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A Comparative Study of Some Cellular Manufacturing Techniques

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ABSTRACT

Cellular manufacturing (CM) is a concept that involves processing of similar parts on dedicated cluster (or cells) of dissimilar machines or manufacturing processes. This paper concentrated on seven cell formation techniques used in Cellular Manufacturing (CM). The techniques were used to develop cells for matrices from various sizes of parts and machines. By randomly rearranging the sequence of the machines in the reference matrices (cited from published journals), 12 new matrices were developed. This paper also concentrated on performing the treatments for bottleneck, exceptional elements or voids using part subcontracting or machine duplication for the developed cells. The performance of each technique was measured using Grouping Measures (GM), where high percentage of GM indicates that the technique has high machine utilization (MU) and low percentage of exceptional elements (EE). Overall, Bond Energy Algorithm (BEA) was found to be the best cell formation technique.

Keywords: Group technology, cellular manufacturing, cell formation techniques, part family, machine group, part machine cell, machine duplication, parts subcontracting

INTRODUCTION

The predominant type of manufacturing in the world today is small-lot production of parts and this classicbatch type production accounts for 60-80% of all manufacturing activities. This small-lot manufacturing is traditionally performed by job shops using simple but often inefficient rules for routing and scheduling. This increases the setup time and at times this become much higher than the processing time. Group technology (GT) plays an important role and helps in reducing throughput and material handling times, which helps in reducing inventories. Increased flexibility in handling forecast errors is one of the main advantages in adopting GT (Mukhopadhyay *et al.*, 1995; Akturk and Wilson 1998).

Group technology is a technique for improving and obtaining economic savings in job and batch-type production. GT helps in achieving a better social system for industry and better labour relations. This is a method to obtain high production rate, a feature of line flow (mass production) as well as high flexibility, which is a characteristic of jobbing production (Mukhopadhyay *et al.* 1995; Cantamessa and Turroni 1997).

A recent change in customers' sense of values and increasing international competition has force many companies to manufacture products with larger product mix from mass production in a specific period, with very short notice, and with the production volume for each product very low. To meet these new requirements, it is very important to have the ability to produce many small volume batches consisting of complex parts in a short production period. This leads to an increased complexity of the management task, increased investments in inventory and decreased efficiency of mass production systems. To maintain high efficiency levels, it is an accepted strategy to adopt a GT philosophy, and to organize a large portion of the manufacturing systems into cells (Crama and Oosten 1996; Akturk and Wilson 1998).

Cellular manufacturing systems have shown encouraging results in batch manufacturing environments. The main advantages reported are set-up time reduction, shorter throughput time, smaller work in process inventories, simpler tool and material flow, decentralization of responsibility, improved human relations and work satisfaction. All these factors have a positive impact both on higher product quality and on sensible cost reductions. Moreover, technological innovation can often be effectively joined to the conversion of the cellular system (Mukhopadhyay et al. 1995; Crama and Oosten 1996; Cantamessa and Turroni 1997; Akturk and Wilson 1998).

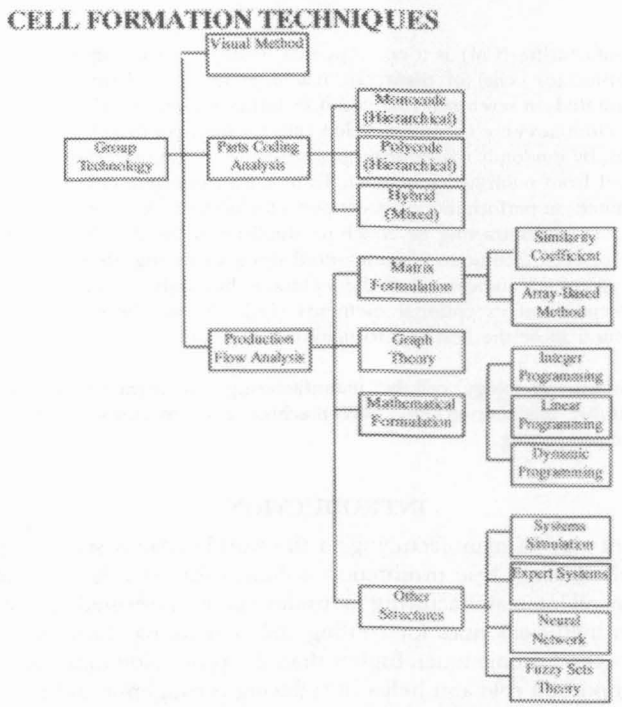

Fig. 1. Framework for Group Technology (Offodile et al. 1994)

CELL FORMATION TECHNIQUES

According to Offodile *et al.* (1994), there are three methods to identify machine-part group formation models in cellular manufacturing (refer to *Figure 1*). The first is the ocular or visual method, and the other two methods are based on part characteristics and production process (also by Groover 1987 and Herag 1994). Offodile *et al.* have also thoroughly reviewed and summarized 48 cell formation techniques published from 1972 to 1991. Each model was developed based on different criteria and the authors had categorized them into 28 different characteristics.

Besides the mentioned authors, Mosier and Taube (1985), Wemmerlov and Hyer (1986), Chu (1989), Singh (1993), and Singh and Rajamani (1996) also reviewed other cell formation techniques. Among the well-known methods of grouping are Bond Energy Algorithm (McCormick et al. 1972), Rank Order Clustering (King 1980, and King and Nakornchai 1982), Direct Clustering Algorithm (Chan and Miller 1982),

Cluster Identification Algorithm (Kusiak and Chow 1987) and Modified Cluster Identification Algorithm (Boctor 1991). Readers are advised to refer to the above authors suggested and their references for further understanding on cell formation techniques.

THE STUDY

In this paper, the seven cell formation techniques were used to develop part-machine cell are Bond Energy Algorithm (BEA), Rank Order Clustering (ROC), Rank Order Clustering 2 (ROC 2), Modified Rank Order Clustering (MODROC), Direct Clustering Algorithm (DCA), Cluster Identification Algorithm (CIA) and Modified CIA (MODCIA). Since all the techniques are well established in the literature, the algorithm or procedure of the techniques will not be discussed in this paper (see Singh and Rajamani, 1996).

Six reference matrices used in this study were 6 x 5 (Aidousari 1993), 9 x 7 (Mukhopadhayay *et al.* 1994), 24 x 14 by (Askin and Standridge 1993), 24 x 18 (Chandra *et al.* 1993), 40 x 24 (Srinivasan & Narendran 1991) and 43 x 16 (Ballakur and Steudel 1987). Using these matrices, another twelve new matrices were randomly developed by rearranging the sequences of the machines until a pattern of part-machine cluster(s) is observed. The matrices can be classified into three types:

1. Type A – one cluster
2. Type B – two clusters
3. Type C – three clusters

The first objective is to observe the relationship between the suitable technique(s) and the number(s) of cluster (if there are any). Moreover, the effect of rearranging the sequence of the machines to the effectiveness of the cell formation techniques and the cells formed can also be determined. Figures 2, 3 and 4 provide three examples for the 40 x 24 type A, B or C matrices. The other matrices developed in this study will not be shown here due to large space required.

Different sizes of matrices can generate different number of new matrices. Smaller matrices can only be rearranged into type A matrix while the bigger matrices can be

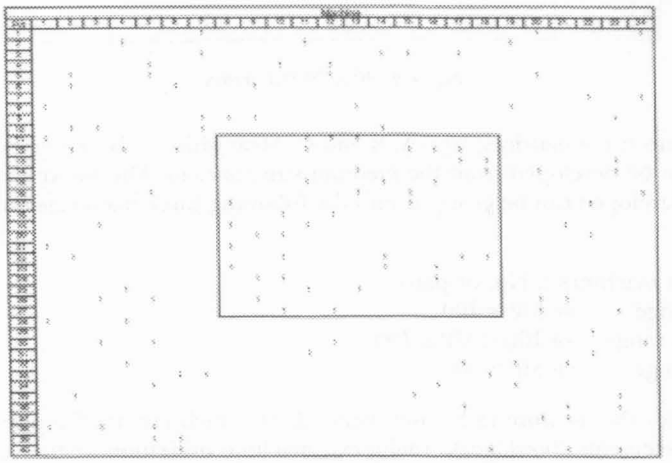

Figure 2: 40 x 24 (A) matrix

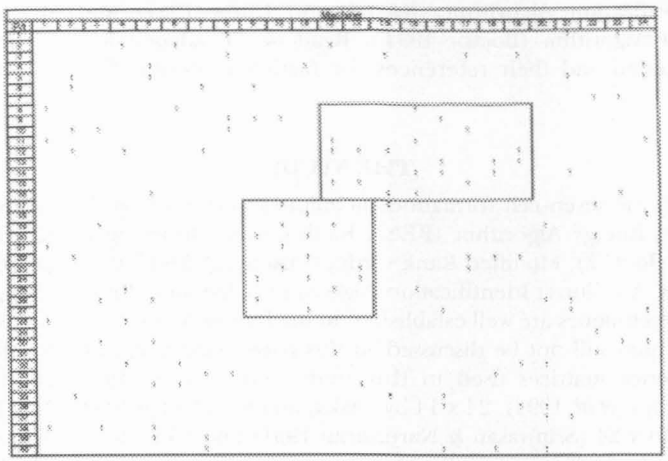

Figure 3: 40 x 24 (B) matrix

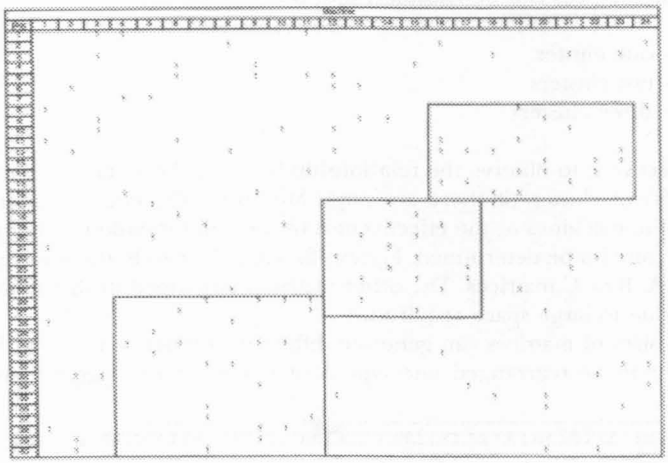

Figure 4: 40 x 24 (C) matrix

generated into three matrices, type A, B and C. Meanwhile, only two types of matrices, A and B, can be developed from the medium size matrices. The twelve matrices which have been developed can be grouped into the following three main categories based on MP, where:

MP = No. of machines x No. of parts
a) Small range $\Rightarrow MP \leq 100$
b) Medium range $\Rightarrow 100 < MP \leq 100$
c) Large range $\Rightarrow MP > 500$

The choice for the measure to be used depends on which criteria the priority is given, exceptional elements (bottleneck machines), machine utilization or the voids, the size of the matrix or the combination of these criteria. The second objective of this study is to produce cells with maximum machine utilization (MU) and minimum percentage of

exceptional elements (EE). Hence, Grouping Measures (GM), which calculates the differences between MU and EE, was chosen to evaluate the performance of the seven cell formation techniques and to choose the best technique as the third objective of this paper. The algorithm for GM can be referred to Singh and Rajamani (1996).

However, before the part-machine cells were developed, treatments for bottleneck, exceptional elements or voids in this study were carried out either by subcontracting the parts or duplicating the machines. Part subcontracting refers to the part(s) being subcontracted to other cells to be processed and machine duplication means that machine(s) to be duplicated in more that one cell. Below are a few criteria that have been set up as a guideline to minimize these problems are shown below.

A) Small or Medium Range
   1. part subcontracting to 3 or less different cells
   2. machine duplication in 2 or less cells
   3. each machine produces 2 or more parts
   4. each cell consists of 3 or more parts

B) Large Range
   1 part subcontracting to 4 or less different cells
   2 machine duplication in 3 or less cells
   3 each machine produces 3 or more parts
   4 each cell consists of 4 or more parts

RESULTS

The part families and machine cells formation using seven cell formation techniques are summarized in Table 1. The total number of cells developed are quite similar because all these techniques can be grouped into part-machine group analysis (Singh and Rajamani 1996).

The results showed that the initial sequence of the machines (or parts) would not give an effect to the number of cells formed. However, the sequence of the machines (or parts) in a cell would be different from one matrix to the other depending to the

TABLE 1
Total number of cells developed

	Formation Techniques						
Matrix	BEA	ROC	ROC2	MODROC	DCA	CIA	MODCIA
6 x 5 (A)	2	2	2	2	2	2	2
9 x 7 (A)	3	3	3	6	6	-	2
24 x 14 (A)	4	4	4	5	3	4	4
24 x 14 (B)	4	4	4	4	5	3	4
24 x 18 (A)	4	9	9	11	9	-	5
24 x 18 (B)	5	10	10	14	9	-	9
40 x 24 (A)	11	16	14	17	10	-	10
40 x 24 (B)	13	13	14	16	12	-	6
40 x 24 (C)	13	15	15	19	13	-	7
43 x 16 (A)	6	10	9	12	9	-	8
43 x 16 (B)	7	8	11	13	9	-	10
43 x 16 (C)	7	8	8	10	9	-	8

initial data. CIA only produces cells for 6 x 5 (A), 24 x 14 (A) and 24 x 14 (B) because this technique will mask the entire matrix to be a cell if the matrix is not mutually separable.

Figure 5 – 22 shows the results for BEA and ROC techniques (except for 43 x 16 type A, B and C). Results for the other cell formation techniques can be referred to Low (1999).

A. BEA (figure 5 – 13)

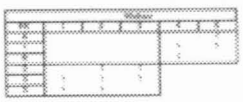

Fig. 5. 6 x 5 (A)

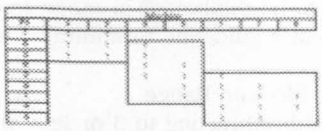

Fig. 6. 9 x 7 (A)

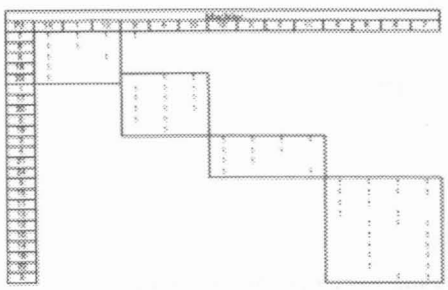

Fig. 7. 24 x 14 (A)

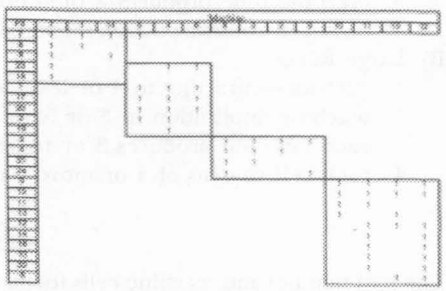

Fig. 8: 24 x 14 (B)

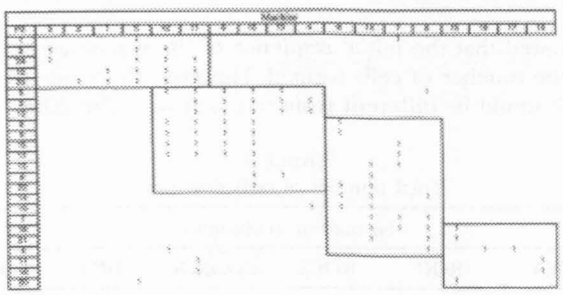

Figure 9: 24 x 18 (A)

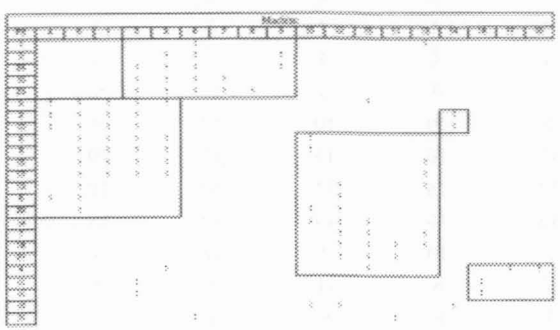

Fig. 10. 24 x 18 (B)

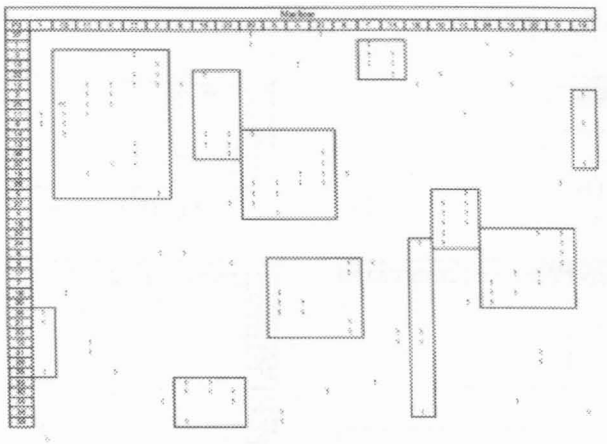

Fig. 11. 40 x 24 (A)

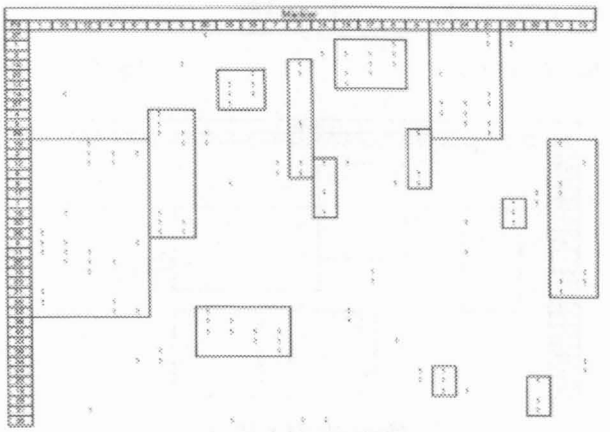

Fig. 12. 40 x 24 (B)

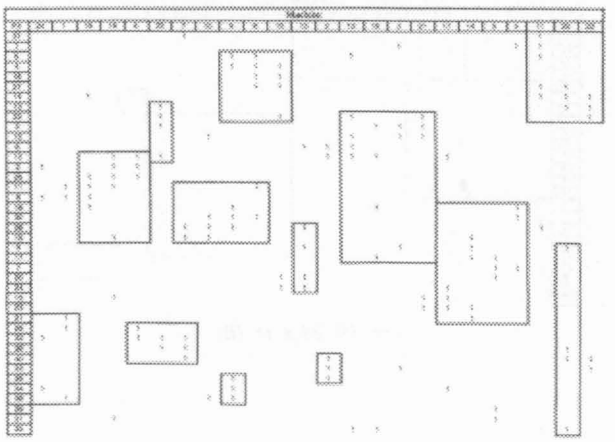

Fig. 13. 40 x 24 (C)

B. ROC (Figure 14 – 22)

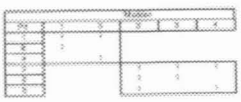

Fig. 14. 6 x 5 (A)

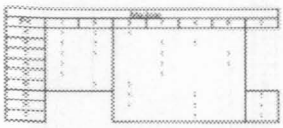

Fig. 15. 9 x 7 (A)

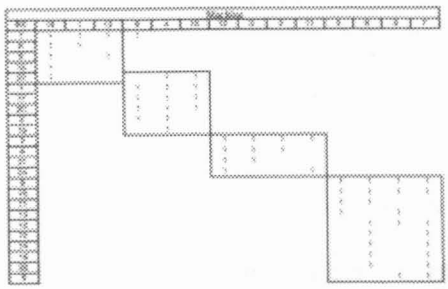

Fig. 16. 24 x 14 (A)

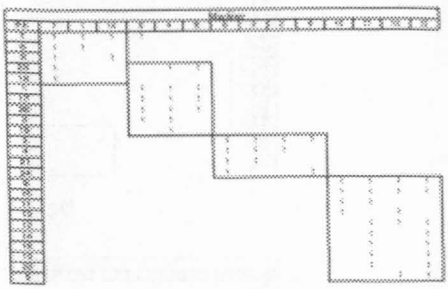

Fig. 17: 24 x 14 (B)

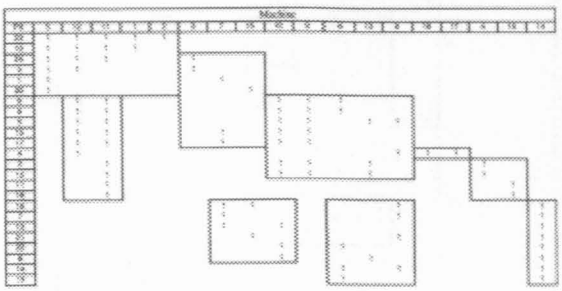

Figure 18: 24 x 18 (A)

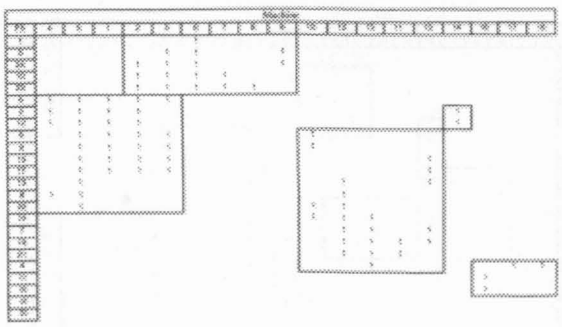

Fig. 19. 24 x 18 (B)

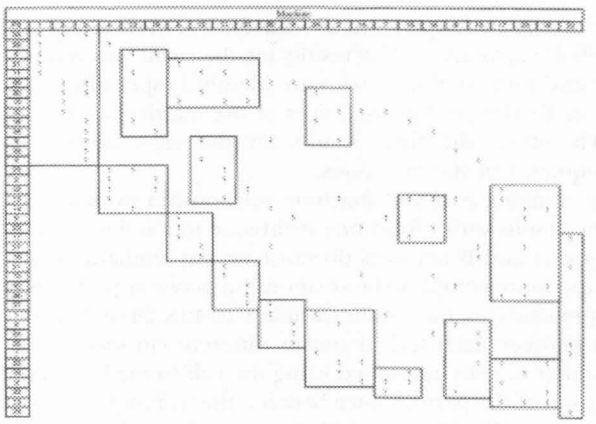

Fig. 20. 40 x 24 (A)

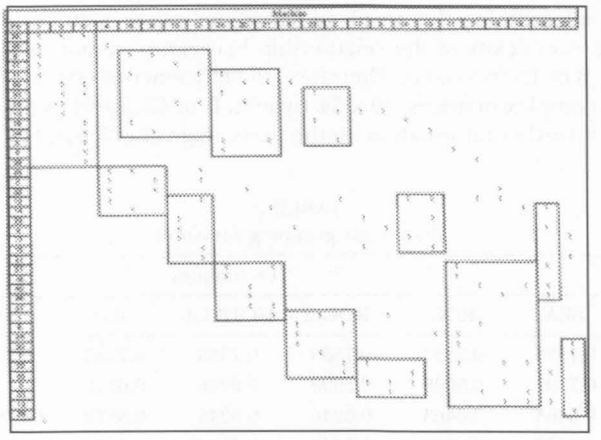

Fig. 21. 40 x 24 (B)

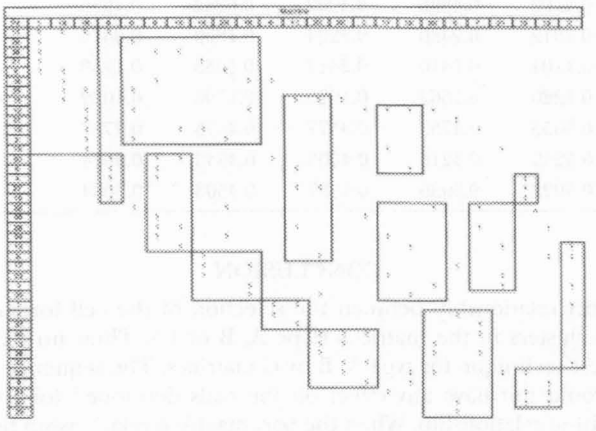

Fig. 22. 40 x 24 (C)

The number of cells developed and the distribution of these cells will depend on the nature of the initial matrix itself. The results for the small and medium range matrices are quite similar and some of the answers are identical especially for matrices 6 x 5 and 24 x 14 (type A or B) due to the small sizes of the matrices and the data involved are not complex. Therefore, the final results for the cells developed are the similar regardless the sequence of the machines.

However, for complex part and machine relationship in matrices 9 x 7 or 24 x 18 (type A or B), the results varies from one technique to another. In addition, the results obtained from type A and B matrices do not have any similarities. The bigger the size of the matrices, the more complex the relationship between parts and machines will be. Therefore for large matrices, the results for matrices 40 x 24 or 43 x 16 (not shown) type A, B or C varies between each techniques or different clusters.

The total number of cells developed using the cell formation techniques will not be used as a comparison of the performance between the techniques. Instead, an established performance measure, GM will be used. Referring to Table 2, the percentage of the GM varies from 41 to 80 % for the small and medium range, 28 to 59 % for the 43 x 16 and 4 to 24 % for the 40 x 24 matrices. The results showed high percentage of efficiencies for the developed cells for the small and medium range matrices. The percentage decreases as the complexity of the relationship between part and machine in matrices 43 x 16 (type A, B or C) increased. Therefore, the efficiency of GM can be as low as only 4% for the very complex matrices, 40 x 24 (type A, B or C). Readers are advised to refer to Low (1999) for further information on the percentage of efficiency of each techniques used.

TABLE 2
Results for grouping measures

	Techniques						
Matrices	BEA	ROC	ROC 2	MODROC	DCA	CIA	MODCIA
6 x 5 (A)	0.7333	0.7333	0.7333	0.7333	0.7333	0.7333	0.7333
9 x 7 (A)	0.7191	0.5098	0.5098	0.8046	0.6373	–	0.6088
24 x 14 (A)	0.6463	0.6463	0.6246	0.6246	0.6522	0.7027	0.6977
24 x 14 (B)	0.6463	0.6246	0.6246	0.6246	0.6522	0.5172	0.6411
24 x 18 (A)	0.4153	0.4859	0.5126	0.5396	0.4965	–	0.4355
24 x 18 (B)	0.4108	0.4896	0.4907	0.6282	0.4965	–	0.5048
40 x 24 (A)	0.1012	0.2430	0.2224	0.1809	0.0446	–	0.0901
40 x 24 (B)	0.1104	0.1410	0.2417	0.1953	0.1159	–	0.0596
40 x 24 (C)	0.1220	0.1662	0.1926	0.1796	0.1032	–	0.0668
43 X 16 (A)	0.5056	0.4753	0.4577	0.4875	0.2787	–	0.5615
43 X 16 (B)	0.5243	0.3216	0.4603	0.4943	0.3084	–	0.5921
43 X 16 (C)	0.5022	0.3936	0.4587	0.4503	0.3084	–	0.4931

CONCLUSION

There is no direct relationship between the selection of the cell formation techniques and the type of clusters in the matrices (type A, B or C). Thus, no techniques can be chosen as the best technique for type A, B or C matrices. The sequence arrangement of the machines would not have any effect on the cells developed for the matrices with simple part-machine relationship. When the part-machine relationship became complex, different results could be developed for different techniques or different clusters.

However, based on the size of the matrices, the suitable technique can be selected. From the results obtained, all the cell formation techniques produced relatively good results for the small and medium range matrices. It is very difficult to select the best technique for the large range matrices due to the large amount of data for parts and machines and the complexity of the relationship of these data. Every matrix could have developed better results using different techniques. As the average, BEA consistently formed cells with among the highest percentage of efficiency. Overall, BEA produced better results compared to the other techniques. For future work, it is proposed that the number of part matrices to increased hypothetical part matrices or real part matrices with one or more clusters in the matrices.

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