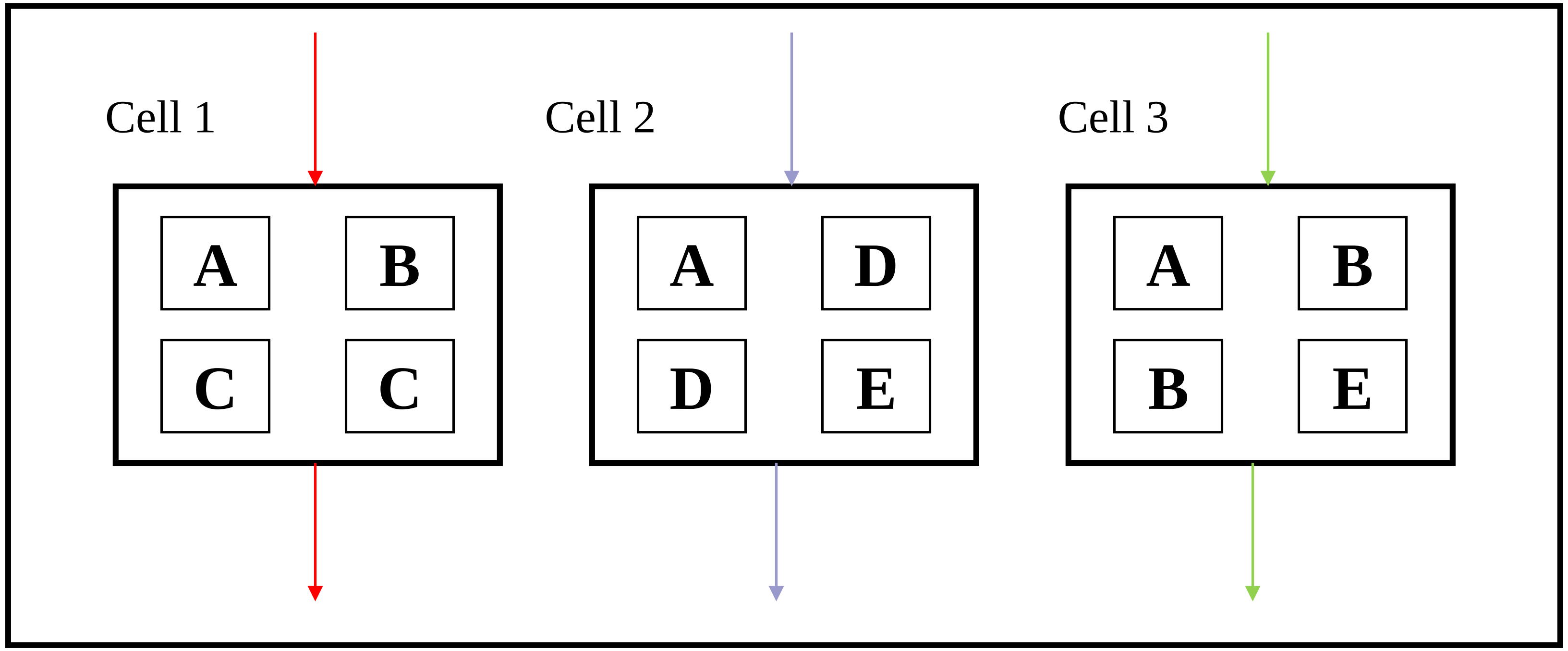
Outline

- General features
- Examples
- Strengths and weaknesses
- Group technology – steps
- System design
- Virtual cellular manufacturing

Manufacturing cells – general features

When cellular manufacturing is applied, parts are grouped into **part families** and machines into **cells**.

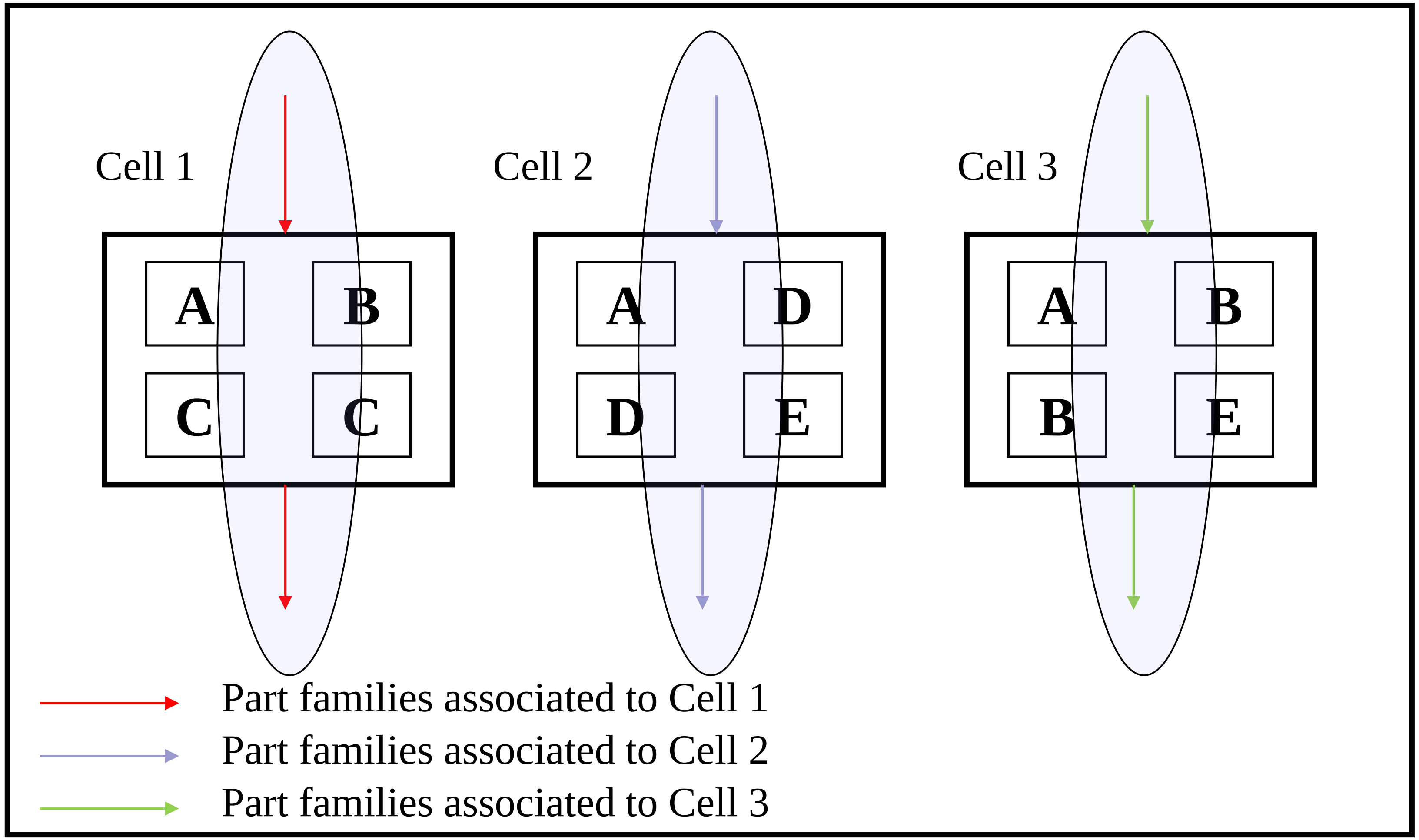
The machines are grouped on the basis of the **processing requirements** of the part families (different technological processes / machines in the same cell).



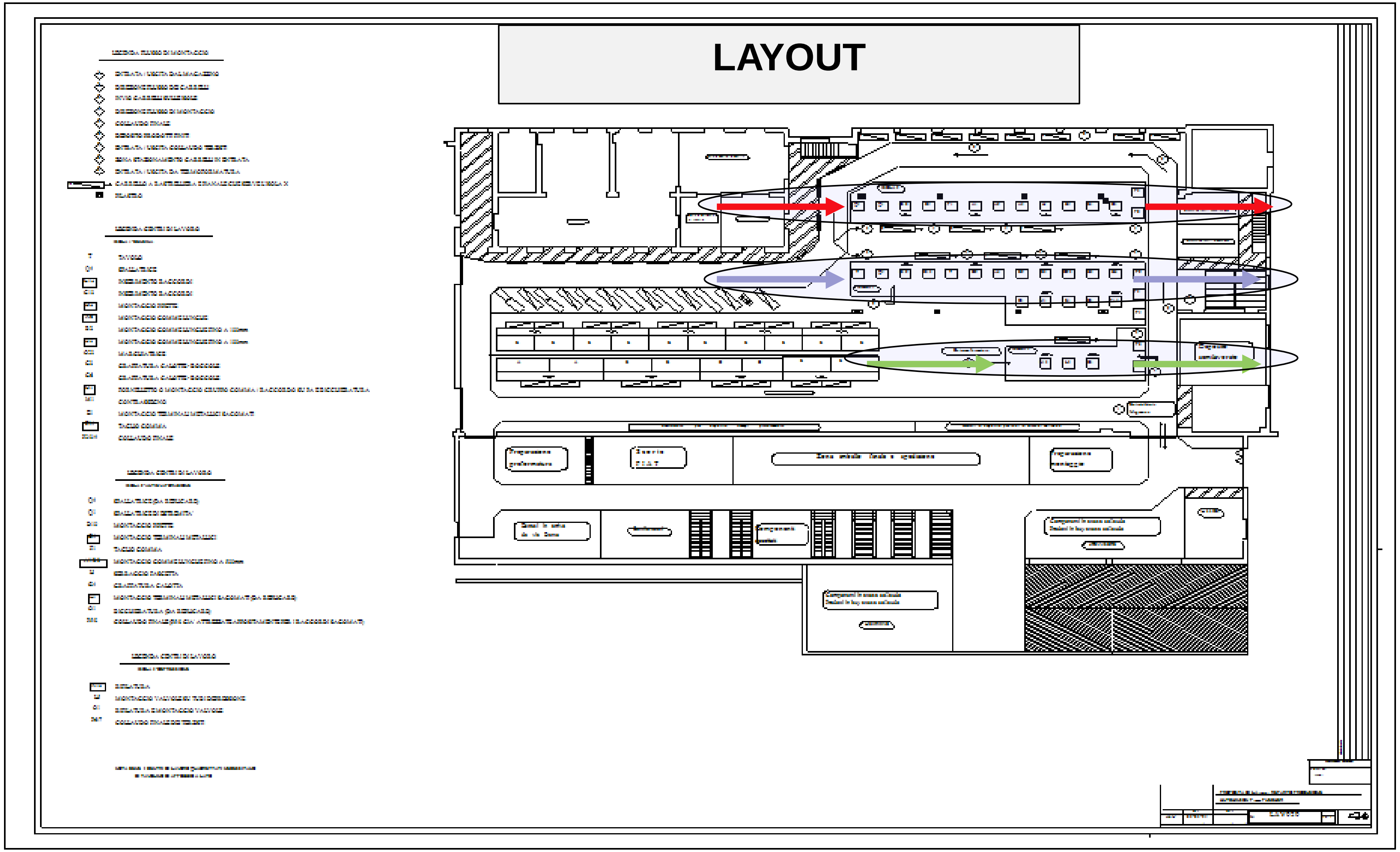
(*) Product and part are terms used as synonymous during this course

Manufacturing cells – general features

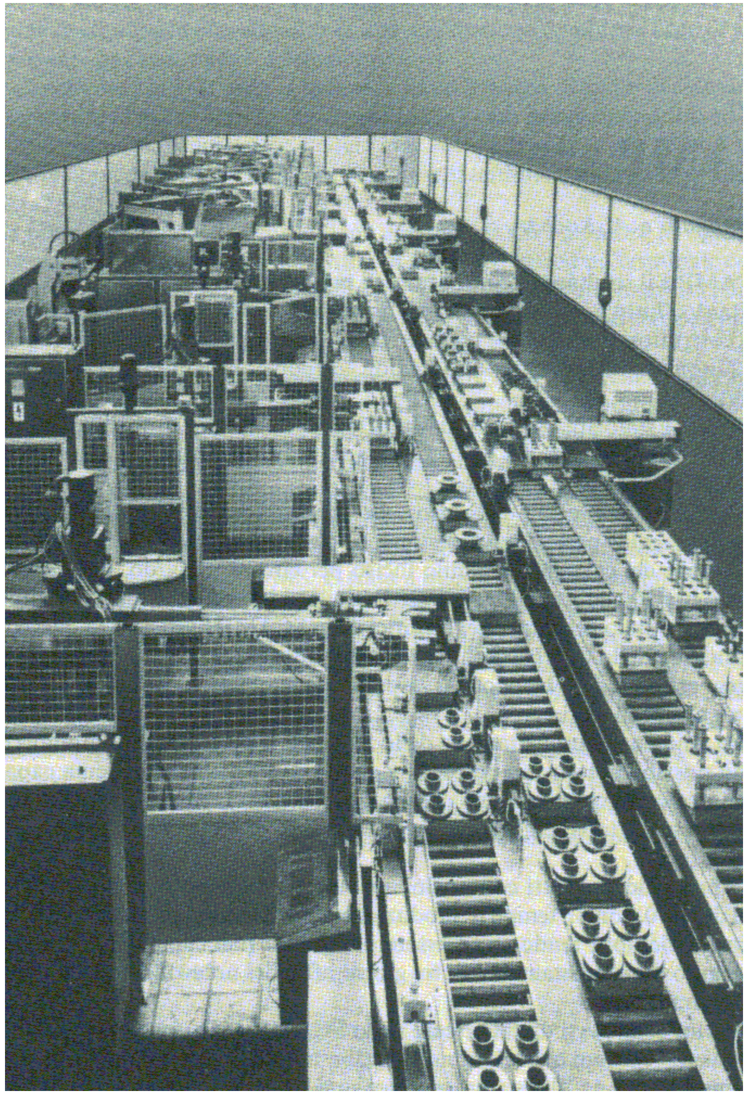
Each product has its own **routing** within the cell (this is the case when no inter-cell move is required > case of complete cell independence).



Example 1



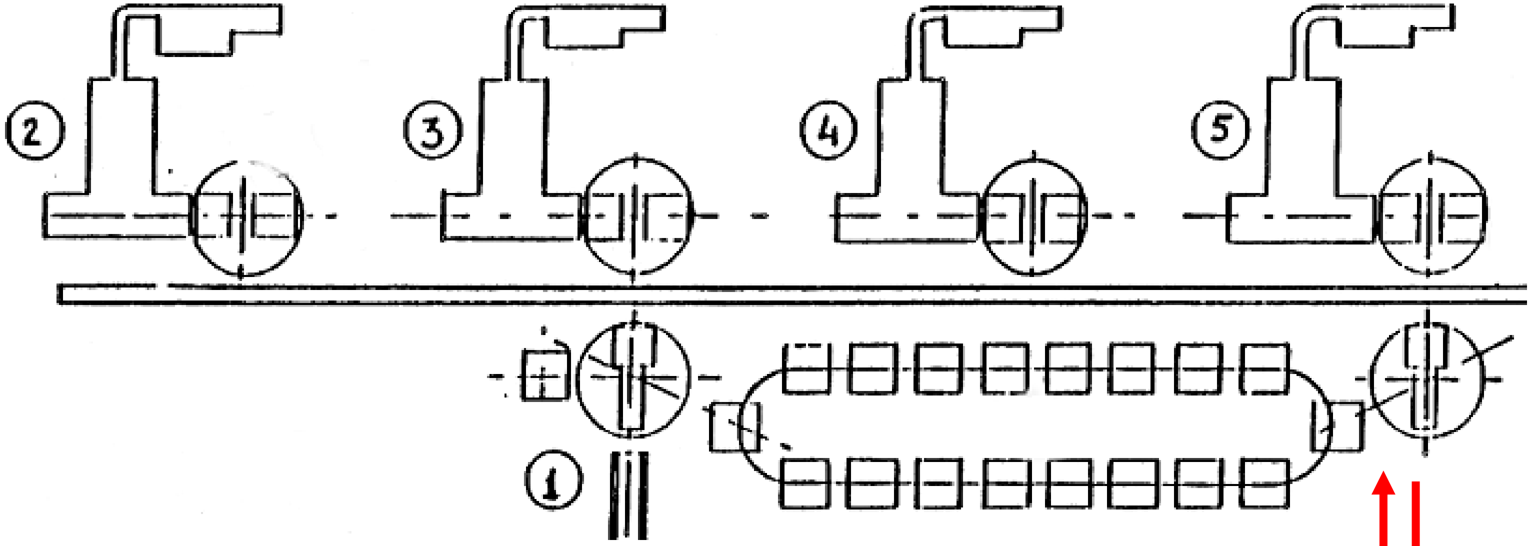
Example 2

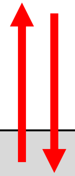


MANNED OPERATIONS AT LOAD / UNLOAD STATIONS

Part families associated to the FMS (Flexible Manufacturing System)

Example 3





Part families associated to the FMC (Flexible Manufacturing Cell)

MANNED OPERATIONS AT LOAD / UNLOAD STATIONS

Some examples

- https://www.youtube.com/watch?v=E54HAZWQpys
- https://www.youtube.com/watch?v=c50_lAIfzsk

Manufacturing cells – general features

When cellular manufacturing is applied, it may lead to:

- re-arrange existent equipment on the factory floor (i.e. machines, …);
- operate with new equipment, often incorporating various forms of flexible automation (i.e. from machines, material handling equipment, …, to FMC/FMS).

In other words, a typical question related to system design is required – "*which machines and their associated parts should be grouped together to form cells?*" – before re-arranging existent equipment on the factory floor, or incorporating flexible automation.

Manufacturing cells – Strengths

- Rationalization of material flows
- Setup time reduction
- Production management is easier

Overall (compared to the job-shop):

- WIP reduction
- Lead time reduction (also considering variability)
- More reliable estimates of delivery lead times

Manufacturing cells – Strengths

- Job enlargement + job enrichment for employees
- Team work within the cell
- Unification of product and process responsibilities
- More control on the quality characteristics of the products

Manufacturing cells – Weaknesses

- Difficulties with work load balancing between cells
- Problems related to production mix variability
- Difficulties with the application to the whole stages of the production chain
- In some cases, necessity of more machines than in a job shop
- Difficulties to manage technological operations outside the cells
- Problems related to breakdowns

Group technology – Steps

- Data collection regarding the production mix and technological routings
- Classification of products
- Standardization of products
- Standardization of technological routings
- Identification of product families
- Identification of machine groups forming the cells

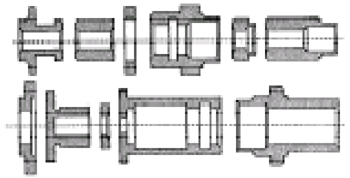
Rough design of a manufacturing cell

After the identification of product families and machine groups, the cells design can be based on the same approach used for the job-shop:

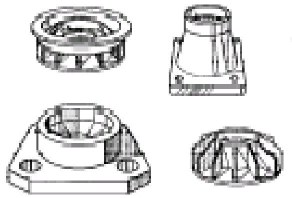
- calculate the number of machines of type i necessary in the cell;
- evaluate the number of shifts/day, computing the yearly costs adopting 1, 2 or 3 shifts/day.

Group technology – Methods

- Identification of product families based on the classification of products
  - Informal methods
    - Based on geometrical features
    - Based on technological features

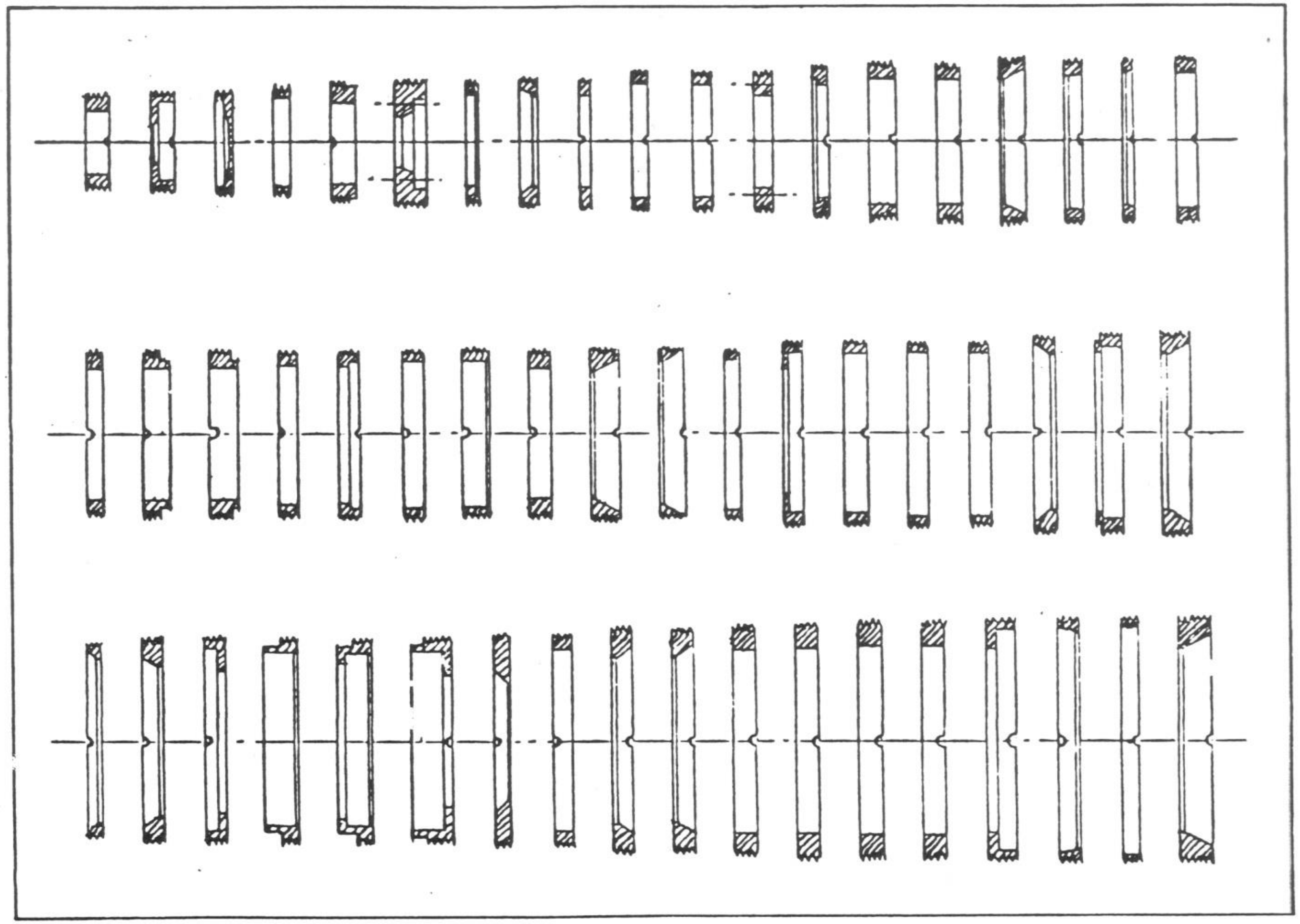


  - Part coding analysis methods
    - Based on geometrical features
    - Based on technological features



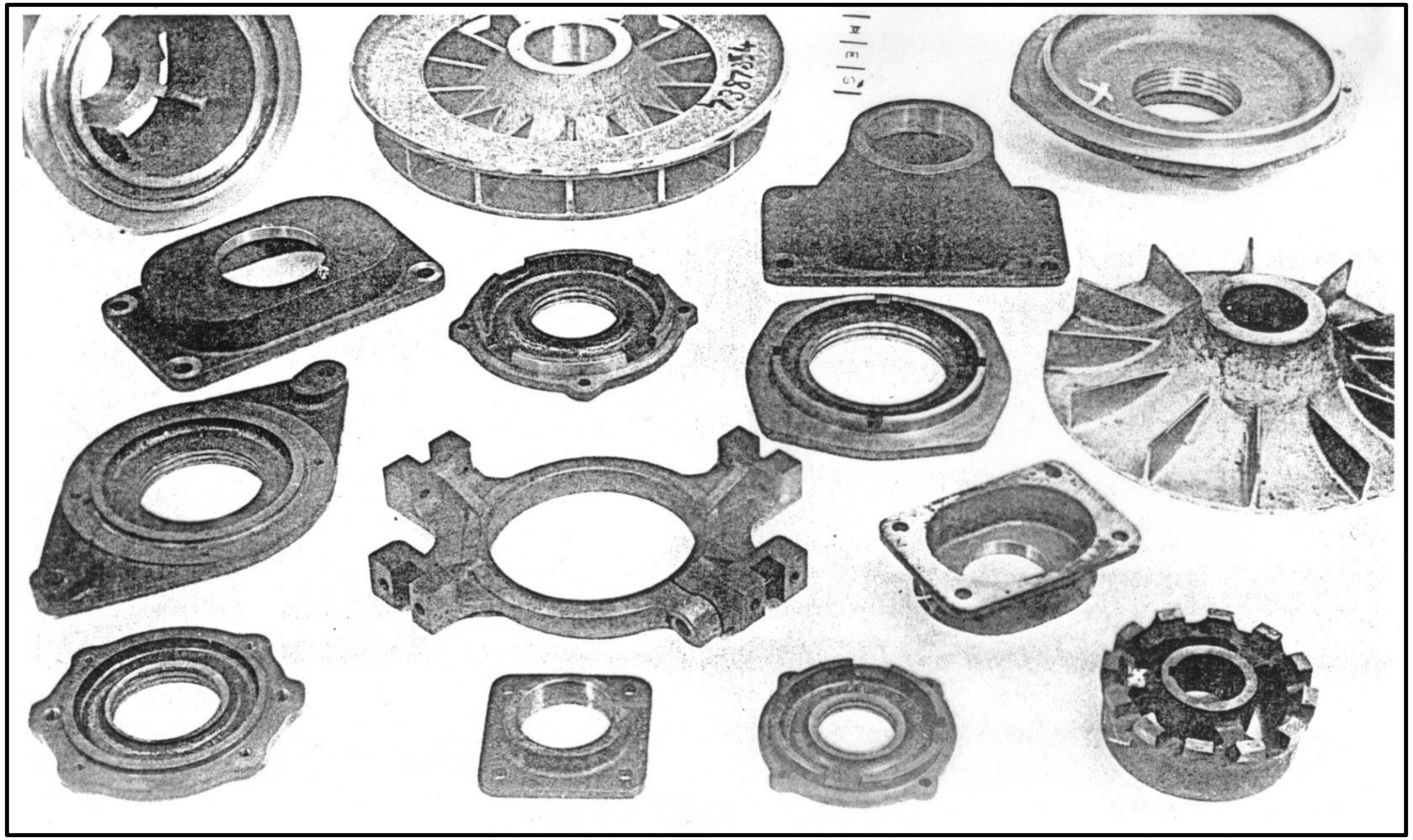
Based on the classification of products

- Based on geometrical features of products



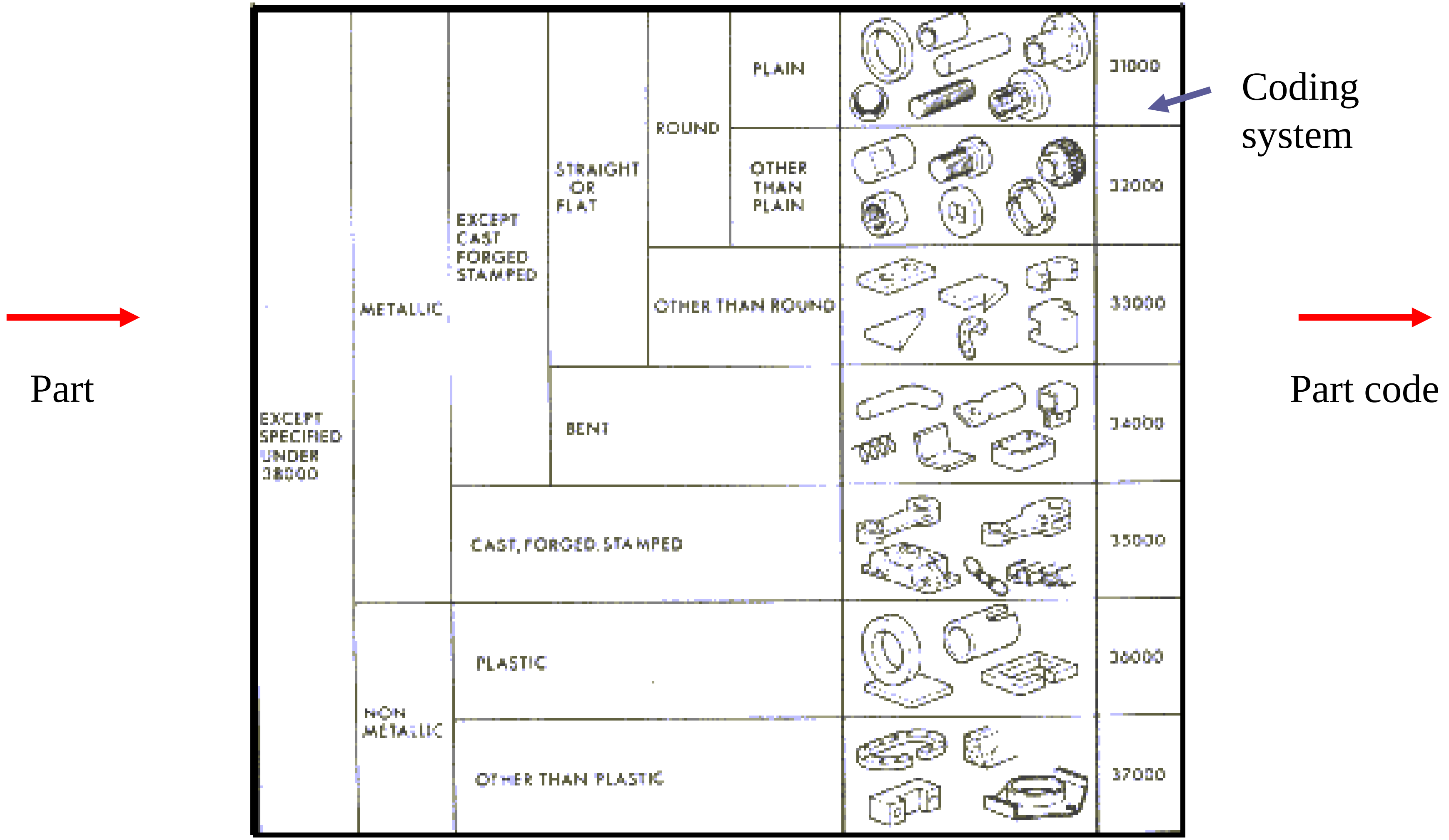
Based on the classification of products

- Based on technological features of products



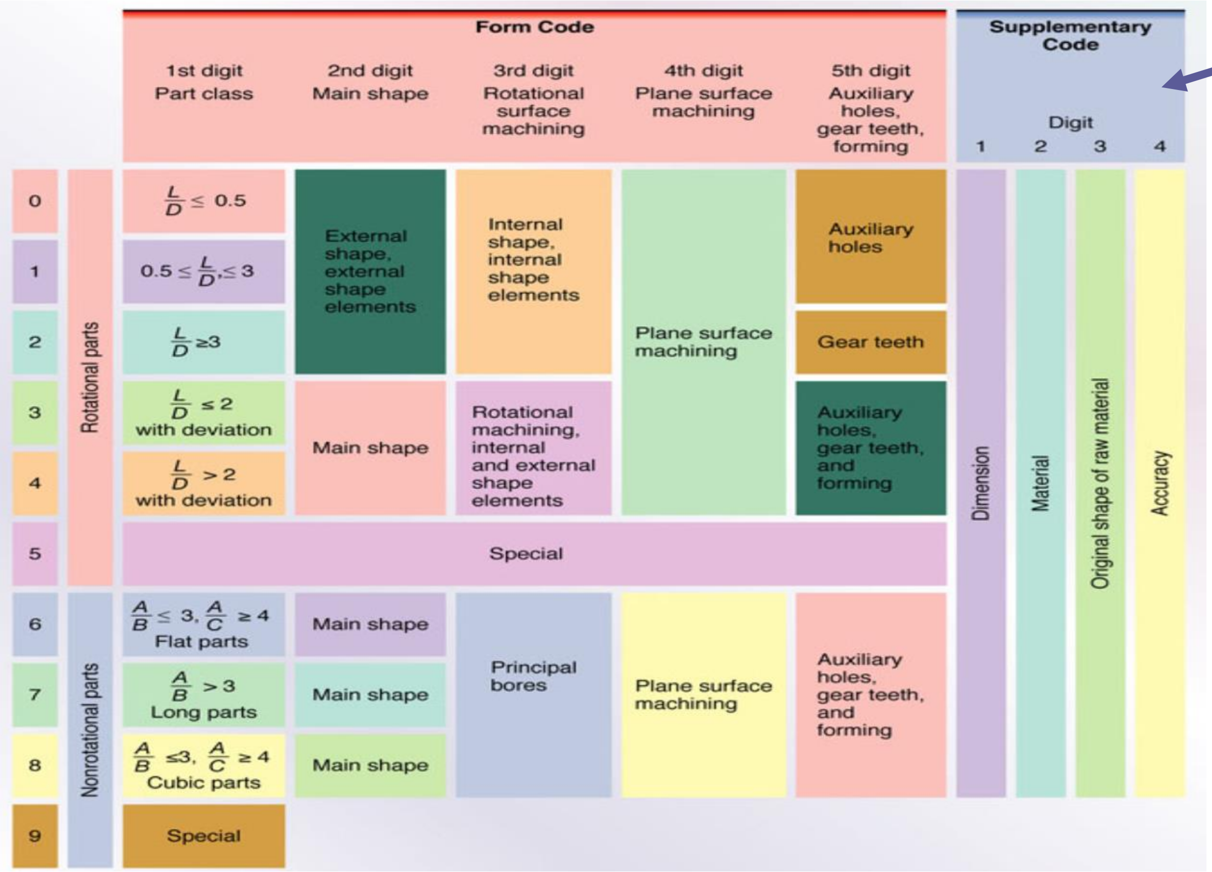
Based on the classification of products

- Part coding analysis (example 1)



Based on the classification of products

- Part coding analysis (example 2)



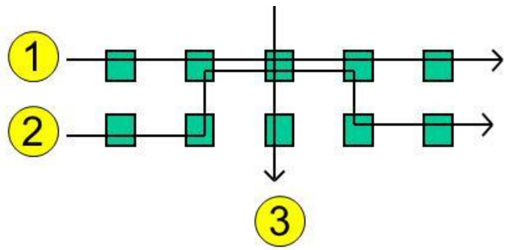
Coding system

Part

Part code

Group technology – Methods

- Identification of product families / machine groups forming the cells simultaneously based on PFA (Production Flow Analysis)
  - Cluster analysis
    - ROC (Rank Order Clustering)
    - Similarity coefficients
  - Graph partitioning
  - Mathematical programming
  - …



Based on PFA – Rank Order Clustering

- Step 1: read each row as a binary number
- Step 2: order rows according to descending binary numbers
- Step 3: read each column as a binary number
- Step 4: order columns according to descending binary numbers
- Step 5: if on steps 2 and 4 no reordering happened go to step 6, otherwise go to step 1
- Step 6: stop

Rank Order Clustering – Example (1/3)

Machine/part matrix

a_{ij} = 1 if part j visits machine i
a_{ij} = 0 otherwise

MACHINE TYPE	PRODUCTS 1	2	3	4	5	6	7	8	Decimal number
A	1	1	0	0	1	0	0	0	200
B	0	0	0	1	0	0	0	1	17
C	0	1	1	0	0	1	1	0	102
D	0	0	0	1	0	0	0	1	17
E	0	0	1	1	0	1	1	0	54
F	1	1	0	0	1	0	0	0	200

(binary number) $1 \times 2^7 + 1 \times 2^6 + 0 \times 2^5 + 0 \times 2^4 + 1 \times 2^3 + 0 \times 2^2 + 0 \times 2^1 + 0 \times 2^0 = 200$

Rank Order Clustering – Example (2/3)

MACHINE TYPE	PRODUCTS 1	2	3	4	5	6	7	8	Decimal number
A	1	1	0	0	1	0	0	0	200
F	1	1	0	0	1	0	0	0	200
C	0	1	1	0	0	1	1	0	102
E	0	0	1	1	0	1	1	0	54
B	0	0	0	1	0	0	0	1	17
D	0	0	0	1	0	0	0	1	17
Decimal n.	48	56	12	7	48	12	12	3	

(binary number) $1 \times 2^5 + 1 \times 2^4 + 1 \times 2^3 + 0 \times 2^2 + 0 \times 2^1 + 0 \times 2^0 = 56$

Rank Order Clustering – Example (3/3)

MACHINE TYPE	PRODUCTS 2	1	5	3	6	7	4	8	Decimal number
A	1	1	1	0	0	0	0	0	224
F	1	1	1	0	0	0	0	0	224
C	1	0	0	1	1	1	0	0	156
E	0	0	0	1	1	1	1	0	30
B	0	0	0	0	0	0	1	1	3
D	0	0	0	0	0	0	1	1	3
Decimal n.	56	48	48	12	12	12	7	3	

Exceptional parts

- inter-cell moves
- duplication of machines
- alternative routings
- buy operations from third parties

Cell formation

- 3 potential cells

Based on PFA – Similarity coefficients

- Step 1: compute the similarity coefficients

Where n_{ij}=number of parts worked by both the machines.

$$s_{ij} = \max\left(\frac{n_{ij}}{n_i} ; \frac{n_{ij}}{n_j}\right)$$

n_i = number of parts worked by machine i

n_j = number of parts worked by machine j

- Step 2: join the couple (i*, j*) with the highest similarity coefficient, thus forming the machine group k
- Step 3: remove rows and columns related to both i* and j* from the original similarity matrix and substitute them with the row and column of the machine group k; then, compute the similarity coefficient

$$s_{rk} = \max(s_{ri^*}, s_{rj^*})$$

- Step 4: go to step 2 (based on a criterion: single machine group, or predetermined number of machine groups)

Similarity coefficients – Example (1/7)

Machine/part matrix ⇨

a_{ij} = 1 if part j visits machine i
a_{ij} = 0 otherwise

MACHINE TYPE	PRODUCTS 1	2	3	4	5	6	7	8	
A	1	1			1				i
B				1				1	
C		1	1			1	1		j
D				1				1	
E			1	1		1	1		
F	1	1			1				

$$s_{ij} = \max\left(\frac{n_{ij}}{n_i}; \frac{n_{ij}}{n_j}\right) = \max\left(\frac{1}{3}; \frac{1}{4}\right) = 0.33$$

Similarity coefficients – Example (2/7)

Similarity matrix → s_{ij} = similarity coefficients

MACHINE TYPE	MACHINE TYPE					
	A	B	C	D	E	F
A	-	0	0.33	0	0	1
B	0	-	0	1	0.5	0
C	0.33	0	-	0	0.75	0.33
D	0	1	0	-	0.5	0
E	0	0.5	0.75	0.5	-	0
F	1	0	0.33	0	0	-

Similarity coefficients – Example (3/7)

Machine/part matrix

$a_{ij} = 1$ if part j visits machine i
$a_{ij} = 0$ otherwise

MACHINE TYPE	PRODUCTS 1	2	3	4	5	6	7	8
A	1	1			1			i*
B				1				1
C		1	1			1	1	r
D				1				1
E			1	1		1	1	
F	1	1			1		j*	

$$s_{ri^*} = \max\left(\frac{1}{4};\frac{1}{3}\right) = 0.33$$

$$s_{rj^*} = \max\left(\frac{1}{4};\frac{1}{3}\right) = 0.33$$

$$s_{rk} = \max\left(s_{ri^*};s_{rj^*}\right) = 0.33$$

Similarity coefficients – Example (4/7)

CELL	CELL				
	A, F	B	C	D	E
A, F	-	0	0.33	0	0
B	0	-	0	1	0.5
C	0.33	0	-	0	0.75
D	0	1	0	-	0.5
E	0	0.5	0.75	0.5	-

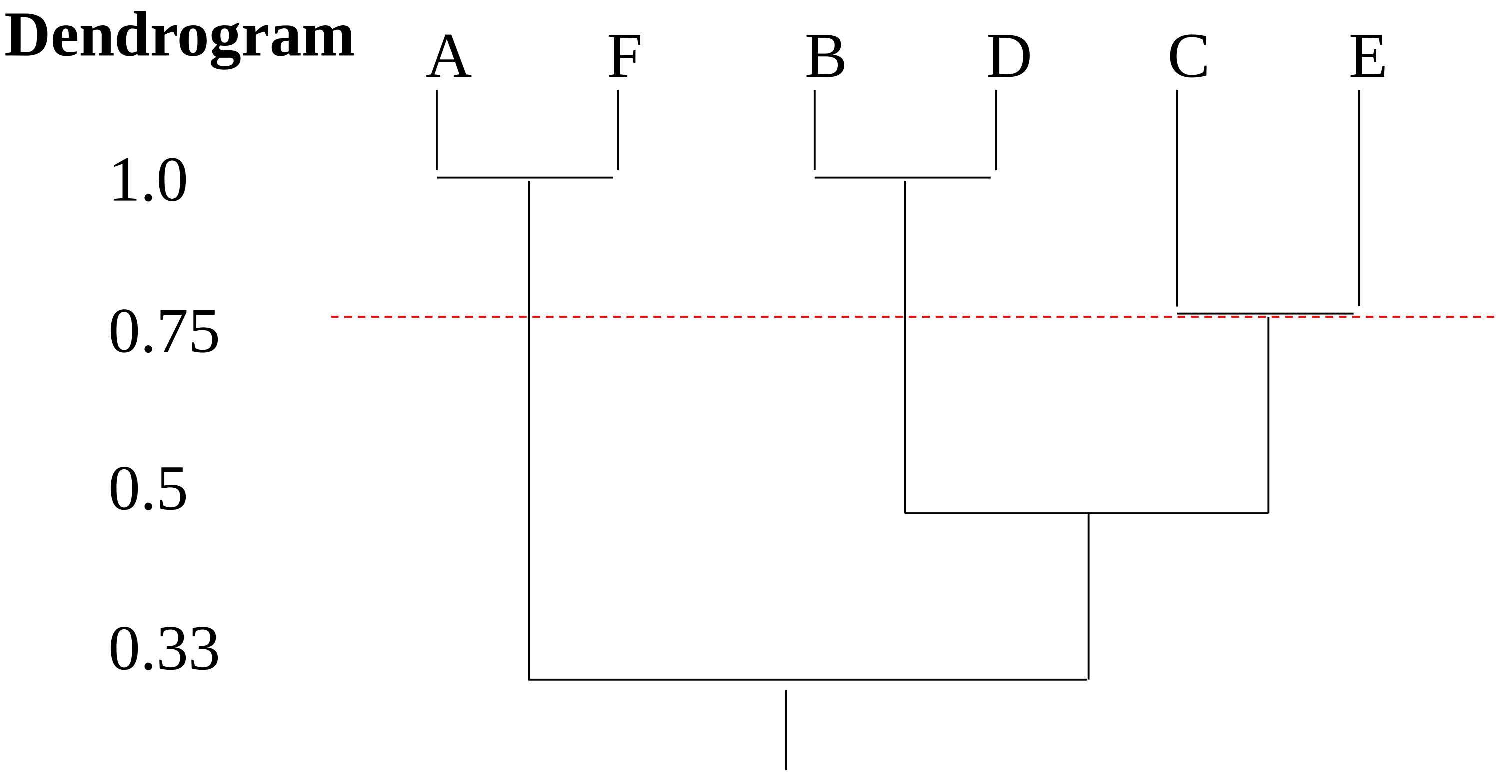
Similarity coefficients – Example (5/7)

CELL	CELL			
	A, F	B, D	C	E
A, F	-	0	0.33	0
B, D	0	-	0	0.5
C	0.33	0	-	0.75
E	0	0.5	0.75	-

Similarity coefficients – Example (6/7)

CELL	CELL		
	A, F	B, D	C, E
A, F	-	0	0.33
B, D	0	-	0.5
C, E	0.33	0.5	-

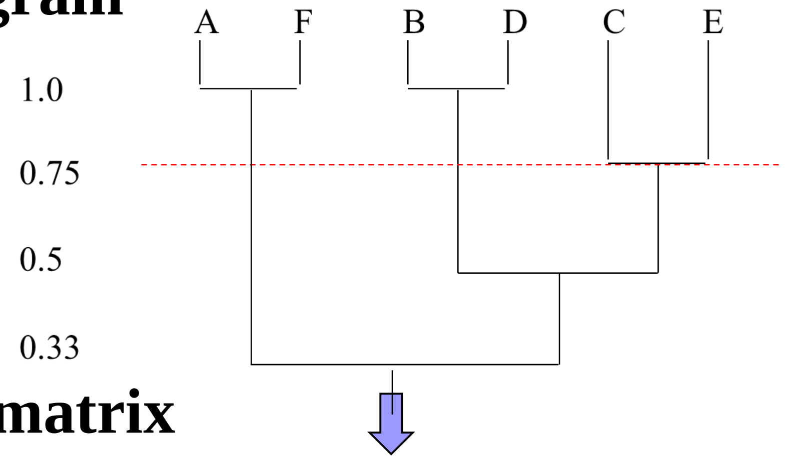
Similarity coefficients – Example (7/7)



The dendrogram is a tree used to show the hierarchy of similarities among all the couples of machines (machine groups).

Similarity coefficients – Example (7/7)

Dendrogram



Cells are formed after defining the minimum similarity coefficients amongst the couples of machines (machine groups)

Machine/part matrix

Machine Type	Product type 1	2	5	4	8	3	6	7
A	1	1	1					
F	1	1	1					
B				1	1			
D				1	1			
C		1				1	1	1
E				1		1	1	1

Cell formation

- ❑ 3 potential cells

Exceptional parts

- ❑ 2 exceptional parts