Outline

Case study 2 “Mechoff”

Design of manufacturing systems – Cellular Manufacturing

- Top management’s questions
- Solution: objective, procedure, alternatives
- Concluding remarks

MECHOFF – ***Top Management's questions***

- Is it possible to meet the demand with **manufacturing cells**?

If yes, some questions to be answered may be:

- How many **machines** do I need?
- How many **fixtures** do I need?

MECHOFF – **Draft solution**

Objective

To evaluate the alternative to switch from a job shop configuration to cellular manufacturing

Assumptions:

- Products from the same family share the same fixture, built to take advantage of similar shapes:

  → this brings to an expected saving in setup times;

  → set-up times in cells 25% of the job shop one.

- The lot size can be half of the job shop case, thanks to the shorter set up times, obtaining lower WIP.
- These assumptions do not hold for those operations that are performed outside the due cell (the so called “exceptions”).

MECHOFF – **Draft solution**

Procedure

The following steps can be followed to find the best solution:

1. Use the **ROC algorithm** to identify the machine groups that will compose the cells;

2. Evaluate the **number of machines** of each type to be used in the cells;

3. Evaluate the **number of fixtures** that are needed for each product family (on each machine type within the cell).

MECHOFF – **ROC algorithm by King**

Given:
j= product index; P = number of products;
i= machine index; M = number of machines;
a_{ij}= 1 if product j needs operation on machine i,
otherwise a_{ij} =0;

1. Per each row compute the rank number:

$$R_i = \sum_{j=1}^{P} (a_{ij} * 2^{P-j})$$

2. Reorder rows by decreasing values of Ri (top to bottom);
3. Per each column compute the rank number:

$$C_j = \sum_{i=1}^{M} (a_{ij} * 2^{M-i})$$

4. Reorder columns by decreasing values of Cj (left to right);
5. Repeat steps 1 to 4 until no reordering of columns or rows is needed.

MECHOFF – **Application of ROC (King)**

In PRACTICE: having the products on rows or on columns **is the same**

		i=1,..,M	1	2	3	4	5	
		2^(M-i)	16	8	4	2	1	
j=1,..,P	2^(P-j)		M1	M2	M3	M4	M5	Rj
1	131072	PZ1	1	1	0	0	0	24
2	65536	PZ2	1	0	1	1	0	22
3	32768	PZ3	1	1	0	1	0	26
4	16384	PZ4	1	0	1	1	0	22
5	8192	DI1	1	1	0	1	1	27
6	4096	DI2	1	1	0	1	1	27
7	2048	DI3	1	0	0	1	1	19
8	1024	DI4	0	1	0	1	1	11
9	512	DI5	1	0	0	1	0	18
10	256	RO1	0	0	1	0	1	5
11	128	RO2	0	0	1	0	1	5
12	64	RO3	0	0	1	0	1	5
13	32	RO4	0	0	1	0	1	5
14	16	RO5	0	0	1	0	1	5
15	8	SP1	1	1	0	0	1	25
16	4	SP2	1	1	0	0	1	25
17	2	SP3	1	1	0	0	1	25
18	1	SP4	1	1	0	0	1	25

Rank rows

MECHOFF – **Application of ROC (King)**

		M1	M2	M3	M4	M5	Rj reordered
131072	DI1	1	1	0	1	1	27
65536	DI2	1	1	0	1	1	27
32768	PZ3	1	1	0	1	0	26
16384	SP1	1	1	0	0	1	25
8192	SP2	1	1	0	0	1	25
4096	SP3	1	1	0	0	1	25
2048	SP4	1	1	0	0	1	25
1024	PZ1	1	1	0	0	0	24
512	PZ2	1	0	1	1	0	22
256	PZ4	1	0	1	1	0	22
128	DI3	1	0	0	1	1	19
64	DI5	1	0	0	1	0	18
32	DI4	0	1	0	1	1	11
16	RO1	0	0	1	0	1	5
8	RO2	0	0	1	0	1	5
4	RO3	0	0	1	0	1	5
2	RO4	0	0	1	0	1	5
1	RO5	0	0	1	0	1	5
	Cj	262080	261152	799	230368	227519	

- Reorder rows;
- Rank columns

MECHOFF – **Application of ROC (King)**

	M1	M2	M4	M5	M3	Rj
DI1	1	1	1	1	0	30
DI2	1	1	1	1	0	30
PZ3	1	1	1	0	0	28
SP1	1	1	0	1	0	26
SP2	1	1	0	1	0	26
SP3	1	1	0	1	0	26
SP4	1	1	0	1	0	26
PZ1	1	1	0	0	0	24
PZ2	1	0	1	0	1	21
PZ4	1	0	1	0	1	21
DI3	1	0	1	1	0	22
DI5	1	0	1	0	0	20
DI4	0	1	1	1	0	14
RO1	0	0	0	1	1	3
RO2	0	0	0	1	1	3
RO3	0	0	0	1	1	3
RO4	0	0	0	1	1	3
RO5	0	0	0	1	1	3
Cj reordered	262080	261152	230368	227519	799	

- Reorder columns;
- Re-rank rows

MECHOFF – **Application of ROC (King)**

	M1	M2	M4	M5	M3	Rj reordered
DI1	1	1	1	1	0	30
DI2	1	1	1	1	0	30
PZ3	1	1	1	0	0	28
SP1	1	1	0	1	0	26
SP2	1	1	0	1	0	26
SP3	1	1	0	1	0	26
SP4	1	1	0	1	0	26
PZ1	1	1	0	0	0	24
DI3	1	0	1	1	0	22
PZ2	1	0	1	0	1	21
PZ4	1	0	1	0	1	21
DI5	1	0	1	0	0	20
DI4	0	1	1	1	0	14
RO1	0	0	0	1	1	3
RO2	0	0	0	1	1	3
RO3	0	0	0	1	1	3
RO4	0	0	0	1	1	3
RO5	0	0	0	1	1	3
Cj	262080	261152	230368	227903	415	

- Reorder rows;
- Re-rank columns

↓

The order must not be changed:

→ this is the final matrix

MECHOFF – **Solution of ROC (King) 1**

Solution with no duplication of resources

Cell 1
Cell 2
Exceptions

	M1	M2	M4	M5	M3
DI1	1	1	1	1	0
DI2	1	1	1	1	0
PZ3	1	1	1	0	0
SP1	1	1	0	1	0
SP2	1	1	0	1	0
SP3	1	1	0	1	0
SP4	1	1	0	1	0
PZ1	1	1	0	0	0
DI3	1	0	1	1	0
PZ2	1	0	1	0	1
PZ4	1	0	1	0	1
DI5	1	0	1	0	0
DI4	0	1	1	1	0
RO1	0	0	0	1	1
RO2	0	0	0	1	1
RO3	0	0	0	1	1
RO4	0	0	0	1	1
RO5	0	0	0	1	1

MECHOFF – **Solution of ROC (King) 2**

Solution with duplication of resources

Cell 1
Cell 2
Exceptions

	M1	M2	M4	*M5 BIS*	M3	M5
DI1	1	1	1	1	0	0
DI2	1	1	1	1	0	0
PZ3	1	1	1	0	0	0
SP1	1	1	0	1	0	0
SP2	1	1	0	1	0	0
SP3	1	1	0	1	0	0
SP4	1	1	0	1	0	0
PZ1	1	1	0	0	0	0
DI3	1	0	1	1	0	0
PZ2	1	0	1	0	1	0
PZ4	1	0	1	0	1	0
DI5	1	0	1	0	0	0
DI4	0	1	1	1	0	0
RO1	0	0	0	0	1	1
RO2	0	0	0	0	1	1
RO3	0	0	0	0	1	1
RO4	0	0	0	0	1	1
RO5	0	0	0	0	1	1

MECHOFF – **Solution of ROC (King) 2**

Solution with duplication of resources

Cell 1
Cell 2
Exceptions

	M1	M2	M4	*M5 BIS*	M3	M5
DI1	1	1	1	1	0	0
DI2	1	1	1	1	0	0
PZ3	1	1	1	0	0	0
SP1	1	1	0	1	0	0
SP2	1	1	0	1	0	0
SP3	1	1	0	1	0	0
SP4	1	1	0	1	0	0
PZ1	1	1	0	0	0	0
DI3	1	0	1	1	0	0
PZ2	1	0	1	0	1	0
PZ4	1	0	1	0	1	0
DI5	1	0	1	0	0	0
DI4	0	1	1	1	0	0
RO1	0	0	0	0	1	1
RO2	0	0	0	0	1	1
RO3	0	0	0	0	1	1
RO4	0	0	0	0	1	1
RO5	0	0	0	0	1	1

We take this configuration

MECHOFF – **Division of products in cells**

Cell	Product	
1	DI1	
	DI2	
	PZ3	
	SP1	
	SP2	
	SP3	
	SP4	
	PZ1	
	DI3	
	PZ2	***
	PZ4	***
	DI5	
	DI4	
2	RO1	
	RO2	
	RO3	
	RO4	
	RO5	

*** exceptional products

Once defined the cell (Product Families and Machine types), dimensioning is carried out with exactly the same approach of job-shop dimensioning, but:

- Setup time is lower in the same cell for each product family (even = 0), due to common machinery fixture : ¼ of the job shop setup time
- Smaller lots: ½ of the job shop lots → lower Lead Time and WIP

MECHOFF – **Cell dimensioning**

As in the job shop case, the formula for the required capacity is the following:

$$NH_i = \sum_{j=1}^{N} \left(\frac{T_{ij} \cdot Q_j}{3600 \cdot \left(1 - SR_{ij}\right)} + \frac{STT_{ij}}{60} \cdot NL_j \right) \cdot \frac{1}{A_i} \cdot \frac{1}{HC_i} \cdot \frac{1}{TR_i}$$

Where:

- i = index of the machine-type
- j = index of the product-type
- N= number of different product-types
- Tij = unit working time [seconds/piece]
- Qj = quantity of product-type j that has to be produced [pieces/year]
- SRij = scrap rate $(0 \leq SRij < 1)$
- STTij = setup time [minutes/setup]
- NLj = number of lots of product-type j [lots/year]
- Ai = availability $(0 < Ai \leq 1)$
- HCi = human coefficient $(0 < HCi \leq 1)$
- TRi = trial rate $(0 < TRi \leq 1)$

MECHOFF – **Cell dimensioning**

As in the job shop case, the required capacity must be compared to the available capacity.
Each machine has the following available capacity:

$$\mathbf{AH_i(s) = WH_i(s) \cdot SE}$$

where:
$WH_i(s)$ =yearly working time available (depending on the number of shifts/day)
SE = scheduling efficiency ($0 < SE \leq 1$), in this case it is equal to 0.85

WH = (7.5 hours/shift * 2 shifts * 220 days/year) = 3300 hours/year
SE = 0.85
AH = WH * SE = **2805 hours/year**

MECHOFF – **Cell 1 dimensioning**

	M1	
	Annual required working hours	Annual required setup hours
DI1	518	40
DI2	705	30
PZ3	207	18
SP1	2591	18,75
SP2	3264	17,5
SP3	808	7,8
SP4	1244	20
PZ1	285	15
DI3	1943	22,5
PZ2	130	4,5
PZ4	207	4,5
DI5	104	7,5
DI4	0	0
	Total	13390

	M2	
	Annual required working hours	Annual required setup hours
DI1	518	30
DI2	1409	20
PZ3	259	27
SP1	1554	6,25
SP2	3627	17,5
SP3	539	9,75
SP4	1658	20
PZ1	648	15
DI3	0	0
PZ2	0	0
PZ4	0	0
DI5	0	0
DI4	5181	25
	Total	17066

	M4	
	Annual required working hours	Annual required setup hours
DI1	389	40
DI2	493	60
PZ3	337	22,5
SP1	0	0
SP2	0	0
SP3	0	0
SP4	0	0
PZ1	0	0
DI3	1101	30
PZ2	104	6
PZ4	181	6,75
DI5	104	22,5
DI4	1295	25
	Total	4623

	M5 bis	
	Annual required working hours	Annual required setup hours
DI1	1295	20
DI2	3523	10
PZ3	0	0
SP1	6218	25
SP2	5803	26,25
SP3	2425	6,5
SP4	3109	20
PZ1	0	0
DI3	4534	15
PZ2	0	0
PZ4	0	0
DI5	0	0
DI4	1036	6,25
	Total	30781

Number of machines = total required hours / available hours (rounded to the next integer)

M1 = 13390 / 2805 = 5

M2 = 17066 / 2805 = 7

M4 = 4623 / 2805 = 2

M5 bis = 30781 / 2805 = 11

MECHOFF – **Cell 2 dimensioning**

	M5	
	Annual required working hours	Annual required setup hours
RO1	4145	37,5
RO2	492	7,5
RO3	6601	25
RO4	544	15
RO5	6736	100
	Total	20508

	M3	
	Annual required working hours	Annual required setup hours
RO1	3316	15
RO2	155	5
RO3	6736	10
RO4	104	11
RO5	5181	50
PZ2	259	36
PZ4	648	49,5
	Total	18175

Number of machines = total required hours / available hours (rounded to the next integer)

M5 = 20508 / 2805 = 8

M3 = 18175 / 2805 = 7

MECHOFF – **Fixture dimensioning**

The ratio behind the fixture dimensioning is the same as the cell dimensioning:

Required hours vs available hours (on each machine type)

The formulas are as usual:

and $$NH_i = \sum_{j=1}^{N} \left(\frac{T_{ij} \cdot Q_j}{3600 \cdot \left(1 - SR_{ij}\right)} + \frac{STT_{ij}}{60} \cdot NL_j \right) \cdot \frac{1}{A_i} \cdot \frac{1}{HC_i} \cdot \frac{1}{TR_i}$$

$AH_i(s) = WH_i(s) \cdot A\_fixture$

where the parameters have the same meaning as in the machine case.
Please note that:

- A_i=1, availability (of the machine) is considered 1 because fixtures are used only when machines are available while they are removed from the machines when maintenance actions are performed leading to machine unavailability;
- A_fixture is here considered as a coefficient to represent that the fixture has to be maintained; hence its availability is set at 0,98.

Therefore:
AH= (7.5 hours/shift * 2 shifts * 220 days/year) * 0,98 = 3234 hours/year

MECHOFF – **Fixture dimensioning for DI product family**

	M1	
	Annual required working hours	Annual required setup hours
DI1	518	40
DI2	705	30
DI3	1943	22,5
DI5	104	7,5
DI4	0	0
	Total	3510

	M2	
	Annual required working hours	Annual required setup hours
DI1	518	30
DI2	1409	20
DI3	0	0
DI5	0	0
DI4	5181	25
	Total	7483

	M4	
	Annual required working hours	Annual required setup hours
DI1	389	40
DI2	493	60
DI3	1101	30
DI5	104	22,5
DI4	1295	25
	Total	3708

	M5 bis	
	Annual required working hours	Annual required setup hours
DI1	1295	20
DI2	3523	10
DI3	4534	15
DI5	0	0
DI4	1036	6,25
	Total	10875

Number of fixture = total required hours / available hours (rounded to the next integer)

Number of fixtures for DI product family:

M1= 3510 / 3234 = 2

M2= 7483 / 3234 = 3

M4 = 3708 / 3234 = 2

M5 bis = 10875 / 3234 = 4

MECHOFF – **Fixture dimensioning for PZ product family**

	M1	
	Annual required working hours	Annual required setup hours
PZ3	207	18
PZ1	285	15
PZ2	130	4,5
PZ4	207	4,5
	Total	907

	M2	
	Annual required working hours	Annual required setup hours
PZ3	259	27
PZ1	648	15
PZ2	0	0
PZ4	0	0
	Total	988

	M4	
	Annual required working hours	Annual required setup hours
PZ3	337	22,5
PZ1	0	0
PZ2	104	6
PZ4	181	6,75
	Total	684

	M5 bis	
	Annual required working hours	Annual required setup hours
PZ3	0	0
PZ1	0	0
PZ2	0	0
PZ4	0	0
	Total	0

Number of fixture = total required hours / available hours (rounded to the next integer)

Number of fixtures for PZ product family
M1 = 907 / 3234 = 1
M2 = 988 / 3234 = 1
M4 = 684 / 3234 = 1
M5 bis = 0

MECHOFF – **Fixture dimensioning for SP product family**

	M1	
	Annual required working hours	Annual required setup hours
SP1	2591	18,75
SP2	3264	17,5
SP3	808	7,8
SP4	1244	20
	Total	8303

	M2	
	Annual required working hours	Annual required setup hours
SP1	1554	6,25
SP2	3627	17,5
SP3	539	9,75
SP4	1658	20
	Total	7741

	M4	
	Annual required working hours	Annual required setup hours
SP1	0	0
SP2	0	0
SP3	0	0
SP4	0	0
	Total	0

	M5 bis	
	Annual required working hours	Annual required setup hours
SP1	6218	25
SP2	5803	26,25
SP3	2425	6,5
SP4	3109	20
	Total	18367

Number of fixture = total required hours / available hours (rounded to the next integer)

Number of fixtures for SP product family
M1 = 8303 / 3234 = 3
M2 = 7741 / 3234 = 3
M4 = 0
M5 bis = 18367 / 3234 = 6

MECHOFF – **Fixture dimensioning for RO product family**

	M5	
	Annual required working hours	Annual required setup hours
RO1	3316	15
RO2	155	5
RO3	6736	10
RO4	104	11
RO5	5181	50
	Total	16233

	M3	
	Annual required working hours	Annual required setup hours
RO1	4145	37,5
RO2	492	7,5
RO3	6601	25
RO4	544	15
RO5	6736	100
	Total	19482

Number of fixture = total required hours / available hours (rounded to the next integer)

Number of fixtures for RO product family
M5 = 16233 / 3234 = 6
M3 = 19482 / 3234 = 7

MECHOFF – **Economic Assessment – Concluding Remarks**

Investment cost	Needed Machines	Existing Machines	No. Of new machines	Machine cost (euros)	Machine lifetime indicator	Yearly cost
M1	5	2	3	150000	0,05	22,500
M2	7	5	2	300000	0,05	30,000
M3	7	8	-1	200000	0,05	-
M4	2	2	0	250000	0,05	-
M5	19	12	7	250000	0,05	87,500
					Total Investment cost	**140,500** Euro/year

Operator cost	no. Of machines	no.of operators per shift
Cell 1	25	13
Cell 2	15	8
	Total	21
	Current	15
	no. Of operators more per shift	6
	Labor cost	**277,200** Euro/year

Total cost =
140000 + 277200 =
417,200 Euro/year

Remarks:

1) This cost does not include the fixture costs;
2) The economic assessment on machines and labour allows to verify the cost of a **STRATEGIC DECISION** aimed at gaining benefits in quality and delivery performance.