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TWO PHASE HEURISTIC BASED APPROACH OF CELL FORMATION IN CELLULAR MANUFACTURING SYSTEM

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ABSTRACT

This research paper presents, implements and tests a two-stage heuristic based procedure for effective part family and machine cell formation in Cellular Manufacturing System. The solution approach includes the operation sequence, minimization of intercell flow, and machines' utilizations. In the first phase; the problem is solved as a bottomup aggregation procedure for machine grouping. Aggregation is based on the minimization of intercell movement of parts. Later the parts are optimally assigned to the cells. Upper bound on the cell size is imposed in the first stage, which is relaxed later in second phase. It ensures the natural cell formation. The solution obtained at the end of first stage is refined in the second phase. Numerical examples are tested and comparisons are made with other results given by different researchers. The results of computational tests presented are very encouraging.

Keywords: cellular manufacturing systems, part grouping, inter-cell movement, operation sequence

Introduction

Group Technology (GT) is an approach to manufacturing and engineering management that helps manage diversity by capitalizing on underlying similarities in products and activities. Within the manufacturing context, GT can be defined as a manufacturing philosophy identifying similar parts and grouping them together into families to take advantage of their similarities in manufacturing and design. One application of the GT philosophy in manufacturing is cellular manufacturing (CM). CM is concerned with the creation and operation of manufacturing cells which are dedicated to the production of a set of part families. In order to introduce CM, it is necessary to identify parts and machine types to be considered in the cellular configuration. The first problem faced in implementing CM is cell formation (CF). CF deals with the identification of the family of parts and the group of machines on which these parts are to be processed. The CF problem may be defined as: "If the number, types, and capacities of production machines, the number and types of parts to be manufactured, and the routing plans and machine standards for each part are known, which machines and their associated parts should be grouped together to form cells?" [Wu et al 1993]. In some cells the problem definition is expanded to allow choice of processing operations to achieve specific features. During the past three decades, a considerable amount of research has been directed at this problem.

Burbidge (1971) developed an intuitive method, namely Production Flow Analysis (PFA)

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which is relatively easy toimplement. PFA may be suitable for the small size problem, but it would definitely have difficulties coping with real life cell formation problems when the machine-part incidence matrix becomes more complex because of problem size.

A large number of approaches have been developed to deal with the intuitive method's difficulties. These approaches are usually classified into Part-oriented approaches (based on part characteristics) and Process-oriented approaches (based on production methods). The part-oriented techniques usually employ some classification and coding system, and analysis parts for their similarities in design features and functionalities. However, they do not influence directly the configuration of manufacturing cells (Choobineh, 1988). The process-oriented approach to the cell formation is based on manufacturing data such as production methods, part routing information and process plans. Yasuda and Yin (1990) divided the process-oriented approach into the following four groups:

1. Descriptive methods: PFA proposed by Burbidge (1971), Component Flow Analysis (CFA) by El-Essawy and Torrance (1972), and Production Flow Synthesis (PFS) by De Beer and De Witte (1978).
2. Array-based methods: Rank Order Clustering (ROC) algorithm developed by King (1980), ROC2 algorithm enhanced by King and Nakornchai (1982), and Direct Clustering Algorithm (DCA) proposed by Chan and Milner (1982).
3. Similarity coefficient methods: clustering approach introduced by McAuley (1972), subsequently employed by Mosier and Taube (1985b), Seifoddini and Wolfe (1987), and Gupta and Seifoddini (1990), and also graph theoretic approach introduced by Rajagopalan and Batra (1975), subsequently employed by De Witte (1980), Chandrasekharan and Rajagopalan (1986a), Yasuda and Yin (2001).
4. Other analytical methods: mathematical programming approach proposed by Purcheck (1975), Steudel and Ballakur (1987), Co and Araar (1988), and also set-theoretic technique developed by Purcheck (1974). Most of the suggested algorithms/models consider binary machine-part incidence matrix A, with

aij = 1 if part i requires machine j, otherwise 0.

The binary part-machine matrix is incapable of presenting the actual relationship between parts and machines. The sequence of operation has an impact on the flow of material in the system. An intermediate operation of a component performed outside its cell involves two inter-cell transfers while the first or last operation requires one such transfer. (Choobineh 1988 and Harhalakis et al. 1990). Therefore we used the operation sequence matrix instead of binary machine-part matrix.

Harhalaskis et al (1990) also considered the same scheme, but there were certain drawbacks in the procedure (Jayakrishnan et al 1998):

1. It requires an a priori specification of the upper bound on the number of machines within a cell and the number of cells. This contradicts the fundamental philosophy of grouping that groups naturally and the task of the analyst is to identify them if they exist (Burdidge 1977, Chandrashekharn et al 1986, Choobineh 1988, Srinivasan et al 1991).at the design stage, the number of cells should be an outcome of the solution procedure and not an input parameter (Srinivisan et al. 1990).
2. Other drawback is the irreversibility of the proposed hierarchal clustering algorithm. When once two machines (or cells) are grouped together at some stage there is no way to retrace the steps even if it leads to suboptimal clustering at the end (Anderberg 1973,

Everitte 1980, Chandersekharan and rajagopalan 1986). Also in the case of ties, selection is made arbitrarily. This precludes formation of better groups at later stage.

3. The Evaluation of results are based on Global efficiency, Grouping Efficiency and group Technology efficiency. Other important evolution criteria like within-cell compactness, minimization of Exceptional Elements, Grouping Efficacy, Grouping capability index(GCI) are not considered.

In this paper, upper bound on the cell size is imposed initially in the first stage to obtain basic feasible solution. The condition is relaxed in second phase (refinement stage) and the cells are formed naturally. In the case of ties optimum decision is taken for proper selection.

The paper is organized as follows: Notations and definitions are explained in section 2. The mathematical model is presented in section 3. The proposed algorithm is presented in section 4. The evaluation criteria are given in section 5. Computational analyses are presented in section 6 to illustrate the proposed algorithm. Discussion and conclusion are presented in section 7.

Notations and Definitions

i = part type

j = machine type

k = cell type

n = operation type

m = number of machines M= (m1, m2, m3,……mj……, mm).

p = number of parts P= (p1, p2, p3, … .pi,……. pp).

c = number of cells C= (c1, c2, c3,…..ck,……..cc).

UB = upper bound on cell size (maximum number of machines in a cell)

mpim = machine-part incidence matrix representing the operation sequence.

(mpim)ij = n, if nth operation of part i is performed on machine j, 0 otherwise.

ab = number of times for any machine assigned to a cell is the immediate successor of any machine assigned to another cell.

Where

$$\psi_{ab} = \sum_{a=1}^{p} \sum_{b=a+1}^{m} \left| (mpim_{a\varepsilon}) - (mpim_{ab}) \right| \quad \varepsilon \leq m\text{, and value of } \varepsilon \text{ incremented by 1 in each iteration.}$$

m (k) = Number of machines in cell type k.

Xjk = 1 if machine j is in cell k and 0 otherwise

Yik = 1 if part i is assigned in cell k and 0 otherwise

Mr = number of machines in cell r

Nr = number of parts in cell r

ed = number of in-cell operations,

eo = number of out-of-cell operations,

k = total number of operation in the kth cell

k = total number of non-operation (voids) in the kth cell

= Compactness

Mathematical Model

The most fundamental objectives for cell formation problem are minimization of intercell flows and maximizing machine utilization. It helps to lower the intercell movement cost and higher within cell machine utilization. In our research, efforts are made to minimise intercell flows and maximize machine utilization with the consideration of operation sequence of parts, optimal part allocation and machine utilization within the cell. The mathematical model is given as below:-

Normalized Intercell flows:

$$\text{Min } Z = \sum_{a=1}^{w} \sum_{b=1}^{w} \left[\frac{\psi_{ab}}{m(a) + m(b)} \right] \tag{1}$$

Subject to constraint:

$$m(a) + m(b) \leq UB \tag{2}$$

$$\sum_{k=1}^{c} x_{jk} = 1 \quad \text{for } j = 1,2,\ldots\ldots, m. \tag{3}$$

$$\sum_{k=1}^{c} y_{ik} = 1 \quad \text{for } i = 1,2,\ldots\ldots, p. \tag{4}$$

$$\sum_{j=1}^{m} x_{jk} \geq 1 \quad \text{for } k = 1,2,\ldots\ldots, c. \tag{5}$$

$$\sum_{i=1}^{p} y_{ik} \geq 1 \quad \text{for } k = 1,2,\ldots\ldots, c. \tag{6}$$

Equation (1) shows the calculation of Normalized intercell flow. Constraint (2) ensures that the merging cells/groups satisfy cell size. Constraint (3) and (4) ensures that each machine and part can only be assigned into one cell. Constraint (5) and (6) ensures that each cell must constrain at least one machine and one part.

Heuristic Solution Approach

The design of cellular manufacturing is combinatorially complex. There are number of approaches which were proposed by different researcher. Heuristic approaches are also used to obtain good solutions within acceptable amount of times. Heuristics can be classified into two categories. The first category is the problem-specific heuristic. This type of heuristic only works for specific type of problem; it cannot be used to solve other type of problem. The second category is the meta-heuristics, which are more general and can be used for different types of problems. Such heuristics include genetic algorithm, simulated annealing, Neural Network, tabu search, memetic algorithm etc. Numerous papers can be found in the literature for cell formation using meta-heuristics. The capability of Genetic Algorithm (Dixit (2004), Gupta

(1994, 1995), Zolfagari (2003), Solimanpur (2004), Yasuda (2005), Onwubolu (2001)), Simulated annealing (Xambre (2003), Baykasoglu (2001), Venugopal (1992 b), Su (1998), Chen (1995), sofianopoulou (1997), Harhalakis (1990 b)), Neural Network (Burke (1992), Carpenter (1987), Lozano (2001), Peker (2004), Dobando (2002)), Tabu search (Cao (2004), Adenso-Diaz (2005)), Memetic algorithm (Muruganandam (2005)); has been explored to solve cell-formation problem. We have applied the problem-specific heuristic to solve cell formation problem.

Phase I.

i. Machine-Cell Formation Algorithm

Step 1: Assign each machine to a cell (Number of cells = Number of machines).

Step 2: Determine Pab between the cells from the operation sequence matrix.

Step 3 : Determine the Normalized Intercell flow between the cells.

Step 4 : Select the minimum normalized Intercell flow value for the give cell-pair satisfying the limit of cell size.

If tie occurs (more than one cell-pair has same value)

Decision: Select cell-pair having maximum Intercell moves.

If TIE still occurs

Decision: Select cell-pair having less number of machines.

Step 5 : Merge the cell-pair to form new cell.

Step 6 : Repeat step (2-4) till upper bound condition on cell size does not violated.

Step 7: Stop.

ii. Optimal Part Allocation Algorithm

Step 1: Part will be assigned to the cell having MAXIMUM number of machines required by the particular part. If the tie occurs:

1) If operations are in same sequence in TIE cells:

a) Part will be assigned to the cell having minimum number of machines

b) If numbers of machines are equal then part will be assigned to the cell having MINIMUM operation sequence.

2) If operations are not in a sequence in one of the TIE cells:

a) Part will be assigned to the cell having operations in sequence.

3) If operations are not in sequence in the TIE cells:

a) Part will be assigned to the cell having minimum no. of machines

b) If number of machines are same then part will be assigned to the cell having MINIMUM operation number

Step 2: Stop

Phase II. (Improvement of Result Obtained From Phase I)

Step 1: Identify the exceptional elements (EE), bottleneck machines, bottleneck parts and their respective cells from the initial solution obtained from Phase-I.

Step 2: Identify the bottleneck machine which is more involved for EE as compared to their regular operations for the part families within the cell.

Step 3: If these EE are from the same cell (having bottleneck parts) Shift the machine to the new cell”

Step 4: if TIES occurred: (Numbers of EE are equal to the numbers of operations within the parent cell of the machine.) if number of parts in Parent cell > number of parts in cell having bottleneck parts, “Shift the machine to the new cell”

Step 5: Repeat the step (2-4) for all the bottleneck machines.

Step 6 : Apply the optimal part allocation algorithm.

Step 7: Stop.

Evaluation Criterion

To compare the quality of solutions reported in research papers, there is need to develop performance measures or criteria. For the performance measures FIVE evaluation criterions: Grouping efficiency (Tg), grouping efficiency (—), Global efficiency (To), and Within-cell compactness (WC), were used to evaluate the quality of the proposed solution. Grouping efficiency (Tg) was proposed by Chandrashekharan and Rajagopalan (1986). This was the first evaluation criteria for final result obtained by different algorithms.

$$\textit{Grouping efficiency } \eta_g = \varpi\eta_1 + (1-\varpi)\eta_2 \tag{7}$$

Where ϖ is the weighting factor ranging between 0 and 1, η_1 is the measure of the density of 1’s in the diagonal clusters of the block diagonal matrix and η_2 measures the density of 0’s outside the diagonal cluster. They are defined below:

$$\varpi = \frac{\sum_{r=1}^{R} M_r N_r}{MN} \tag{8}$$

$$\eta_1 = \frac{e_d}{\sum_{r=1}^{R} M_r N_r} \tag{9}$$

$$\eta_2 = 1 - \frac{e_o}{MN - \sum_{r=1}^{R} M_r N_r} \tag{10}$$

Grouping efficacy was proposed by Kumar and Chandrashekharan (1990).

$$\textit{Grouping efficacy } \Gamma = \frac{e_d}{e_o + \sum_{r=1}^{R} M_r N_r} \tag{11}$$

Machine Utilization —1 (given by equation 9) is defined by Chandrashekharan and Rajagopalan (1986) as the frequency of visits to machines within the cells. Global Efficiency was proposed by Harhalakis et al. (1990). It is the ratio of the number of operations that are performed within cells to the total number of operations in the systems.

$$\textit{Global Efficiency } \eta_o = \frac{e_d}{e_d + e_o} \tag{12}$$

Compactness (proposed by Jayakrishnan et al. (1998)) of cell is defined as the ratio of the number of operations within it to the maximum number of operations possible in it. To compute the maximum number of operations within a cell, it is assumed that every machine in it processes every component of its corresponding component-family at least at once.

$$\text{Within cell-compactness } \xi = \frac{\sum_{k=1}^{c} \Theta_k}{\sum_{k=1}^{c} \left(\Theta_k + \delta_k\right)} \tag{13}$$

For perfect diagonal block

$$\xi = 1 \text{ as } \delta_k = 0$$

Computational Analysis

The algorithm has been programmed in script programming in MATLAB 7.0 and the experiment has been run on a Pentium IV, with 1.8 GHz and 256 MB RAM. In order to validate the proposed heuristic, a set of problems have been used from different research papers.

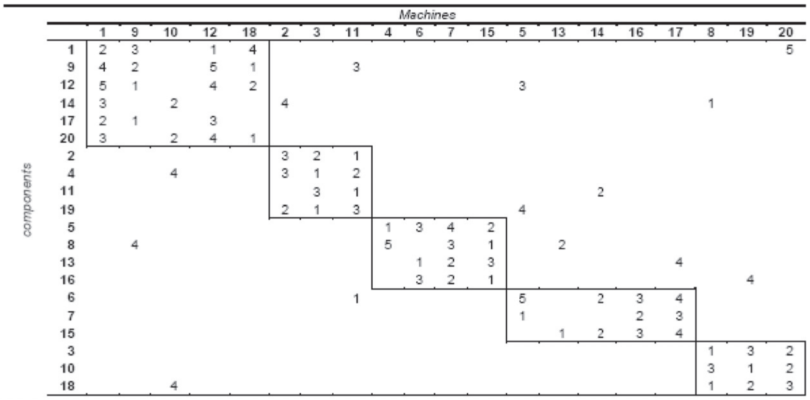
Example 1

Consider the example of 20 machines, 20 parts given by Harhalakis et al. (1990). Table 1 shows the incidence matrix. The results after Phase-I are shown in table 2. This solution is same as reported by Harhalaskis et al (1990). In the reported solution, machine 14 is assigned to cell 2. Machine 14 is engaged for performing 2nd operation on part 11. So this machine is performing only one operation in the assigned cell. Rest of the time it is engaged with bottleneck parts (6 and 15 of cell 4). This fact has been taken into consideration in Phase-II and the machine 14 is shifted to cell 4. As a result number of exceptional elements has been reduced to 14. Also number of voids due to machine 14 in cell 2 was 3. After reallocation of machine 14 in cell 4, the number of voids due to machine 14 in cell 4 is 1. The improved solution is shown in Table 3. The final machine-cells and component-families are given in Table 5. The performance measures like Grouping efficiency, Grouping Efficacy, Global Efficiency and within-cell compactness has been improved approximately by 2 to 5% (Indicated in table 12) as compared to the values of the best solution reported by Harhalaskis et al (1990).

Table 1: Machine-Part Incidence Matrix (Example 1)

	Machines																			
components	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	2								3			1						4		5
2		3	2								1									
3								1											3	2
4		3	1							4	2									
5				1		3	4								2					
6					5						1			2		3	4			
7					1											2	3			
8				5			3		4				2		1					
9	4								2		3	5						1		
10								3											1	2
11			3								1			2						
12	5				3				1			4						2		
13						1	2								3		4			
14	3	4						1		2										
15													1	2		3	4			
16						3	2								1				4	
17	2								1			3								
18								1		4									2	3
19		2	1		4						3									
20	3									2		4						1		

Table 2: Improved part-machine cell matrix after phase-II-Final Solution (Example 1)

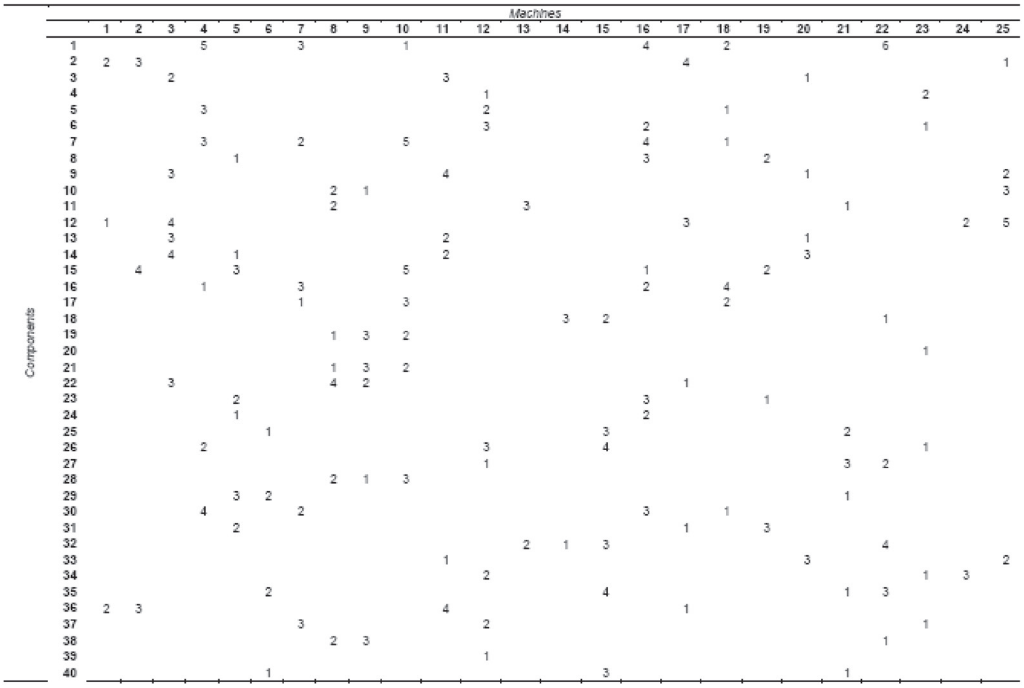


components	Machines																			
	1	9	10	12	18	2	3	11	4	6	7	15	5	13	14	16	17	8	19	20
1	2	3		1	4															5
9	4	2		5	1			3												
12	5	1		4	2								3							
14	3		2			4												1		
17	2	1		3																
20	3		2	4	1															
2						3	2	1												
4			4			3	1	2												
11							3	1							2					
19						2	1	3					4							
5									1	3	4	2								
8		4							5		3	1		2						
13										1	2	3					4			
16										3	2	1							4	
6								1					5		2	3	4			
7													1			2	3			
15														1	2	3	4			
3																		1	3	2
10																		3	1	2
18			4															1	2	3

Example 2

The large matrix used by Jayakrishnan et al.(1998) is considered in this example. Table 3 shows the incidence matrix. The improved solution after phase-II is shown in Table 4. The number of exceptional elements in the reported solution is 35. The number of exceptional elements by the proposed solution methodology has been reduced to 32 in the final solution. This solution is better as compared to the solution reported by Jayakrishnan et al. (1998). The improved performance measures are indicated in table 12.

Table 3: Machine-Part incidence matrix (Example 2)



Components	Machines																								
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1				5			3			1						4		2				6			
2	2	3															4								1
3			2								3									1					
4												1											2		
5				3								2						1							
6												3				2							1		
7				3			2			5						4		1							
8					1											3			2						
9			3								4									1					2
10								2	1																3
11								2					3								1				
12	1		4														3							2	5
13			3								2									1					
14			4		1						2									3					
15		4			3					5						1			2						
16				1			3									2		4							
17							1			3								2							
18														3	2							1			
19								1	3	2															
20																							1		
21								1	3	2															
22			3					4	2								1								
23					2											3			1						
24					1											2									
25						1									3						2				
26				2								3			4								1		
27												1									3	2			
28								2	1	3															
29					3	2															1				
30				4			2									3		1							
31					2												1		3						
32													2	1	3							4			
33											1									3					2
34												2											1	3	
35						2									4						1	3			
36	2	3									4						1								
37							3					2											1		
38								2	3													1			
39												1													
40						1									3						1				

Table 4. Improved part-machine cell matrix after phase-II-Final Solution (Example 2)

	Machines																								
Components	1	2	17	24	25	3	11	20	12	23	5	16	19	6	15	21	22	4	7	10	18	8	9	13	14
2	2	3	4		1																				
12	1		3	2	5	4																			
36	2	3	1				4																		
3						2	3	1																	
9					2	3	4	1																	
13						3	2	1																	
14						4	2	3			1														
33					2		1	3																	
4									1	2															
6									3	1		2													
20										1															
26									3	1					4			2							
34				3					2	1															
37									2	1									3						
39									1																
8											1	3	2												
15		4									3	1	2							5					
23											2	3	1												
24											1	2													
31			1								2		3												
18															2		1								3
25														1	3	2									
27									1							3	2								
29											3			2		1									
35														2	4	1	3								
40														1	3	1									
1												4					6	5	3	1	2				
5									2									3			1				
7												4						3	2	5	1				
16												2						1	3		4				
17																			1	3	2				
30												3						4	2		1				
10					3																	2	1		
11																1						2		3	
19																				2		1	3		
21																				2		1	3		
22			1			3																4	2		
28																				3		2	1		
38																	1					2	3		
32															3		4							2	1

Example 3

The matrix used by Jayakrishnan et al.(1998) is considered in this example. Table 5 shows the incidence matrix. The improved solution after phase-II is shown in Table 6. This solution is same as reported by Jayakrishnan et al. (1998).

Table 5. Machine-Part incidence matrix (Example 3) Table

	Machines							
Components	1	2	3	4	5	6	7	8
1					2	1		
2	1		2					
3	2	1		5			3	4
4		1		2			3	4
5					2	1		
6		1		2	5		3	4
7		4		2			3	1
8	1		2					
9	1		3			2		
10				2	3	1		
11	3		2				1	
12					1	3	2	
13	1		2					
14	1	2	3					
15				1	2			
16	1		2					
17	3		1		2			
18		2		1			4	3
19	1		2					
20		2		1		3	4	5

6. Improved part-machine cell matrix after phase-II-Final Solution (Example 3)

	Machines							
Components	1	3	2	4	7	8	5	6
2	1	2						
8	1	2						
9	1	3						2
11	3	2			1			
13	1	2						
14	1	3	2					
16	1	2						
17	3	1					2	
19	1	2						
3	2		1	5	3	4		
4			1	2	3	4		
6			1	2	3	4	5	
7			4	2	3	1		
18			2	1	4	3		
20			2	1	4	5		3
1							2	1
5							2	1
10				2			3	1
12					2		1	3
15				1			2	

Example 4

Consider the example of 17 machines, 20 parts given Harhalakis et al. (1994). Table 7 shows the incidence matrix. The improved solution after Phase-II is shown in Table 8. The number of exceptional elements is 4. Harhalakis et al. solved the problem by heuristic based approach and also by state-search algorithm, proposed by Ghosh et al. (1993). The number of exceptional elements is 5 in both the cases.

The values of Grouping efficiency, Grouping Efficacy, Global Efficiency and within-cell compactness is presented in table 12.

Table 7: Machine-Part incidence matrix (Example 4)

		Machines																
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Components	1		5			3			2					4			1	
	2						1					3			4			2
	3	1		3								4	2					
	4				4					1	3					2		
	5				3						2					1	4	
	6	4		3				2					1					
	7					1			3					2				
	8						4					3			2			1
	9			1				2					3					
	10		1			2			4					3				
	11				4					2						1	3	
	12	4		1				2					3					
	13				2					3	1					4		
	14	1		3								4	2					
	15		3			2			1					4				
	16				1					2	3						4	
	17						2								3			1
	18	3		2				1				4						
	19		3			4			2					1			5	
	20			2				3					1					

Table 8: Improved part-machine cell matrix after phase-II-Final Solution (Example 4)

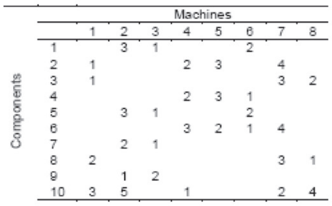
		Machines																
		1	3	7	11	12	2	5	8	13	4	9	10	15	16	6	14	17
Components	3	1	3		4	2												
	6	4	3	2		1												
	9		1	2		3												
	12	4	1	2		3												
	14	1	3		4	2												
	18	3	2	1	4													
	20		2	3		1												
	1						5	3	2	4					1			
	7							1	3	2								
	10						1	2	4	3								
	15						3	2	1	4								
	19						3	4	2	1					5			
	4										4	1	3	2				
	5										3		2	1	4			
	11										4	2		1	3			
	13										2	3	1	4				
	16										1	2	3		4			
	2				3											1	4	2
	8				3											4	2	1
	17															2	3	1

Example 5

Consider the example of 8 machines, 10 parts. Table 2 shows the incidence matrix. The number of exceptional elements is 7. In this intermediate solution (After Phase-I Table 11), the machine 6 is performing two operations, one each on part 1 and 5. This machine is also engaged for bottleneck parts 4 and 6 of cell 3. So there is a TIE in the number of assigned and bottleneck operations. The decision for the reallocation is made in phase-II. The number of voids due to machine 6 in cell 2 is 2 and it will create only one void in cell 3. So the machine is reallocated to cell 3. The improved solution after Phase-II is shown in Table 8. The final machine-cells and component-families are given in Table 10.

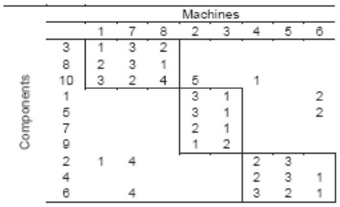
The values of Grouping efficiency, Grouping Efficacy, Global Efficiency and within-cell compactness are given in table 12.

Table 9: Machine-Part incidencematrix (Example 5)



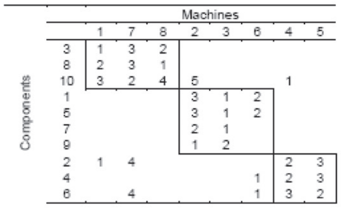
	Machines							
Components	1	2	3	4	5	6	7	8
1		3	1			2		
2	1			2	3		4	
3	1						3	2
4				2	3	1		
5		3	1			2		
6				3	2	1	4	
7		2	1					
8	2						3	1
9		1	2					
10	3	5		1			2	4

Table 10: Improved part-machine cell matrixafter phase-II-Final Solution (Example 5)



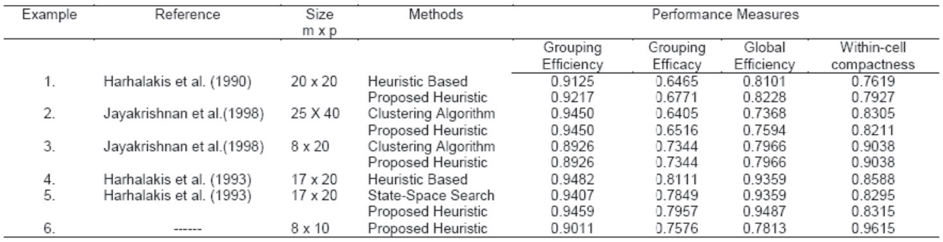
	Machines							
Components	1	7	8	2	3	4	5	6
3	1	3	2					
8	2	3	1					
10	3	2	4	5		1		
1				3	1			2
5				3	1			2
7				2	1			
9				1	2			
2	1	4				2	3	
4						2	3	1
6		4				3	2	1

Table 11: Part-machine cell matrixafter phase-I (Example 5)



	Machines							
Components	1	7	8	2	3	6	4	5
3	1	3	2					
8	2	3	1					
10	3	2	4	5			1	
1				3	1	2		
5				3	1	2		
7				2	1			
9				1	2			
2	1	4					2	3
4						1	2	3
6		4				1	3	2

Table 12: Summary of new results and best-known results using published matrices in literatures



Example	Reference	Size m x p	Methods	Performance Measures			
				Grouping Efficiency	Grouping Efficacy	Global Efficiency	Within-cell compactness
1.	Harhalakis et al. (1990)	20 x 20	Heuristic Based	0.9125	0.6465	0.8101	0.7619
			Proposed Heuristic	0.9217	0.6771	0.8228	0.7927
2.	Jayakrishnan et al.(1998)	25 X 40	Clustering Algorithm	0.9450	0.6405	0.7368	0.8305
			Proposed Heuristic	0.9450	0.6516	0.7594	0.8211
3.	Jayakrishnan et al.(1998)	8 x 20	Clustering Algorithm	0.8926	0.7344	0.7966	0.9038
			Proposed Heuristic	0.8926	0.7344	0.7966	0.9038
4.	Harhalakis et al. (1993)	17 x 20	Heuristic Based	0.9482	0.8111	0.9359	0.8588
5.	Harhalakis et al. (1993)	17 x 20	State-Space Search	0.9407	0.7849	0.9359	0.8295
			Proposed Heuristic	0.9459	0.7957	0.9487	0.8315
6.	------	8 x 10	Proposed Heuristic	0.9011	0.7576	0.7813	0.9615

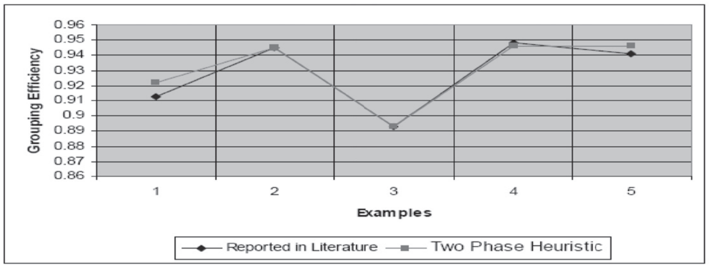


Figure 1: Comparison of Grouping Efficiency result of experiments

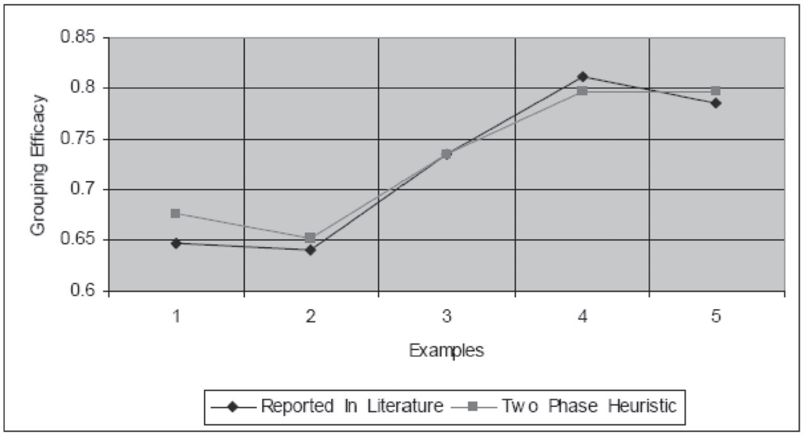


Figure 2: Comparison of Grouping Efficacy result of experiments

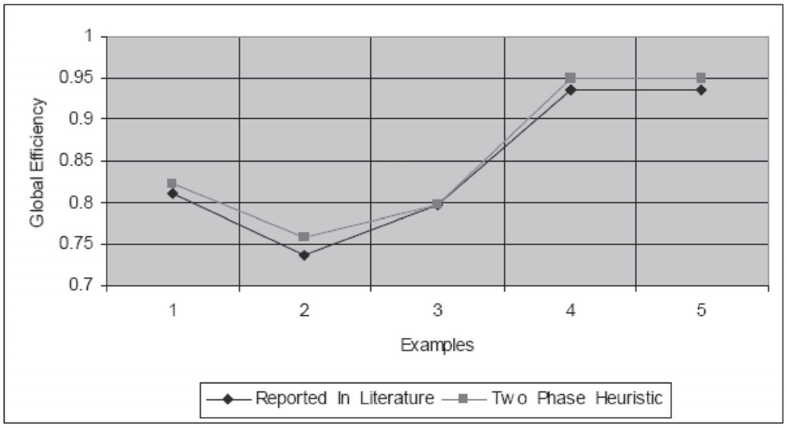


Figure 3: Comparison of Global Efficiency result of experiments

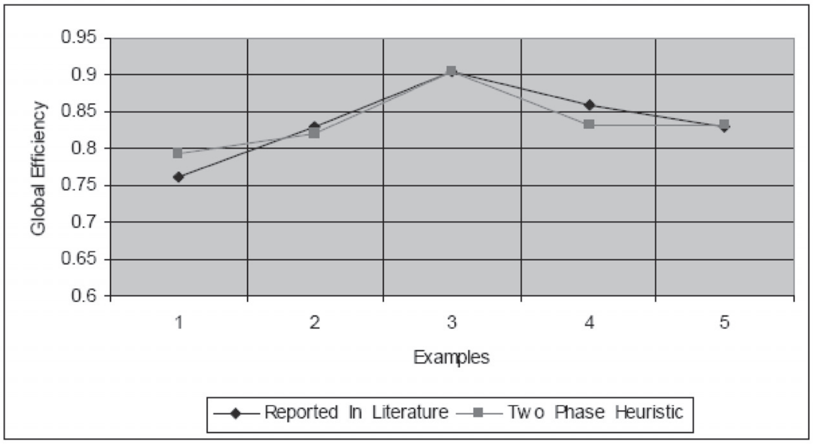


Figure 4: Comparison of Cell-Compactness result of experiments

Conclusion

In this paper, a Two-Phase heuristic based approach is presented for part-family and machine-cell formation. Most of the existing methods are indifferent to the processing sequence. In this paper, a model and solution methodology for a problem of cell formation to minimize Intercell moves and maximize machine utilization is developed. The models takes into account the operation sequence in the computation of Intercell moves and optimum allocation of parts to the machine cells. The solution algorithm is developed to solve the model. In order to evaluate the performance of the algorithm, grouping efficiency, grouping efficacy, global efficiency and within-cell compactness has been used as a performance measure. Computational experiences shows that the algorithm generates a good quality solution and capable of solving large problem.

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