PROBABILISTIC APPROACH TO MACHINE-COMPONENTS GROUPING IN CELLULAR MANUFACTURING SYSTEMS

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ABSTRACT
In this paper existing group technology techniques are reviewed and an alternative method using probabilistic approach to machine-components grouping in cellular manufacturing systems is introduced where it is based on production flow analysis, which uses routing information. A common feature of this approach is that it sequentially rearranges row and columns of the machine part incidence matrix according to predefined index and block diagonal is generated. The steps of this method are to assign the 1's in each row and column a probability weight, which alternately rearranged in descending order until a block diagonal matrix is created. It does not need to decide in advance, the number of required cells. It also overcomes the limitation of computational complexity, inherited in exiting group technology methods, especially for large scale and complex problems.

الخلاصة
يتناول البحث دراسة لطرق تكوين الخلايا التكنولوجية و من ثم طرح طريقة جديدة باستعمال الاحتمالية في تكوين المجاميع التكنولوجية في الخلايا التصنيعية التي يتكون منها المصنع. ان الطريقة تعتمد على التسلسل التكنولوجي للاجزاء المكونة للمنتجات المراد تجميعها في المجاميع التكنولوجية. ان هذه الطريقة تقوم في اعادة تنظيم السطر و العواميد للمصفوفة المكونة للاجزاء و المكائن التي تنتج عليها و بالتالي تكوين مصفوفة من مجاميع مستقلة. في هذه نقوم بتخصيص احتمالية لكل من الاجزاء التي تعمل على المكائن و من ثم تنظيمها لحين ظهور مجاميع مستقلة للأجزاء العاملة على المكائن. ان هذه الطريقة لا تحتاج الى تحديد العدد المطلوب من الخلايا. وفي الوقت نفسه تتجاوز الصعوبات المترتبة في الحسابات، التي تعاني منها الطرق المعروفة حاليا و خاصة في الخلايا التي تحوي على عدد كبير من الاجزاء و المكائن.

KEY WORDS
Group Technology. Celluar Manufacturing. Flow Production. Rank Order Clustring.

INTRODUCTION

Group technology (GT) is one of the important techniques used in the formation of cellular manufacturing system. It is used for the purpose of transferring the advantages of flow production organization to be obtained in what otherwise would be jobbing or batch manufacture. GT is defined as the discipline of identifying things; such as parts, processes, equipment, tools, people, and customers; by their attributes. These attributes are then analyzed to identify similarities between among them. These things are then grouped according to similarities. GT is used to increase efficiency and effectiveness of managing the cellular manufacturing system (Hunt, 1989).

Cellular manufacturing system as an application of group technology concept is defined as the pursuit of smaller batch production of discrete parts, in which the manufacturing system is decomposed into sub-systems (clusters of dissimilar machines located in close proximity) each of which is viewed as an independent entity dedicated to the production of sub-set of similar parts (Ballakur and Steudel, 1987).

Production flow analysis is a method for group technology, developed by Burbidge (1971), which has particular appeal in that it requires no special part coding system, is relatively simple to implement and can be applied to the reorganization of existing, as well as the design of a new manufacturing systems. The method involves a number of stages, which are described in more details by Burbidge (1975).

Using route card data, a machine-component matrix is prepared, in which the rows represent machines and the columns represent components, or vice-versa. If the cell entry A_{ij}=1, it indicates that machine "i" makes component "j", or if =0, then there is no relation between the two. So, the complete matrix is a random array of 0's and 1's. The clustering algorithms, which this paper discusses, rely on these assumptions that the machines and components can be partitioned into matched groups of machines and components. These will be represented as clusters along the diagonal of the matrix. This visual presentation of the possible constitution of the cells is the key merit of these methods.

In this paper, the probabilistic relation between the occurrence of the operations of the components on the machines that will perform it and the order that it is performed is taken into considerations so as the final 0-1 matrix, representing the clustering gives the groups of machines that will be assigned to the manufacturing of the components. It is more accurate and quicker to evaluate the machine-component groups.

GROUP TECHNOLOGY METHODS

There are several methodologies developed based on cluster analysis. These are:

Matrix Formulation

In matrix formulation a (0-1) machine-part incidence matrix a_{ij} is constructed, in which elements 1(0) indicate that machine i is used (not used) to process part j. Normally the machine-part incidence matrix constructed based on the production route data. To arrange the matrix into block diagonal form, a number of methods were developed such as:

a- Similarity coefficient, the procedure uses the route information represented by the machine-part incidence matrix to compute the similarity coefficient between machines (i) and (k). The similarity coefficient S_{ik} is the number of parts, which visit both machines 'i' and 'k' divided by the number of parts, which visit at least one of them. Then based on this machine groups are generated. The 1st research that involved in developing this type of technique was (McAuley, 1972). Then he was followed by many others as have been evaluated and/or surveyed by (Shafer and Rogers, 1993 and 1994), (Seifoddini and Hsu, 1994), (Loh and Taylor, 1994), (Seifoddini and Djassemy, 1995) and (Mosier et la, 1997).

b- Array Based Clustering, this method is based on production flow analysis, which uses routing information. A common feature of this approach is that it sequentially rearranges rows and columns of the machine-part incidence matrix according to a predefined index and block diagonal is generated. King (1980) developed the Rank Order Clustering (ROC). The limitation of the ROC method was overcame by introducing the improved method (ROC2), (King and Nakornchai, 1982). The method was furtherly developed by introducing the block and slice method known as (MODROC), (Chandrasekharan and Rajagopalan, 1986). A non-hierarchical clustering algorithm was developed, called " GRAFICS", (Srinivasan and Narendran, 1991).

c- Fuzzy Clustering, the presence of uncertain or vague information of part features, demand or processing time etc., create an inefficient solution, if grouping problem is solved by deterministic type of algorithms. Fuzzy clustering or fuzzy mathematical programming provides a good solution for cell formation with vague information. The 1st presentation of a fuzzy mathematics for part family formation problem was introduced by (Xu and Wang, 1989). Method based on fuzzy set theory was introduced by (Zhung and Wang, 1991), while a method based on a fuzzy c-means clustering algorithm for cell formation was proposed by (Chu and Hayya, 1991), and fuzzy logic approach to consider parts features was presented by (Narayanaswamy and others, 1996). A fuzzy mixed-integer programming is proposed to minimize the cost to exceptional elements, (Tsai and others, 1997).

Rank Order Clustering Algorithm

The rank order-clustering algorithm (ROC), introduced by (King, 1980), represents route card data as a binary matrix. Using a positional weighing technique for the "1" entries in the matrix, the rows and columns are alternatively rearranged in order of decreasing rank. The result is a diagonalization of the 1's into several clusters. If independent machine-component groups do exist in the sample data provided, each machine will occur in only one cluster. Components will be uniquely assigned to any one of the clusters. Using this algorithm, the analyst can obtain a visual assessment of the machine groups and the associated families of parts simultaneously. With such an approach, a very valuable preliminary assignment of machines can be obtained because, if a large number of machines are shared over several clusters, plans for cellular manufacture can be shelved at the outset. There are few weaknesses in this algorithm, which affect its performance, caused by two types of cell entries, which prevent cluster formation and create dispersion away from the diagonal. These are (Tsai and others, 1997):

a- Exception elements: these are a few cell entries that occur outside a pair of clusters. However, only one cluster can contain that machine, resulting in an inter-cell move of the other components requiring that machine to complete their processing. The occurrence of such entries is expected but the ROC solution is disrupted, due to the method adopted for ranking. It reacts on pairwise comparison of cell entries in the leftmost column (when ranking rows) and topmost (when ranking columns). So if the positional occurrence of these elements is such that they influence the ranking, poor cluster formation will result.

b- Bottleneck machines: these are machines that are used by a large number of components. Since these components can be expected to be dispersed over more than one cluster, such machines must appear in more than one row in the matrix. Otherwise, the ranking procedure creates large dispersed cluster with many machines and components contained in them.

The ROC algorithm work only after these two types of elements are identified and suppressed after visual analysis of the initial matrix solutions. Such prior assumptions bias solution, especially as the algorithm must indicate exceptions and bottleneck machines, not rely on their temporary suppression to be effective. Other drawbacks are:

- An inability to analyze large matrices since the binary words lengths increase. Rows and columns are compared pair wise increasing the number of comparisons necessary for a solution. The ranking being dependent on the positional coordinates of the entries in the matrix. The complete matrix needs to be analyzed, which increases computational time.
- *Inconsistency in the number of clusters, the identity of the exceptional elements and the machine

–component constitution of the clusters, is depending on the initial input matrix.

- Total neglect of load figures to decide the allocation of bottleneck machines among the clusters.

PROBABILISTIC APPROACH ALGORITHM

To overcome most of the limitation of other methods, the following approach is suggested. It will:

a- Use the machine-component matrix only, with no need for special coding or rearrangement to fit particular solution.

b- Simplify the identification of both exceptional elements and bottleneck machines by grouping correctly all the machines.

c- Ability to analyze large matrices, since it is only dealing with small values in comparison.

If there are M machines processing N components, then a machine i is assigned to process component j, hence their relation can be expressed by an incidence matrix A(i,j)=0, otherwise A(i,j)=1. The objective of the method is to rearrange the machine-component incidence matrix such that the element "1" focuses on the diagonal blocks of the matrix. This is achieved by introducing the probability of each component j processed on machine i, by means of determining the total number of components and then finding the probability of occurrence of each one independently by using the formulas:

Total number of components performed on machine i, which is indicated by ($TOTC_i$), is:

$$TOTC_i = \sum_{j=1}^{N} X_{i,j}$$

Probability of occurrence of component j on machine i, which is indicated by ($P\{X_{i,j}\}$), is:

$$P\{X_{i,j}\} = \frac{1}{TOTC_i}$$

Therefore the sum of each machine i, which is indicated by ($SUMC_i$), is: $SUMC_i = \sum_{j=1}^{N} P\{X_{i,j}\} * j$

Then this is sorted in decreasing value order, the ones with the same value are arbitrary ordered in the same order in which they appear in the current matrix.

Similarly, the same is done for the machines, i.e.:

Total number of machines used by component j in accordance to its process technology, indicatedby ($TOTM_j$), is: $TOTM_j = \sum_{i=1}^{M} Y_{i,j}$

Probability of occurrence of machines i used by component j for processing, which is indicated by$(P\{Y_{i,j}\})$, is: $(P\{Y_{i,j}\}) = \frac{1}{TOTM_j}$

Therefore the sum of each component j, which is indicated by ($SUMM_j$), is:

$$SUMM_j = \sum_{i=1}^{M} P\{X_{i,j}\} * i$$

Then this is sorted in decreasing value order; the ones with the same value are arbitray ordered in the same order in which they appear in the current matrix.

At the end of each stage the total of the rows and columns for the current matrix, indicated by $GRDTOT_k = SUMC_i + SUMM_j$, where k=1,.......,n; is determined and then compared with previous one. If they are equal then the method is terminated i.e. it has reached its optimum and then they are the clusters which gives the groups. Otherwise it is repeated with same steps as above. **Fig. (1)** indicates the flow chart for the algorithm.

The algorithm can start with any form of a machine-component matrix since it is an iterative approach that will converge to the optimal solution in a finite number of iterations.

PRACTICAL APPLICATION

The algorithm then was programmed on a computer using data from a company so as to find the optimum number of g oups. The application uses (42) machines and (72) components, as shown in **Table (1)** below.

Table (1) Machine- Component Original Matrix

```
00000000001111111111222222222233333333334444444444555555555566666
66666777
0012345678901234567890123456789012345678901234567890123456789012345
56789012
011                          1
0211  1  1 1 1     1 11       11  11           1    1    1
031
041                                1   1 1              1      1
051                     1
06 1  1    1 1                   1
07  1          1
08   1                 1 1                                  1
09    1                   1          1   1        1  11      1
10    1
11    1                            1  1                   1
12    11 1 111        1      1  1      1     1   1    11
13     1  1 1            1      11   1111 1 111 11
1
14      1                  11       1      1              1
15      1                  11       1      1              1
16        1
17        1   1 11       1                                 1
18        1              1              1            1
19        1    1       1                          1   1
20          1            1      1 1       1
21           1     1                              1
1
22            1 11  1                                      1
23                1
24                      1
25                      1
26                      1      1
27                      1
28                      1
29                      1
30                      1
31                        1              1           1       1
32                        1          1   1              11  1 11
33                             1
34                               1   1
35                                                 1            1
1111111
36                                                 1
111111
37                                                 1
38                                                           1
39                                                            1
40                                                              1
41                                                              1
42                                                              1
```

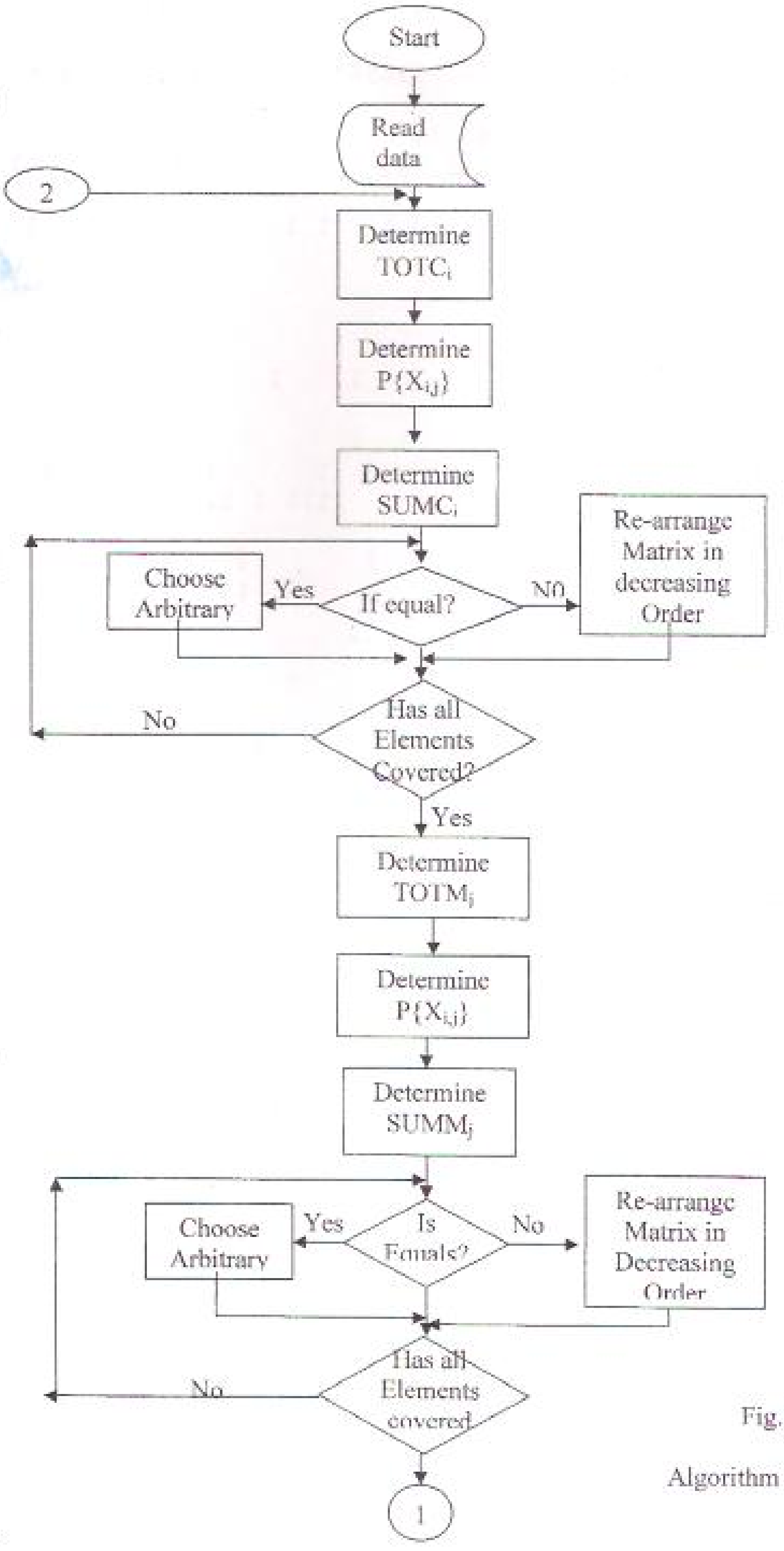

Fig. (1)

Algorithm Flowchart

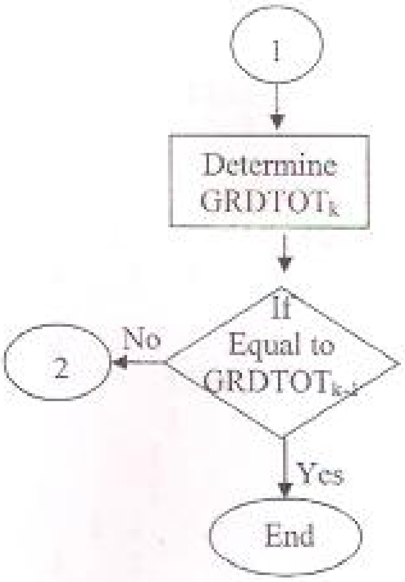

Fig. (1) continued

Then applying the algorithm produced, the result shown in Table (2).:

Table (2) The resulted matrix after the application of the algorithm

```
0003011002351322453564223513044535245672466033444621566667760111501
0223451
0014520281378009728630382411659560513124202979468524167890144356939
7675387
021111111111111111
0411              1111
051                   1
011                    1
031
06  1111                1
12  111 11        1    1
11  1     11
09  1
10  1
21   1      1
20        1
32         1       11
26           1        1
33           1
13                1  1  1
18                   1
24                    1
25                    1
27                    1
28                    1
29                    1
30                    1
34                      1
```

```
12                        1111111
11                               1
09                        1      111111
21                                1    1
20                         11           11
32                               1 11      11
13                         11111        11  1111111
18                                   1  1   1
34                               1
19                        1       1         1      11
31                                 1111
38                                    1
35                                     1
42                                     1
08                                      1 1        1
17                                      1   1
39                                         1
16                                          1
07                                                  1
35                                                   1111111
08                                                            1
17                                                             1111
07                                                                 1
36                                                   1111111
37                                                   1
40                                                           1
41                                                           1
22                                                             1111
1
14
111111
15
111111
23
1
```

EXCEPTIONAL ELEMENTS

There were many exceptional elements in the final matrix, and then a re-assignment was made to these elements. This has resulted in determining the group matrix as shown in **Table (3).** This group matrix contains three groups, without any exceptional parts.

Table (3) Groups after re-assignment

```
000301100235132245356422351304453524567246603344462156666776011150
10223451
001452028137800972863038241165956051312420297946852416789014435693 .
97675387
021111111111111111
0411              1111
051                   1
011                    1
031
06  1111                1
12  111 11        1    1
11  1     11
09  1
10  1
21   1      1
20        1
32         1       11
26           1        1
33           1
13                1  1  1
18                   1
24                    1
25                    1
27                    1
28                    1
29                    1
30                    1
34                      1
12                       1111111
11                              1
09                       1      111111
21                               1    1
20                        11           11
32                              1 11     11
13                        11111        11  1111111
18                                  1  1   1
34                              1
19                       1       1         1      11
31                                1111
38                                   1
35                                    1
42                                    1
08                                     1 1        1
17                                     1   1
39                                        1
16                                         1
07                                                 1
```

```
35   11111111
08           1
17            1111
07                1
36   1111111
37   1
40          1
41          1
22            1111
14           111111
15           111111
23                1
```

CONCLUSIONS

The method introduced in this study has simplified the calculation for the (0-1) matrix because of the use of probability which lead to the use of small numbers in calculations and therefore less time needed in the manupalation of the group matrix.

Also the introduced method is able easily to deal with a large number of components and machine without having to extend memory or splitting of matricies.

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