

Developing a Heuristic Model To Solve Cell Formation Problem In Cellular Manufacturing

¹Gagan Pansare , ²Dr. Archana Nema

¹Research Scholar, Mechanical Department, Bansal institute of Science &Technology, Bhopal, India

²Professor, Mechanical Department, Bansal institute of Science &Technology, Bhopal, India

Abstract - In this work a new Heuristic Model has been developed to solve Cell Formation Problem in Cellular manufacturing. A mathematical model has been developed to count actual intercellular movements. Operation Sequence & Production Volume taken as a criterion for forming the cell. A performance measure is used after some modification on existing method of Nair & Narendran model (1998).The work is going to generate an algorithm for optimal number of Cells calculation. The number of machines & number of parts are taken as criteria for the calculation of number of Cells to be form for given production plan. Between an upper and lower limit on number of Cells Form is use to restrict the unwanted cell configuration and increase the efficiency of Model. The Best Cell configuration select on the bases of minimum Intercellular Movement which also turn cut the Material Handling cost. So for all size (small medium & large) problems, proposed Model can be use to get the real number of inter-cell movement and number of cells calculation on the bases of given Production plan

Index Terms- Cellular manufacturing system, cell formation, Grouping efficiency, Group technology, inter-cellular movement, Part machine Incidence Matrix, production Volume. (*Keywords*)- CMS, CF, GE, GT, ICM, PMIM, PV

I. INTRODUCTION

Cellular Manufacturing is an application of Group Technology has been recognized as one of the most recent technological innovation in batch type production. Cellular Manufacturing is a tool to gain economic advantage of similar product .CM is an approach that helps to build variety of product with minimum wastage of resources. The primary difference between Cellular Manufacturing and other manufacturing methods is that Cellular Manufacturing is focused on one piece flow design instead of on making multiple parts and sending them to the next machine/process, as in batch production. The determined is to minimize waste and maximize value added productivity. Cellular Manufacturing is based on the concept of process balancing, which results in continuous product flow, reduced inventory, increased production, reduced wait time between operations, and minimized part movement. One of the most important problem faced in practice of Cellular Manufacturing is grouping of parts and machines into families called Cell Formation.

Cell Formation ideas were first systematically presented by Burbidge (1963)[5] following the pioneering work of Mitrofanov (1959)[13]. The literature on Cell Formation can be broadly classified in two ways – one based on techniques used for Cell Formation and other one the way the Cell Formation problem is modeled. Crama and Oosten (1996)[6] made a study on various models for Cell Formation problems

II. LITRATURE REVIEW

Cell Formation using Heuristics-"Heuristics stand for strategies using readily accessible though loosely applicable information to control problem-solving processes in human beings and machines."(Pearl 1984)[17]Heuristics, in more popular understanding, are rules of thumb, educated guesses, intuitive judgments or simply common sense ideas to solve a particular problem. A heuristic improves the efficiency of a search process, possibly by sacrificing claims of completeness (Rich and Knight 1991)[19].Heuristic algorithms are used to provide quick approximate solutions to hard combinatorial optimization problems. A heuristic algorithm is called an approximate algorithm where the performance of the heuristic is assessed in terms of worst and average case behavior. They do not guarantee optimal solutions. Similarly, close neighbor algorithm by Boe and Cheng (1991)[3]. GRAFICS by Srinivasan and Narendran (1991)[22], CASE by Nair & Narendran (1998)[14], ACCORD by Nair & Narendran (1999)[15] are some well-known heuristics for solving CF problem found in the literature.

Cell Formation using Mathematical Programming Techniques -A number of research studies for cell formation using mathematical programming approach appeared in literature. They are classified under integer programming (Kusiak 1987[11], Co and Araar 1988[7]), dynamic programming (Ballakur and Steudel 1987) [1], goal programming (Shafer and Rogers, 1993a)[21], and linear programming (Boctor 1991)[4].

Operation Sequence based approaches- Most CF methods use binary machine part/matrix and do not have operation sequence information. The approaches reviewed under this section further have operation sequence as part of the input data. Sofianopoulou (1997)[23] presented a CF method formulated as a linear integer program. It tries to minimize the inter-cellular flow between cells. This method does not pre-specify the number of cells to be formed.

Cell Formation with Production Factors Researchers started considering production factors while processing Cell Formation.Vannelli and Ravikumar (1986)[25] proposed a method to find minimum number of bottleneck cells for grouping part-machine families. Vakhaira and Wemmerlov (1990)[24] considered a cell formation which integrates the issue of cell formation

and within cell material flows using similarity co-efficient approach to cluster parts and machines. But, this approach failed to take into account the issues of number of cells and duplication. Won & Lee (2001)[27] also considered the production volume factor in his formulation but the model was failed due to erroneous intercellular count.

III. PROBLEM IDENTIFICATION

Most of previous researches that addressed Cell Formation technique were focused on methodologies where grouping of machines/resources were done based on similarity, and operation sequence. Also in the previous researches none have addressed the number of cells to be formed for given a set of information like number of machines, number of parts, operation sequence and production volume. Nair & Narendran (1998)[14] used most of the above factors for the formation of cells. But the solution he obtained lacked optimality for formation of cells. New method of Cell Formation eliminate these all problem & provides an optimal solution with efficient grouping and count actual number of intercellular movement along with a performance measure for the cells being formed. The new method also includes an algorithm for number of cells calculation.

NOTATIONS USED IN MODEL

n	number of parts
m	number of machines
p_{min}	minimum number of cells
p_{max}	maximum number of cells
r	index of part type, $r = 1, \dots, n$
i, j	index of machine type, $1, \dots, m$
k	index of cells (families), $k = 1, \dots, p$
L_f	lower limit of part family size assign to 1 cell
U_f	upper limit of part family size assign to 1 cell
L_c	lower limit of machines inside 1 cell
U_c	upper limit of machines inside 1 cell
n_r	Total number of operation required by part 'r'
d_r	Production volume of part 'r'
$TOTOP_k$	Total number of operations in the kth cell
NOP_k	Total number of non-operations(voids) in the kth cell

IV. ALGORITHM

Step 1: Start the Process

Step 2: Input the number of machines, m

Step 3: Input the number of parts, n

Step 4: If number of machines, $m \leq 24$, and then $L_{cmin} = 2$, $L_{cmax} = \frac{\text{no.of machines}}{L_{cmin}}$

Go to Step 6 Else Go to Step 5

(Here the algorithm makes sure that the maximum Number of machines that can be allotted is 12)

Step 5: Calculate $L_{cmin} = \left(\frac{\text{no.of machines}}{12}\right)$, $L_{cmax} = \frac{\text{no.of machines}}{L_{cmin}}$

Step 6: If number of parts, $n \leq 24$ and then $L_{fmin} = 2$, $L_{fmax} = \frac{\text{no.of parts}}{L_{fmin}}$

Go to Step 8 Else Go to Step 7

(Here the algorithm makes sure that the maximum Number of parts that can be allotted is 12)

Step 7: Calculate $L_{fmin} = \left(\frac{\text{no.of parts}}{12}\right)$, $L_{fmax} = \frac{\text{no.of parts}}{L_{fmin}}$

Step 8: Set Minimum no. of cells, $P_{min} = \text{Max}(L_{cmin}, L_{fmin})$

Step 9: Set Maximum no. of cells, $P_{max} = \text{Min}(L_{cmax}, L_{fmax})$

Step 10: Set $L_f = L_{fmin}$ and $U_f = 12$

Step 11: Set $L_c = L_c \text{ min}$ and $U_c = 12$

Step 12: Group the machines using New CF Method

Step 13: Calculate Inter-cellular flow count and Bond Efficiency

Step 14: Display the result

Step 15: If $P_{min} = P_{max}$, Go to Step 18 Else Go to Step 16

Step 16: Set $P_{min} = P_{min} + 1$

Step 17: Go to step 9

Step 18: Stop the process

V. MATHEMATICAL MODEL

To begin with, PMIM representing the operation sequences and production volumes for grouping of machines into cells and components into part families are given. The inter-cell flows or the sum of the exceptional elements are minimized using a mathematical model. The formulation of the model is shown below

$$ICM = \text{Min} \sum_{k=1}^{p_{min}} \sum_{r=1}^n \sum_{i=1}^m \sum_{j \neq i}^m (d_r * b_{ijr} * X_{ijrk}) \quad \text{Eq. 3.1}$$

Where,

$$b_{ijr} = \begin{cases} 1 & \text{if volume of material flows from machine 'i' to machine 'j' of part 'r'} \\ 0 & \text{otherwise} \end{cases}$$

$$x_{irk} = \begin{cases} 1 & \text{if machine 'i' of part 'r' belongs to cell k} \\ 0 & \text{otherwise} \end{cases}$$

$$x_{jrk} = \begin{cases} 1 & \text{if machine 'j' of part 'r' belongs to cell k} \\ 0 & \text{otherwise} \end{cases}$$

$$X_{ijrk} = |x_{irk} - x_{jrk}| \quad \text{Eq. 3.2}$$

$$\sum_{k=1}^p x_{rk} = 1, \quad r = 1 \dots \dots \dots n. \quad \text{Eq. 3.3}$$

$$x_{rk} = \begin{cases} 1 & \text{if part 'r' belongs to cell k} \\ 0 & \text{otherwise} \end{cases}$$

$$L_f \leq \sum_{r=1}^n x_{rk} \leq U_f, \quad k = 1 \dots \dots \dots p. \quad \text{Eq. 3.4}$$

$$\sum_{k=1}^p y_{ik} = 1, \quad i = 1 \dots \dots \dots m. \quad \text{Eq. 3.5}$$

$$y_{ik} = \begin{cases} 1 & \text{if machine 'j' belongs to cell k} \\ 0 & \text{otherwise} \end{cases}$$

$$L_c \leq \sum_{i=1}^m y_{ik} \leq U_c, \quad k = 1 \dots \dots \dots p. \quad \text{Eq. 3.6}$$

Eq.3.1 minimizes the intercellular movement for any part machine configuration. Eq.3.2 checks whether there exists any intercellular movement between machines for each product. Constraint sets Eq.3.3 and Eq.3.5 are to ensure that a part and a machine can be assigned to only one cell. Constraint sets Eq.3.4 and Eq.3.6 are to restrict the number of parts and machines that can be allotted to a cell.

The proposed model uses reduced inter-cellular movement as the criterion for grouping resources; single cell configuration could be the optimal configuration for any case. But in pragmatic terms, it cannot be a feasible solution. Hence, the

algorithm is run for different part/machine configurations with 2 cluster configuration being the least configuration. The proposed model is used to calculate both the minimum and maximum number of cells to be formed, based on the number of machines and parts given as input. The algorithm as is follows.

VI. PERFORMANCE MEASURES

Compactness-Compactness of each cell is defined as the ratio of the number of operations within it to the maximum number of operations possible in it.

$$\text{Compactness} = \frac{\sum_{k=1}^{P_{\min}} \text{TOTOP}_k}{\sum_{k=1}^{P_{\min}} (\text{TOTOP}_k + \text{NOP}_k)}$$

CF Efficiency-Cell Formation efficiency is defined as the ratio of the difference between the maximum number of inter-cell travels possible and the number of inter-cell travels actually required by the system to the maximum number of inter-cell travels possible.

$$\text{CF efficiency} = \frac{X-Y}{X}$$

Where,

X=The maximum number of inter-cell travels possible

Y=The number of inter-cell travels actually required by the system.

There exists a trade-off between intercellular movement and compactness of cells formed. With an increase in the number of cells, there is a chance of getting high compactness but the number of intercellular movement also increases. So both values are selected in such a way that an optimal solution is obtained without suppressing both of them.

$$\text{Bond Efficiency} - (\beta) = (\text{CF efficiency} + \text{Compactness}) / 2$$

The new method of Bond efficiency which minimizes intercellular flow and maximizes the density of 1's is used for determining the cell configuration. Bond Efficiency (β), equation 3.7 is defined as a weighted average of Compactness& CF efficiency.

$$\text{BOND EFFICIENCY} = \left\{ \frac{X-Y}{X} + \frac{\sum_{k=1}^P \text{TOTOP}_k}{\sum_{k=1}^P (\text{TOTOP}_k + \text{NOP}_k)} \right\} / 2 \quad \text{EQ. 3.7}$$

$$\text{CF efficiency} = \frac{X-Y}{X} \quad \text{Eq.3.8}$$

Where,

$$X = \sum_{r=1}^n d_r (n_r - 1)$$

$$Y = \sum_{r=1}^n \sum_{1}^{n_r-1} X_{ijr} d_r$$

$$\text{Compactness} = \frac{\sum_{k=1}^P \text{TOTOP}_k}{\sum_{k=1}^P (\text{TOTOP}_k + \text{NOP}_k)} \quad \text{Eq.3.9}$$

For a perfect diagonal block, Compactness takes the value of '1; and NOP_k takes the value '0'.

VII. METHODOLOGY

Analysis (7 Machines & 4 Parts)

	MACHINE							
P	1	2	3	4	5	6	7	PV

PART	A	1	2	3	4				800
	B		3	2	1		4		200
	C			2	1		3	4	250
	D				1	2	3	4	1000

Table3.6 Part Machine Matrix with sequence and production volume

The step-by-step procedure for the above case study is detailed below, from the algorithm (3.2.4.)

Number of machines, $m = 7$

Number of parts, $n = 4$

Since number of machines, $m \leq 24$, then

$$L_{c \min} = 2$$

$$L_{c \max} = \frac{\text{no.of machines}}{L_{c \min}}$$

$$= (7/2) = 3.5 = 3 \text{ (rounding off to lower integer value)}$$

i.e. $L_{c \max} = 3$

Since number of parts, $n \leq 24$, $L_{f \min} = 2$,

$$L_{f \max} = \frac{\text{no.of parts}}{L_{f \min}}$$

$$= (4/2)$$

i.e. $L_{f \max} = 2$

Minimum cells required,

$$p_{\min} = \text{Max} (L_{c \min}, L_{f \min})$$

$$= \text{Max} (2, 2)$$

$$p_{\min} = 2$$

Maximum cells required,

$$p_{\max} = \text{Min} (L_{c \max}, L_{f \max})$$

$$= \text{Min} (3, 2)$$

$$p_{\max} = 2 \text{ (maximum no. of cell required)}$$

Setting $L_f = L_{f \min}$ & $U_f = 12$, but in this case $U_f = 4$,

But the sequence information is captured using the below formula,

$$b_{jir} = \begin{cases} 1 & \text{if volume of material flows from machine 'i' to machine 'j' of part 'r'} \\ 0 & \text{otherwise} \end{cases}$$

d_r = production volume of part 'r'

		Machine From -To										
P		1 to 2	2 to 3	3 to 4	4 to 3	3 to 2	2 to 6	3 to 6	6 to 7	4 to 5	5 to 6	6 to 7

A	A	800	800	800								
R	B				200	200	200					
T	C				250			250	250			
S	D									1000	1000	1000

The volume of material flowing between different machines for parts A, B, C and D are shown in Table 3.7.

Table 3.7 From –To chart for all Parts

Calculation of Inter-cellular Moves based on New Model

Table 3.7 is taken as input for the formation of cells, by minimizing the intercellular movement as the criterion for Cell Formation, using Eq.3.1. After inputting the values, Eq.3.1 becomes,

$$\text{Min} \sum_{k=1}^2 \sum_{r=1}^4 \sum_{i=1}^7 \sum_{j \neq i}^7 (d_r * b_{ijr} * x_{ijrk}) / 2$$

The cell configuration obtained after using the above formula for Cell Formation is detailed in Table 3.8.

		MACHINE						
		1	2	3	4	5	6	7
PART	A	800	800	800	800			
	B		200	200	200		200	
	C			250	250		250	250
	D				1000	1000	1000	1000

Table 3.8.Part- Machine Matrix

The intercellular movement is calculated by,

$$(d_{1b_{121}}X_{1211} + d_{1b_{121}}X_{1212} + d_{1b_{231}}X_{2311} + d_{1b_{231}}X_{2312} + d_{1b_{341}}X_{3411} + d_{1b_{341}}X_{3412} + d_{2b_{432}}X_{4321} + d_{2b_{432}}X_{4322} + d_{2b_{322}}X_{3221} + d_{2b_{322}}X_{3222} + d_{2b_{262}}X_{2621} + d_{2b_{262}}X_{2622} + d_{3b_{433}}X_{4331} + d_{3b_{433}}X_{4332} + d_{3b_{363}}X_{3631} + d_{3b_{363}}X_{3632} + d_{3b_{673}}X_{6731} + d_{3b_{673}}X_{6732} + d_{4b_{454}}X_{4541} + d_{4b_{454}}X_{4542} + d_{4b_{564}}X_{5641} + d_{4b_{564}}X_{5642} + d_{4b_{674}}X_{6741} + d_{4b_{674}}X_{6742}) / 2$$

$$= ((800*1*0) + (800*1*0) + (800*1*0) + (800*1*0) + (800*1*1) + (800*1*1) + (200*1*1) + (200*1*1) + (200*1*0) + (200*1*0) + (200*1*1) + (200*1*1) + (250*1*0) + (250*1*0) + (250*1*0) + (250*1*0) + (250*1*0) + (250*1*0) + (250*1*0) + (1000*1*0) + (1000*1*0) + (1000*1*0) + (1000*1*0) + (1000*1*0)) / 2,$$

Total inter-cellular count= 1200

PERFORMANCE MEASURES-

In order to evaluate the performance of the cells formed measures like Compactness and Bond efficiency are used from the proposed algorithm

$$CF \text{ efficiency} = \frac{X-Y}{X}$$

Where,

$$\begin{aligned} X &= \sum_{r=1}^n d_r (n_r - 1) \\ &= \sum_{r=1}^4 d_r (n_r - 1) \\ &= ((800*3) + (200*3) + (250*3) + (1000*3)) \end{aligned}$$

$$X = 6750$$

And

$$\begin{aligned} Y &= \sum_{r=1}^n \sum_1^{n_r-1} X_{ijr} d_r \\ &= \sum_{r=1}^4 \sum_1^{4-1} X_{ijr} d_r \\ &= (1*800) + (2*200) \end{aligned}$$

$$Y=1200$$

$$CF \text{ efficiency} = \frac{6750-1200}{6750} = 0.8223$$

$$\begin{aligned} Compactness &= \frac{\sum_{k=1}^{P_{min}} TOTOP_k}{\sum_{k=1}^{P_{min}} (TOTOP_k + NOP_k)} \\ &= \frac{(3+8)}{(3+8)+(1+2)} = 0.7857 \end{aligned}$$

Bond Efficiency (β)

$$(\beta) = (CF \text{ efficiency} + Compactness) / 2$$

$$= \left\{ \frac{X-Y}{X} + \frac{\sum_{k=1}^P TOTOP_k}{\sum_{k=1}^P (TOTOP_k + NOP_k)} \right\} / 2$$

$$= (0.8222+0.7857)/2$$

$$\beta = 0.8040$$

Since the maximum number of cells (p_{max}) possible for the above case is only 2, the algorithm is stopped at this point. Otherwise the algorithm is run until the maximum value of cell configuration is reached and the results are calculated in the same manner for all cell configurations

VII. Conclusion

In this work, a systematic Heuristic Model has been developed For Cell Formation in Cellular Manufacturing for all (small-medium and large) size problems. A mathematical model has been developed to count actual intercellular movement. The developed model includes details like Production volume and Operation sequence for Cell Formation. The performance measure is used to test the cells efficiency which being formed after few modifications in the existing method from Nair & Narendran (1998). In order to check the entire methodology three different problems small, medium and large size were used. An algorithm is generated to calculate the optimal number of cells on the bases of given input like number of machine and number of parts. Upper and lower limit of number of cells used to eliminate unwanted configuration of cells. The methodology is run for different part/machine configurations with 2 cell configuration being the least configuration for when of small problem (machines or parts limited to 24). In case of medium & large size problem (more than 24 machines and parts) the least cell configuration is calculated using a small algorithm and the configuration is set based on the obtained value. The model is also used to calculate the most allowable cell configuration for any given production plan. Limitations are also placed on the number of machines and parts that can be assigned to a cell.

References

- [1] Ballakur, A. and Steudel, H.J., 1987. A with-in cell utilization based heuristic for designing cellular manufacturing systems. *International Journal of Production Research*, **25** (5), 639-655.
- [2] Beaulieu, A. Gharbi, A. And Ait-Kadi., 1997. An algorithm for the cell formation and the machine selection problems in the design of a cellular manufacturing system. *International Journal of Production Research*, **35** (7), pp.1857-1874.
- [3] Boe, W.J. and Cheng, C.H., 1991. A close neighbour algorithm for designing cellular manufacturing systems. *International Journal of Production Research*, **29**(10), 2097-2116.
- [4] Boctor, F.F., 1991. A linear formulation of the machine-part cell formation problem. *International Journal of Production Research*, **29** (2), pp.343-356.
- [5] Burbidge, J.L. (1963) Production flow analysis. *Production Engineer*, 42, 742.
- [6] Crama, Y. and Oosten, M., 1996. Models for machine part grouping in cellular manufacturing. *International Journal of Production Research*, **34**(6), pp.1693-1713.
- [7] Co, H.C. & Araar, A., 1988, "Configuring cellular manufacturing system" *International Journal of Production Research*, **26**(9), 1511-1522.
- [8] Dimopoulos, C and Mort, N. 2001. A hierarchical clustering methodology based on genetic programming for the solution of simple cell-formation problems. *International Journal of Production Research*, **39**(1), 1-19.
- [9] Gupta, T., 1991. Clustering algorithms for the design of a cellular manufacturing system – an analysis of their performance. *Computers and Industrial Engineering*, **20** (4), pp.461-468.
- [10] Kandiller, L., 1994, A Comparative study of cell formation in cellular manufacturing system. *International Journal of Production Research*, **32**, pp.2395-2429
- [11] Kusiak, A., 1987. The generalized group technology concept. *International Journal of Production Research*, **25**(4), pp.561-569.

- [12] Miltenburg, J. and Zhang, W., 1991. A comparative evaluation of nine well known algorithms for solving the cell formation problem in group technology. *Journal of Operations Management*, **10** (1), pp.44 -72.
- [13] Mitrofanov, S.P., 1959. *Russian Text*; also 1966 *Scientific Principles of Group Technology*. Part I, Boston: National Lending Library of Science and Technology.
- [14] Nair, G.J. and Narendran, T.T., 1998. CASE: A clustering algorithm for cell formation with sequence data. *International Journal of Production Research*, **36**(1), pp157-179.
- [15] Nair G.J and Narendran T.T., 1999. ACCORD: a bicriterion algorithm for cell formation using ordinal and ratio level data. *International Journal of Production Research*, **37**(3), pp.539–556
- [16] Panneerselvam, R. and Balasubramanian, K.N., 1985. Algorithm grouping of operations sequences. *Engineering costs and production economics*, **9**, pp.125-135
- [17] Pearl, J. (1984) *Heuristics: intelligent search strategies for computer problem solving*, Addison-Wesley, Reading, MA
- [18] Ramabhatta, V. and Nagi, R., 1998. An Integrated formulation of manufacturing cell formation with capacity planning and multiple routings. *Annals of Operations Research*, **77**, pp.79-95.
- [19] Rich, E. and Knight, K. (1991) *Artificial Intelligence*, McGraw-Hill, New York.
- [20] Sarker, Kun Li, (1997). Simultaneous route selection and cell formation: a mixed integer programming time-cost model. *Integrated Manufacturing Systems*, Volume: 8 Issue: 6 Page: 374 – 377.
- [21] Shafer, S.M. and Rogers, D.F., 1993a, Similarity and distance measures for cellular manufacturing, *International Journal of Production Research*, **31** (5), 1131-1142.
- [22] Srinivasan, G. & Narendran, T.T. (1991) GRAPHICS - Loss of Pooling Synergy in Cellular Manufacturing Systems. *Management Science*, 40(4), 466-483.
- [23] Sofianopoulou, S., 1999. Manufacturing cells design with alternative process plans and / or replicate machines. *International Journal of Production Research*, **37**(3), pp.707-720.
- [24] Vakharia, A.J. and Wemmerlov, U., 1990. Designing a Cellular manufacturing system a material flow approach based on the operation sequences. *IIE Transactions*, **22** (1), pp.84-97.
- [25] Vannelli and Kumar, K.R., 1986. A method for finding minimal bottle-neck cells for grouping part machine families. *International Journal of Production Research*, **24** (2), pp.387-400.
- [26] Waghodekar, P.H. and Sahu, S., 1984. Machine-component cell formation in group technology. *MACE International Journal of Production Research*, **22** (6), pp.937-948.
- [27] Wemmerlov and Hyer. 1987. Research issues in cellular manufacturing, *International Journal of Production Research*, **25**, 413–431
- [28] Won, Y. and Lee, K.C., 2001. Group technology cell formation considering operation sequence and production volumes. *International Journal of Production Research*, **39**(13), pp.2755-2768.