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Group Technology: Generation and Selection of the Best Multi-Criteria Alternative

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Abstract

Group technology is a modern manufacturing approach which has been widely used in many industries. This paper addresses the machine-part cell formation problem while several criteria are considered for the evaluation of alternatives. The criteria include the number of work stations or cells, the cost of set-up and operation of different designs, and the volume of inter-flow traffic. Methods are presented for generation of efficient alternatives, evaluation of alternatives, and selection of the best alternative. This paper develops an approach to determine the machine-part cells and to choose the part processing plans minimizing the inter-cell part flow. The proposed approach solves the problem iteratively until a set of plans and the machine-part cells are obtained with minimal inter-cell part flow.

1. INTRODUCTION

Many US firms are utilizing the cellular manufacturing technology to increase their productivity and quicken their responses to market change. The design of a cellular manufacturing system consists of three major stages: 1) economical and technical feasibility study; 2) design of manufacturing systems; and 3) systems implementation (Wemmerlov and Hyer 1987). A cellular manufacturing system (CMS) can be designed by applying group technology and just-in-time concepts. One of the first problems to be solved in the system design stage is the machine-part cell formation. According to similarities in design features or processing requirements, the parts are grouped into families, and machines into cells. Families of parts can then be completely processed in their corresponding machine cells. The design procedures based on design features of parts require a classification and coding system that is time-consuming and demands additional expertise

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to develop. Most design methods use the processing requirements of parts to form machine-part cells (King and Nakornchai 1982; Kusiak 1987; Srinivasan and Narendran 1991).

The processing requirements of parts on machines can be represented in the form of a matrix $\{a_{ij}\}$ which is called the machine-part incidence matrix. The incidence matrix has m rows representing the machines and n columns representing the parts. An element a_{ij} in the incidence matrix is 1 if part j requires an operation to be performed on machine i; otherwise a_{ij} is zero. The grouping of parts into families and machines into cells results in row and column exchanges of the incidence matrix. The expected solution is a block-diagonal matrix. But in most cases, the final grouped cells are not mutually exclusive. A few entries outside the diagonal blocks represent operations to be performed outside the assigned machine cells. These elements are called exceptional elements. The corresponding machine is called a bottleneck machine, and the corresponding part is called an exceptional part.

During the past two decades, numerous research papers have been published for cell formation. These methods are based on the following approaches:

1) Coding and classification (Bedworth et al. 1991, Xu and Wang 1989); 2) Machine-part group analysis (Burbidge 1971, King 1980, Chan and Milner 1982, Chandrasekaran and Rajagopalan 1986); 3) Similarity coefficients (Seifoddini and Wolfe 1986, Askin et al. 1991); 4) Knowledge-based (ElMaraghy and Gu 1988, Singh and Qi 1991); 5) Mathematical programming (Choobineh 1988, Rajamani et al. 1992, Logendran 1990); 6) Fuzzy clustering (Li et al. 1988, Xu and Wang 1989).

Most of these methods concentrate on forming the machine-part cells. If there exist exceptional elements in the final cell structure, these methods suggest duplicating all bottleneck machines or to subcontracting exceptional parts. They do not provide systematic means to handle the cell structure with exceptional elements.

In this paper, we propose a multiple criteria decision making (MCDM) framework for generating alternative cell structures and selecting the best one. The approach includes three levels. First, the seed alternative is formed by using our ANN-based clustering method (Malakooti and Yang 1995). Next, a heuristic procedure is proposed to generate alternatives from the seed alternative. This approach can generate alternatives for any feasible number of cells. Finally, the best machine-cell structure is found with considerations of maximizing the machine utilization rate, minimizing the number of duplicated machines, and minimizing the number of exceptional elements. We investigate relationships among several criteria and report experimental results.

The rest of the paper is organized as follows. In section 2, we give the multiple criteria approach for the machine-part cell formation problem. In section 3, an example is solved and the relationship among several criteria is also investigated. Section 4 is the conclusions.

2. MULTIPLE CRITERIA DECISION MAKING DESIGN APPROACH FOR MACHINE-PART CELL FORMATION IN CELLULAR MANUFACTURING

From our experiments and other researchers' experiments, we note that the final cell structures for most practical problems include some exceptional elements. These exceptional parts need to be moved among different machine cells. To decrease this kind of intercell part flow, the corresponding bottleneck machines could be duplicated, but this could result in increased capital cost and decreased machine utilization rate. Thus, there is a trade-off among intercell part flow and the number of duplicated machines, as well as other criteria such as machine utilization, cell utilization, machine loading, etc. We propose a multiple criteria decision making approach to design the machine-part cells to minimize the exceptional elements, to minimize the number of duplicated machines (capital cost), to maximize the machine utilization rate, and to find the best number of machine-part cells.

Most methods require the number of cells, K, as a known parameter. But in the practical design, the optimal number of cells is unknown and needs to be determined. Clearly, to put all machines and parts into one single cell, or to put only one machine into each cell does not make any sense. We assume that the minimum number of machine-part cells R_{min} is two.

2.1. Model Formulation

2.1.1. Definitions

1) An alternative a_i is a machine-part cell structure which can be represented as $\{(m_{ir}, p_{ir}), r = 1, 2, ..., R\}$, where m_{ir} is the index set of machines in cell r, p_{ir} is the index set of parts in cell r, and R is the number of cells.

2) R_{min} is the minimum possible number of cells and R_{max} the maximum possible number of cells.

3) Machine Utilization (MU)

MU can be computed as (Chandrasekharan and Rajagopalan 1986):

$$MU = N1/\left(\sum_{r=1}^{R} m_r n_r\right)$$

where N1 is the total number of 1's within the groups, R is the number of groups, m_r is the number of machines in the *rth* group, and n_r is the number of components in the *rth* group. Generally speaking, the higher the MU, the better the machines are being utilized, and the better the machine-part cell structure.

2.1.2. Model

1) P1 (multiple criteria problem):

From the set of q alternatives (machine-part cell structures) $A = \{a_i, i = 1, 2, ... , q\}$, find the alternative with the best number of cells which optimizes the following objectives:

$\min f_1(a_i)$ = number of duplicated machines

$\min f_2(a_i)$ = number of exceptional elements

$\max f_3(a_i)$ = machine utilization rate

$$a_i \in A$$

The problem formulated above is a discrete multiple criteria decision making one. There are two kinds of approaches to solving discrete MCDM problems (Malakooti 1988): a) One assumes that there exists a utility function for a given Decision Maker (DM) that can predict his/her behavior and interest; b) One makes no assumptions regarding the existence of a utility function, but provides the DM with a set of simple but effective tools and lets him/her, by trial and error, and if-then type of statements, obtain the best alternative.

Under the assumption of an additive utility function:

$$U(a_i) = U(f_1^*(a_i), f_2^*(a_i), f_3^*(a_i)) = w_1 f_1^*(a_i) + w_2 f_2^*(a_i) + w_3 f_3^*(a_i)$$

where w_1, w_2, and w_3 are weights representing the importance of each criterion to the DM; and $f_1^*(a_i)$, $f_2^*(a_i)$, and $f_3^*(a_i)$ are normalized values of $f_1(a_i)$, $f_2(a_i)$, and $f_3(a_i)$. P1 can be transformed into the following single objective problem P2. Under the above formulation, an alternative $a_i \in A$ is quasi-nondominated if and only if another alternative $a_{i'} \in A$ such that $f_1^*(a_{i'}) > f_1^*(a_i)$, $f_2^*(a_{i'}) > f_2^*(a_i)$ does not exist.

2) P2 (additive utility problem):

From the set of alternatives $A = \{a_i, i = 1, 2, ..., q\}$ find the alternative with the best number of cells which maximizes the utility function:

$$\text{Maximize } U(a_i) = w_1 f_1^*(a_i) + w_2 f_2^*(a_i) + w_3 f_3^*(a_i)$$

$$a_i \in A,$$

where $w_1 + w_2 + w_3 = 1$ and $w_1, w_2, w_3 \geq 0$;

$$f_1^*(a_i) = (f_{1max}(a_i) - f_1(a_i)) / (f_{1max}(a_i) - f_{1min}(a_i)) \quad (2\text{-}1)$$

and $f_2^*(a_i) = (f_{2max}(a_i) - f_2(a_i)) / (f_{2max}(a_i) - f_{2min}(a_i))$. (2-2)

$f_3^*(a_i) = f_3(a_i)$ (2-3)

Our purpose in solving this problem is to find an alternative $a_i \in A$ such that $U(a_i) \geq U(a_i')$ for any $a_i' \in A$.

2.2. A Three-Level Approach to Find the Best Alternative

Level 1: An artificial neural network (ANN) approach for Family Formation of Group Technology (Malakooti and Yang 1995) can be used to solve P2 to generate a seed alternative a_0 for each given number of cells, R. We start cell number at R = 2 and increase the cell number by one for each iteration until the cell structure has a cell containing only one machine or one part.

Clearly, a_0 is a quasi-nondominated alternative because $f_1^*(a_0) = 1$ is the maximum value of f_1^* (Steuer 1986).

Level 2: Generate a set of local nondominated alternatives from the seed alternative a_0.

The heuristic procedure to generate alternatives from the seed alternative is as follows:

1) Check if there exist exceptional elements in thr seed alternative a_0. If there are none, stop.

2) Find the bottleneck machine j* associated with the most exceptional elements.

3) Find the corresponding machine-part cell C_r^* in which the highest number of parts need to be processed on bottleneck machine j*.

4) Duplicate machine j*, and put it in cell C_r^* to generate an alternative. Go to step 1).

From this heuristic procedure, we know that each new alternative is generated by duplicating one bottleneck machine to decrease the number of exceptional elements. Although f_1^* of a new alternative decreases, the corresponding f_2^* increases. We conclude that the generated alternatives are always local nondominated (or global quasi-nondominated). The best alternative is one of those quasi-nondominated alternatives.

Level 3: Evaluate the alternatives based on P2 to find the best alternative (the one having the highest utility value).

In order to evaluate all alternatives, we need to assess the importance weights w_1, w_2, and w_3 that the DM attaches to the criteria. There are a number of methods available, such as directly rating or ranking the criteria, or using indifference tradeoffs. In this paper, we assume that w_1, w_2, and w_3 are known, so the set of alternatives can be evaluated by their utility values. An alternative $a_i \in A$ is the best one when $U(a_i) \geq U(a_i')$ for any $a_i' \in A$.

3. AN EXAMPLE TO EXPLAIN THE THREE-LEVEL MCDM APPROACH

Problem 3 in this section is solved by our approach. We generate alternatives for each seed alternative and represent them using three objective values (number of duplicated machines f_1, number of exceptional elements f_2, machine utilization rate f_3, and their corresponding normalized values f_1^*, f_2^*, f_3^*). We also calculate utility values for each alternative using two sets of preference values: 1) $w_1 = w_2 = w_3 = 1/3$; 2) $w_1 = 0.2$, $w_2 = 0.4$, and $w_3 = 0.4$. The purpose of using two sets of preference values is to show that the best machine-part cell structure is chosen based on the Decision Maker's preference to each objective. The best machine-part cell structure corresponding to each set of preference values is also given.

Problem 3 (5x7) (Waghodekar and Sahu 1984)

The initial incidence matrix:

	1	2	3	4	5	6	7
01		1		1			1
02			1		1		
03	1	1		1			1
04	1		1			1	
05			1	1	1	1	

The seed alternative a_0 for $R = 2$:

	1	2	4	7	3	5	6
01		1	1	1			
03	1	1	1	1			
02					1	1	
04	1				1		1
05			1		1	1	1

The seed alternative a_0 for $R = 3$:

	1	2	4	7	3	5	6
01		1	1	1			
03	1	1	1	1			
02					1	1	
05	1				1	1	1
04			1		1		1

The 8 alternatives are:

	R=2			R=3				
	a_0	a_1	a_2	a_0	a_1	a_2	a_3	a_4
f_1	0	1	2	0	1	2	3	4
f_2	2	1	0	4	3	2	1	0
f_3	0.82	0.71	0.64	0.92	0.92	0.88	0.75	0.67
f_1^*	1.00	0.91	0.82	0.73	0.64	0.55	0.45	0.36
f_2^*	0.25	0.40	0.50	0.60	0.70	0.80	0.85	0.90
f_3^*	0.93	0.93	0.93	0.90	0.88	0.83	0.79	0.78
U_1	0.77	0.74	0.71	0.64	0.64	0.63	0.58	0.56
U_2	0.73	0.73	0.76	0.57	0.62	0.64	0.65	0.67

Note

R: Number of cells

f_1: Number of duplicated machines

f_2: Number of exceptional elements

f_3: Machine utilization rate

f_1^*: Normalized value of f_1 using (2-1)

f_2^*: Normalized value of f_2 using (2-2)

f_3^*: Normalized value of f_3 using (2-3)

$U_1 = 1/3(f_1^*) + 1/3(f_2^*) + 1/3(f_3^*)$

$U_2 = 0.2(f_1^*) + 0.4(f_2^*) + 0.4(f_3^*)$

The best cell structure is a_0 with R=2 when $w_1 = w_2 = w_3 = 1/3$:

	1	2	4	7	3	5	6
01		1	1	1			
03	1	1	1	1			
02					1	1	
04	1				1		1
05			1		1	1	1

The best cell structure is a_2 with R=2 (machines 02 and 05 are duplicated) when $w_1 = 0.2$, $w_2 = 0.4$, and $w_3 = 0.4$:

	1	2	4	7	3	5	6
01		1	1	1			
03	1	1	1	1			
02'	1						
05'			1				
02					1	1	
04					1		1
05					1	1	1

We observe the following:

1) Regardless of the weights w_1, w_2, w_3, the machine utilization rate, f_3, for the best cell structure is higher when R=3 than it is when R=2. Thus, as the number of cells decreases, the machine utilization rate decreases.

2) f_3, - machine utilization rate, always decreases as f1, number of duplicated machines, increases.

3) f_2, the number of exceptional elements, is higher when R=3.

4. CONCLUSIONS

In this paper, we proposed a multiple criteria decision making approach to solve machine-part cell formation problems, especially those problems with exceptional elements. This three-level method generates a seed machine-part cell structure, and alternative structures from the seed, for every feasible number of cells. These alternative machine-part cell structures were evaluated by several criteria: the number of duplicated machines, the number of exceptional elements, and the machine utilization rate. An example was solved to show that the proposed approach can successfully solve the problems. We investigated the relationship among these criteria. We have the following observations from our experiment: 1) Machine utilization rate will decrease when the number of cells decreases; 2) Machine utilization rate will decrease when the number of duplicated machines increases; 3) Number of exceptional elements will increase when the number of cells increases. We gave experimental results on several problems from the literature.

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