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Cellular manufacturing system design with proper assignment of machines and parts

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Abstract

This study is concerned with the strict machine-cell and part-family grouping (MCPFG) in cellular manufacturing system design. Most of MCPFG methodologies often suffer from improper assignment of machines and parts in which exceptional machine has more common operations with machines in a cell other than its own cell and exceptional part has more operations through machines in a cell other than the cell corresponding to its own family. This results in the loss of similarity in part design or common setup of machines and the benefits from the conversion of job shop manufacturing into cellular manufacturing are lost. In this study, a two-phase methodology is proposed to find the machine-cells and part families under the strict constraints in which all machines and parts are assigned to its most proper cells and families. Test results with moderately medium-sized ill-structured MCPFG problems available from the literature show the substantial efficiency of the proposed approach..

1. Introduction

During the last three decades, cellular manufacturing(CM) has received considerable attention since CM has been proved a very effective approach for improving the productivity of batch-type manufacturing systems. The fundamental step toward designing CM system is to create part families and associated machine cells or vice versa, which is known as the machine-cell and part-family grouping (MCPFG) problem in literature. Part family is a collection of parts that have similar operations and require a similar set of machines for the completion of these operations. A set of machines grouped to produce the parts in a specific part family is called the machine cell. The objective of MCPFG is to find independent machine cells with minimum interaction between cells so that a set of part family can be completely produced in a cell.

MPG problem is often made complicated by exceptional parts and/or exceptional machines. An exceptional part is a part that requires processing in another machine cell. An exceptional machine is a machine that processes parts from a different family. Both exceptional parts and exceptional machines cause inter-cell movement of parts. An effective CM system needs a MCPFG approach that produces part families and machine cells to minimize inter-cell moves.

The basic input to analysis of MCPFG is a binary machine-part incidence matrix $A(=[a_{ij}])$ where the element a_{ij} is 1 or 0 depending on whether or not part j requires processing on machine i. Given a binary machine-part incidence matrix, similarity coefficients defined between machines or parts are used to group machines and parts in most MCPFG algorithms.

Most of the approaches for solving MCPFG problems attempts to find cells and families by transforming its initial machine-part incidence matrix into the block diagonal matrix. The best block diagonal structure from the initial incidence matrix means the best cell configuration with minimum number of inter-cell part moves. In order to evaluate the performance of MCPFG, a lot of measures assessing the goodness of solutions have been proposed and the properties of those measures have been discussed[9]. In spite of some drawbacks, grouping efficiency[2] and grouping efficacy[6] have been used as the most popular measures for evaluating the goodness of MCPFG.

However, most of the traditional methods dealing with MCPFG suffered from the illogical grouping of machines or parts. MCPFG algorithms which seek to find the best solution in terms of the efficiency measure for the goodness of block diagonal matrix often produce illogical machine cells due to improper machine assignment in which an exceptional machine may have more common operations with machines in a cell other than its own cell[10]. From practical manufacturing point of view, the cell configuration with improper machine assignment implies that the corresponding machine cell does not fully utilize the benefit of from cellularization based on the similarity of machine or parts. In extreme case, in a specific cell the machines perform no operations to process the parts assigned to the part family corresponding to that machine cell and this illogical grouping leads to the diagonal blocks containing rows or columns only of zeros in the solution matrix. This is known as the degeneracy in block diagonalization[8]. Sandbothe claims that disallowing degenerate solutions should be included as a constraint on the formation of machine cells or part families since grouping efficacy could be improved possibly by rearranging the primary solution of degeneracy.

The objective of this study is twofolds. First, we show that attempting to eliminate illogical machine or part assignments can leads to a better solution to the MCPFG problem in terms of the grouping efficiency or the grouping efficacy or both. Second, an effective two-phase approach to logical MCPFG which seeks to find the diagonal blocks under the strict constraints assuring that all machine and parts are logically assigned to its proper cells and families is proposed to improve the quality of the initial solution by reassigning exceptional machines and exceptional parts with a view to totally eliminate illogical grouping. Computational experiments with well-known data sets from literature favorably compare the effectiveness of the proposed approach.

2. Logical machine-cell and part-family grouping

Through out the paper, the following definitions, most of which comes from Seifoddini[8] and Kumar and Chandrasekharan[6].

Definitions

- Block(cluster): a submatrix of the machine-part incidence matrix formed by the intersections of rows(machines) representing a machine cell and columns representing a part family
- Exceptional machine: the machine required by more than one cell
- Exceptional part: the part requiring operations in more than one cell.
- Singleton cell: the cell containing only a machine
- Singleton family: the family containing only a part
- Improperly assigned exceptional machine: the exceptional machine having more common operations with machines in a cell other than its own cell.
- Improperly assigned exceptional part: the exceptional part having more operations through machines in a cell other than its own cell corresponding to its initial family
- Degenerate block: diagonal block with improperly assigned exceptional machines or parts by containing rows of only zeros or columns only of zeros

Based on the above definitions, logical MCPFG seeks to find the logical blocks of cells and families satisfying the following strict constraints:

(1) No machine cell(part family) is singleton.
(2) No exceptional machine(part) is improperly assigned to cell(family)
(3) No block is degenerate.

Constraint (1) indicates that each machine cell(part family) contains at least two machines(parts). From constraint (1), the MCPFG problems the optimal solution of which contains singleton cells or families are not considered in this study. Constraint (2) ensures that every machine is assigned to the cell in which the machine has most common operations with machines other than remaining cells and every part is assigned to a family corresponding to the cell in which that part has most operations through the machines other than the ones in remaining cells. Degeneracy of blocks implies the extreme result from improper assignment of machines or parts. Empty cell to which no part is assigned is an example of degeneracy of block. From manufacturing point of view, improper assignment of machines implies that the resulting system does not fully utilize the benefits from cellular manufacturing most of which comes from are . Constraint (3) avoids such the extreme assignments of machines or parts so that each machine cell fully utilizes the benefits from cellular manufacturing.

3. Two-phase approach to logical grouping

To find machine cells and part families, two-phase methodologies have been wildly adopted in literature and shown the successful application to MCPFG. Basically, two-phase nature of the solution approach to MCPFG is not a serious drawback in the design of CM system[10]. Since the purpose of this study, however, does not consist in adding another algorithm over the heap of numerous grouping methods, two-phase approach based on the application of existing efficient grouping algorithm is proposed.

In phase 1, an initial solution is found by applying the p-median mathematical model. The p-median model is adopted in this study since it has gained considerable attention from the research community in cellular manufacturing systems as one of the efficient methodologies for solving MCPFG problem. In this study, a modified version of the p-median formulation by Wang and Roze[11] which is slightly adjusted with additional constraint expressing the lower limit on the cell size so as to avoid the formation of singleton machine cell. As a similarity coefficient, Wei and Kern's coefficient[12] is adopted for maximization of the objective function since Wang and Roze reports that Wei and Kern's coefficient gives the best results compared to the results with other well-known coefficients. If the solution obtained by solving the p-median model contains no illogical groups, the MCPFG procedure stops. Otherwise, go to phase 2.

In phase 2, illogical machine cells are first eliminated by reassigning improperly assigned machines to its most proper cells and illogical families are then eliminated by reassigning improperly assigned parts to its most proper families. In this study, the reassignment procedure in Won[13] is adopted to eliminate illogical blocks. Seifoddini claims that the reassignment of exceptional machines is the only remedy for improving the solution by reducing the number of inter-cell moves of parts since the similarity coefficient-based approaches to MCPFG do not always eliminate the improper machine assignment.

4. Computation experiment

To test the effectiveness of the proposed approach, three well-known data sets are selected from the open literature and the solution matrices are illustrated. Those data sets have been frequently cited for comparative purpose by many authors since they are ill-structured and shows significant gap among the existing methods used for computation experiment.

The proposed approach was coded in TURBO PASCAL 5.0 version and implemented on a Pentium 133 MHz personal computer with the HYPER LINDO program. The lower limit on cell size is set at 2 and the upper limit on cell size is set at the same level as the total number of machines in each problem. The problem instances were run under the limit on the number of iterations preset by the HYPER LINDO program given an instance of optimization problem.

The first data set is taken from King[5]. The problem set includes 16 machines and 43 parts. The proposed approach was implemented for the values of p varying 3 to 8. Figure 1 shows a six-group solution matrix without improper assignment of machines and parts. Figure 2 is the solution matrix given by Dimopoulos and Mort[4]. The solution in figure 2 gives higher grouping efficacy than the solution in figure 1, but shows the illogical grouping due to improper assignment of machine 1. This implies that from the illogical solution of figure 2 the number of groups should be reduced to five so as to obtain the logical groups without improper assignment of machines. In this case, however, the grouping efficacy may be deteriorated due to increased voids as a result of merging the groups.

The second data set is taken from Carrie[1]. The problem set includes 20 machines and 35 parts. The proposed approach produces the four-group solution as shown in figure 3 with the grouping efficiency of 88.10%, while Ng[7] gives the fifteen-group solution as shown in figure 4 with the grouping efficiency of 94.5% which is higher than the proposed approach. But Ng states that from practical sense, the solution in figure 3 is more satisfactory than the one in given in figure 4 even though the latter gives higher grouping efficiency than the former. Note that the illogical solution in figure contains seven empty groups due to improper assignments of machines. This implies that maximizing only a single efficiency measure of goodness of MCPFG may often produce illogical solution with improper assignment of machines and parts due to too many groups.

The third data set is taken from Chandrasekharan and Rajagopalan[3]. The authors gave seven data sets with a variety of grouping efficiency. But in this study only a data set which is mostly ill-structured among the seven data sets is used for comparative purpose. Figure 5 shows an eleven-group logical solution matrix with no improper assignment of machines and parts. Dimopoulos and Mort also obtained an eleven-group solution with the grouping efficacy of 43.7% which is higher than the one of 42.58% from the solution in figure 5. But the authors'solution contains illogical groups due to singleton cells.

5. Concluding remarks

This study shows that existing approach to MCPFG which attempts to maximize a single efficiency measure of goodness often leads to illogical grouping due to improper assignment of machines and parts. To find logical groups, a simple two-phase p-median approach is proposed. Computational results with the well-known ill-structured data sets available in open literature shows the proposed approach can effectively be applied to produce logical groups with proper assignment of machines and parts.

References

[1] Carries, A. S.(1973). Numerical taxonomy applied to group technology and plant layout. *International Journal of Production Research*, **11**(4), 399-416.

[2] Chandrasekharan, M.P., and Rajagopalan, R.(1986). An ideal seed non-hierarchical clustering algorithm for cellular manufacturing. International Journal of Production Research, 24(6), 451-464.

[3] Chandrasekharan, M.P., and Rajagopalan, R.(1989). GROUPABILITY: an analysis of the properties of binary data matrices for group technology. *International Journal of Production Research*, **27**(6), 1035-1052.

[4] Dimopoulous, 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.

[5] King, J. R.(1980). Machine-component grouping in production flow analysis: review and extension. . *International Journal of Production Research*, **18**(2), 213-232.

[6] Kumar, C. S., and Chandrasekharan, M. P.(1990). Grouping efficacy: a quantitative criterion for goodness of block diagonal forms of binary matrices in group technology. *International Journal of Production Research*, 28(2), 603-612.

[7] Ng, S. M.(1996). On the characterization and measure of machine cells in group technology. *Operations Research*, **44**(5), 735-744.

[8] Sandbothe, R. A.(1998). Two observations on the grouping efficacy measure for goodness of block-diagonal forms. *International Journal of Production Research*, **36**(11), 3217-3222.

[9] Sarker, B. R., and Khan, M.(2001). A comparison of existing grouping measures and a new weighted grouping efficiency measure. *IIE Transactions*, **33**(1), 11-27.

[10] Seifoddini, H.(1989). A note on the similarity coefficient method and the problem of improper machine assignment in group technology applications. *International Journal of Production Research*, **27**(2), 1161-1165.

[11] Wang, J., and Roze, C.(1997). Formation of machine cells and part families in cellular manufacturing: a modified p-median model and a comparative study. *International Journal of Production Research*, **35**(5), 1259-1286.

[12] Wei J. C., and Kern, G. M.(1989). Commonality analysis: a linear cell clustering algorithm for group technology.

International Journal of Production Research, 27(12), 2053-2062.

[13] Won, Y.(2000). Two-phase approach to GT cell formation using efficient *p*-median formulations. *International Journal of Production Research*, 38(7), 1601-1613.

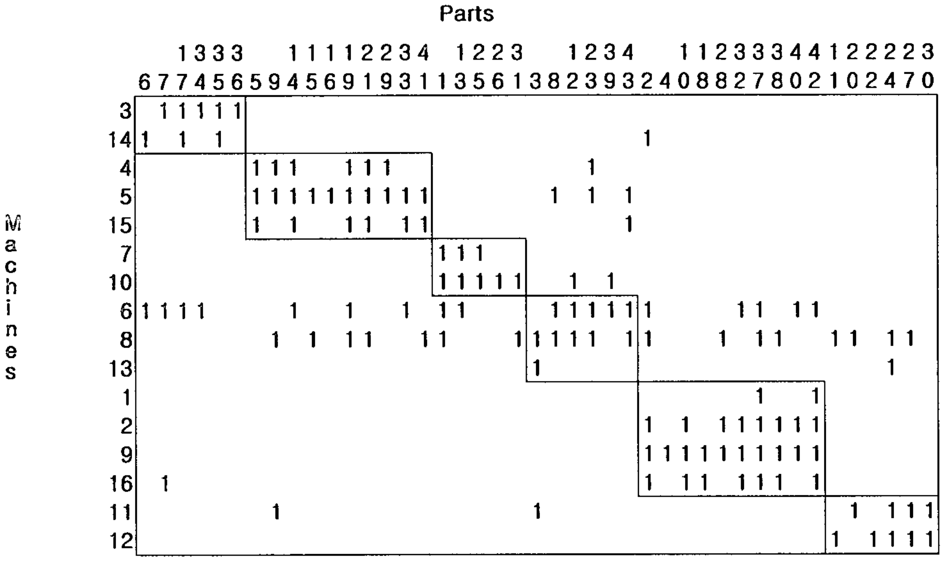

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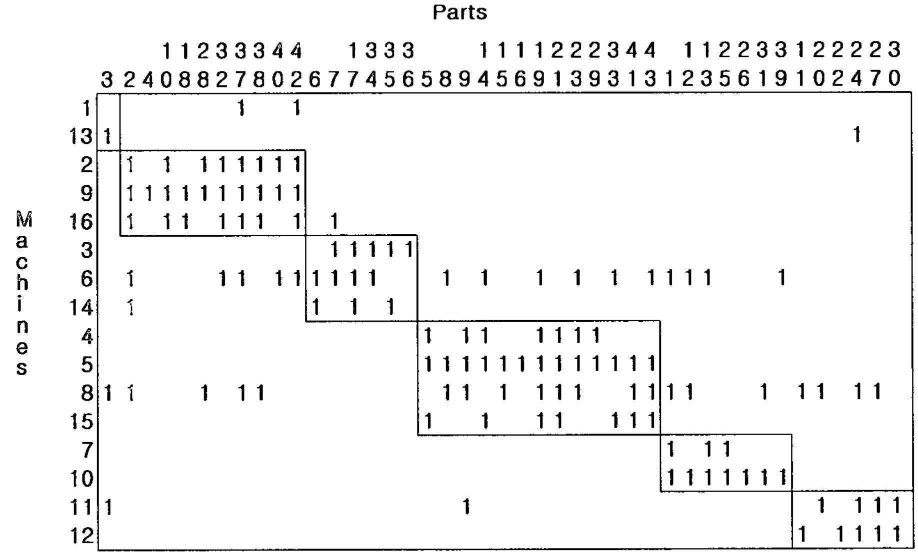
Figure 1. 6-group solution to King's data set with proper assignment of machines and parts



	3	2	4	10	18	28	32	37	38	40	42	6	7	17	34	35	36	5	8	9	14	15	16	19	21	23	29	33	41	43	1	12	13	25	26	31	39	11	20	22	24	27	30
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Figure 2. Dimopoulos and Mort's 6-group solution with improper assignment of machines and parts

Parts

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

Figure 3. 4-group solution to Carrie's data set with proper assignment of machines and parts

Parts

Machines		35			33	34		1	3	5	15	17	20	23	25	29			4	6	11	21	28	30	32	2	7	10	12	13	18	24	27	31		9	8	14	16	19	22	26
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Figure 4. Ng's 15-group solution with improper assignment of machines and parts

Parts

Machines	5	16	30	34	38	2	25	28	32	6	12	22	39	10	15	23	3	21	35	8	11	1	26	36	37	4	18	24	27	13	14	33	40	7	17	19	29	31	9	20
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8	1	1	1	1	1								1										1			1														
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Figure 5. 11-group solution to Chandrasekharan and Rajagopalan's data set with proper assignment of machines and parts