ANALYSIS OF EFFICIENCY MEASURES FOR BLOCK DIAGONAL MACHINE-COMPONENT CHARTS

Hamid Seifoddini and Manoocher Djassemi

Industrial and Systems Engineering Department
University of Wisconsin-Milwaukee

Abstract

Group efficiency measures have been developed to evaluate machine-component charts for the formation of cellular manufacturing systems. In this paper the existing grouping efficiency measures will be evaluated by determining the relationship between the values of a grouping efficiency measure and the performance of the corresponding cellular manufacturing system.

Key words: Cellular manufacturing, group technology, machine-component grouping, and grouping efficiency.

1 Introduction

The data for machine-cell formation for the development of cellular manufacturing systems is organized in a matrix called "machine-component chart." The machine-component chart represents the machining requirements of parts in a manufacturing system. A "one" entry in the machine-component chart indicates the presence of an operation on a machine while a zero entry indicates the absence of such an operation [1,11].

A block-diagonal form of a machine-component chart in which "one" entries are concentrated in blocks along the diagonal of the matrix is used to form a cellular manufacturing system. Blocks in this form of machine-component chart represent machine-component groups. Machine-component grouping algorithms are used to convert a machine-component chart to its block diagonal form [2,3,4,6,9,13,14].

A complete block diagonal form with no interactions between blocks is necessary for the formation of a cellular manufacturing system with independent machine-cells. Interactions between blocks in the machine-component chart represent intercellular moves. The performance of a cellular manufacturing is adversely affected by the number of intercellular moves. For this reason, a number of grouping efficiency measures have been developed to evaluate a block diagonal form for its suitability for developing a cellular manufacturing system.

In this paper a procedure based on simulation modeling is used to determine the relationship between the values of different grouping efficiency measures of a machine-component chart and the performance of the corresponding cellular manufacturing system.

2 Grouping Efficiency Measures

In this section, a number grouping efficiency measures including bond energy (BE), grouping efficiency (GE), grouping efficiency (GC), and grouping capability index (GCI) will be discussed.

One of the first algorithms for converting a binary matrix into a block diagonal form uses a grouping measure called "bond energy" (BE) [9]. This measure is calculated as follows:

$$BE = \sum_{i=1}^{m} \sum_{j=1}^{n} d_{ij} \left[d_{i,j+1} + d_{i,j-1} + d_{i+1,j} + d_{i-1,j} \right]$$

where

m = number of rows in the binary matrix
n = number of columns in the binary matrix
d_{ij} = a binary (zero or one) entry in row i and column j of the binary matrix
$d_{o,j} = d_{m+1,j} = d_{i,0} = d_{i,n+1} = 0$

Since this measure is at its maximum value when the desirable block diagonal form is achieved, it can be used as a grouping efficiency measure.

Grouping efficiency (GE) is, specifically, developed to evaluate the efficiency of block diagonal matrices [4]. It is defined as:

$$GE = q E_1 + (1 - q) E_2$$

where

$$E_1 = \frac{\text{Number of ones in the diagonal blocks}}{\text{Total number of elements in the diagonal blocks}}$$

$$E_2 = \frac{\text{Number of zeros in the off-diagonal blocks}}{\text{Total number of elements in the off-diagonal blocks}}$$

q = A weighting factor ranging between zero and one

The selection of q for grouping efficiency is arbitrary and the range of values for this measure is limited to 75-100%.

To overcome the problems of the selection of q and the limited range of grouping efficiency, another grouping performance measure has been developed. This measure is grouping efficacy (GC) and is defined as [7]:

$$GC = q \cdot E_1 + (1-q)\ E_2$$

in which

$$q = \sum_{r=1}^{K} M_r \cdot N_r \ /\ m \cdot n$$

$$E_1 = \frac{e_d}{\sum_{r=1}^{K} M_r \cdot N_r}$$

$$E_2 = 1 - \frac{e_d}{m \cdot n - \sum_{r=1}^{K} M_r \cdot N_r}$$

where

K	=	number of blocks
M_r	=	number of rows in rth block
N_r	=	number of columns in rth block
m	=	number of rows in the machine-component chart
n	=	number of columns in the machine-component chart
e_d	=	number of ones in the diagonal blocks

Grouping efficacy overcomes the problem of grouping efficiency by incorporating the size of the matrix into the calculation of the measure. It also provides a quantitative basis for calculating the weighing factor, q.

In a study by Hsu [5], it is shown that neither group efficiency nor group efficacy is consistent in predicting the performance of a cellular manufacturing system based on the structure of the corresponding machine-component chart.

Group capability index (GCI) [5] is defined as:

$$GCI = 1 - \frac{e_o}{e}$$

where

e_o	=	number of exceptional elements in the machine-component chart
e	=	total number of one entries in the machine-component chart

Contrary to the previous two measures, GCI excludes zero entries from the calculation of grouping efficiency.

In this paper, simulation modeling is used to compare the existing grouping efficiency measures by determining their effectiveness in predicting the performance of a cellular manufacturing system.

3 A Comparative Study

Two performance measures: average flow time and work-in-process will be used. Simulation methodology will be employed to determine these measures for a cellular manufacturing system. The purpose is to determine how accurately a grouping efficiency measure predicts the performance of a cellular manufacturing system through the evaluation of the corresponding machine component chart. The algorithmic form of the procedure for comparison of different grouping efficiency measures is as follows.

1. Use one of the existing machine-component grouping algorithms to convert the machine-component chart to a block diagonal form and develop the corresponding cellular manufacturing system.
2. Calculate the efficiency of the machine-component chart using bond energy (BE), grouping efficiency (GE), grouping efficacy (GC), and grouping capability index (GCI).
3. Develop the simulation model of the cellular manufacturing system in Step 1.
4. Estimate the average flow time and average in-process inventories using simulation.
5. Repeat steps 1-4 for all grouping efficiency measures and evaluate the relationship between the values of grouping efficiency measures and the performance measures estimated in step 4.

This procedure will be used in the next section to compare the four grouping efficiency measures discussed here.

4 Analysis of Results

The machine-component chart used for the analysis is presented in Figure 1. The block diagonal form of this machine-component chart is depicted in Figure 2. Other assumptions about the manufacturing system are as follows:

- The average time between orders for parts is 10 hours (exponential p.d.f.). The size of each order is uniformly distributed between 1-10 parts.
- The processing and set-up times are deterministic.
- Set up times are sequence dependent. Set up times within a part-family are half of those parts from two different part-families. This ratio is 0.1 when two identical parts visit a machine in row.
- Batch formation is used between machine cells, but within each machine cell, parts are processed and transferred in batches of size one.

To evaluate the relationship between the value of grouping efficiency measures and the performance of the cellular manufacturing system, four different versions of the machine-component chart in Figure 1 is used.

		Parts										
		1	2	3	4	5	6	7	8	9	10	11
M	1			1				1				1
a	2	1	1				1			1		
c	3	1	1				1			1		
h	4				1	1			1		1	
i	5			1				1				1
n	6			1				1				1
e	7				1	1			1		1	

Fig. 1. Initial machine-component chart.

		Part Families										
		1	2	6	9	3	7	11	4	5	8	10
M	2	1	1	1	1							
a	3	1	1	1	1							
c	1					1	1	1				
h	5					1	1	1				
i	6					1	1	1				
n	4								1	1	1	1
e	7								1	1	1	1

Fig. 2. Block diagonal form of the machine-component chart.

The block diagonal form in Fig. 2 is used as the first version. In this version there is no intercellular move. As expected, all grouping efficiency measures yield 100% efficiency (the value of BE is adjusted to be 100% at its maximum to be consistent with other measures). The values of these measures are presented in Table 1 and the corresponding values of average flow time and work-in-process include 35 and 19 units respectively.

Table 1. Efficiency Measure for Version 1.

Efficiency Measures			
BE	GE	GC	GCI
1	1	1	1

The second version is different from the first version, in that part 1 has one operation outside machine cell 1. Since this part has minimum work load content (processing time x volume), its effect on the performance of the cellular manufacturing system is minimal. The simulation results reflect this as the average flow time and work-in process inventories are 38 and 19 units respectively. The grouping efficiency measures, on the other hand, vary as shown in Table 2.

Table 2. Grouping Efficiency Measures for Version 2.

Grouping Efficiency			
BE	GE	GC	GCI
.93	.97	.92	.96

In the third version, part 8 in the original machine-component chart is modified to have an operation on machine 3 instead of machine 4. This part has a high work load content and the change of its status significantly changes the two performance measures in this version. The average flow time and average work-in-process in this version include 78 and 40 units respectively. Again, deterioration of grouping efficiency measures varies as indicated in Table 3.

Table 3. Grouping Efficiency Measures for Version 3.

Grouping Efficiency			
BE	GE	GC	GCI
.90	.97	.92	.96

Finally, in the fourth version, two exceptional parts are introduced including parts 1 and 5 which have operations on machines 4 and 5 respectively. The work load content of these two parts combined is less than the work load content of part 8 in the previous case. As a result their impact on the performance of the cellular manufacturing system is less than the impact of parts which yield 43 and 19 units for the average flow time and in-process inventories, respectively. The grouping efficiency measures are not consistent with the simulation results and indicate deterioration in the efficiency of the machine-component chart as depicted in Table 4.

Table 4. Grouping Efficiency Measures for Version 4.

Grouping Efficiency			
BE	GE	GC	GCI
.84	.94	.85	.92

5 Conclusions

Four grouping efficiency measures were discussed and simulation modeling was used to evaluate their effectiveness in predicting the performance of a cellular manufacturing system. Average flow time and average in-process inventory were used as performance measures. The simulation results indicate that these grouping efficiency measures are not consistent in predicting the performance of a cellular manufacturing system. A grouping efficiency measure based on work load contents of parts should be developed.

6 References

1. Burbidge, J. L., "A Manual Method of Production Flow Analysis," *The Production Engineer*, 56(1), 1977, p. 34.
2. Carrie, A. S., "Numerical Taxonomy Applied to Group Technology and Plant Layout," *Int. J. Prod. Res.*, 11(4), 1973, pp. 399-416.
3. Chan, H. M. and Milner, D. A., "Direct Clustering Algorithm for Groups Formation in Cellular Manufacturing," *J. Manuf. Systems*, 1(1), 1982, pp. 65-74.
4. Chandrasekharan, M. P. and Rajagopalan, R., "ZODIAC — An Algorithm for Concurrent Formation of Part Families and Machine Cells," *Int. J. Prod. Res.*, 25(6), 1987, pp. 835-850.
5. Hsu, C. P., "Similarity Coefficient Approaches to Machine-Component Cell Formation in Cellular Manufacturing: A Comparative Study," unpublished Ph.D. thesis, Industrial and Systems Engineering, University of Wisconsin-Milwaukee, 1990.
6. King, J. R. and Nakornchai, V., "Machine-Component Group Formation in Group Formation in Group Technology — Review and Extension," *Int. J. Prod. Res.*, 20(2), 1982, pp. 117-133.
7. Kumar, C. S. and Chandrasekharan, M. P., "Grouping Efficacy: A Quantitative Orientation for Goodness of Block Diagonal Forms of Binary Matrices in Group Technology," *Int. J. Prod. Res.*, 28(2), 1990, pp. 233-243.
8. Law, A. M. and Kelton, W. D., *Simulation Modeling and Analysis*, McGraw-Hill, New York, 1982.
9. McAuley, J., "Machine Grouping for Efficient Production," *Prod. Eng.*, 51, Feb. 1972, pp. 53-57.
10. McCormick, W. T., Schweitzer, P. J. and White, T. W., "Problem Decomposition and Data Reorganization by a Clustering Technique," *Operations Research*, 52, Feb. 1972, pp. 993-1009.
11. Seifoddini, H. and Wolfe, P. M., "Application of the Similarity Coefficient Method in Group Technology," *Institute of Industrial Engineers (IIE) Transactions*, 18(3), 1986, pp. 271-277.
12. Seifoddini, H., "Duplication Process in Machine Cell Formation in Group Technology," *Institute of Industrial Engineers (IIE) Transactions*, 21(4), 1989, pp. 382-388.
13. Sokal, R. R. and Sneath, P. H. A., *Principles of Numerical Taxonomy*, Freeman, San Francisco, California, 1963.
14. Wei, J. C. and Kern, G. M., "Commonality Analysis: A Linear Cell Clustering Algorithm for Group Technology," *Int. J. Prod. Res.*, Vol. 27, No. 12, pp. 2053-2062, 1989.