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Clustering algorithm for solving group technology problem with multiple process routings ☆

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ABSTRACT

Cell formation is an important problem in the design of a cellular manufacturing system. Most of the cell formation methods in the literature assume that each part has a single process plan. However, there may be many alternative process plans for making a specific part, specially when the part is complex. Considering part multiple process routings in the formation of machine-part families in addition to other production data is more realistic and can produce more independent manufacturing cells with less intercellular moves between them. A new comprehensive similarity coefficient that incorporates multiple process routings in addition to operations sequence, production volumes, duplicate machines, and machines capacity is developed. Also, a clustering algorithm for machine cell formation is proposed. The algorithm uses the developed similarity coefficient to calculate the similarity between machine groups. The developed similarity coefficient showed more sensitivity to the intercellular moves and produced better machine grouping.

1. Introduction

Group Technology (GT) is a manufacturing philosophy that identifies the similar attributes of product design and manufacturing processes. The main objective of GT is the identification of machine groups and part families for the creation of cells, in which the parts in each cell are processed with minimum moves into other cells. The benefits of machine groups with lower intercellular moves include the reduction in transportation cost, queuing and processing times, elimination of the need for frequent set-ups, reduction of inventories, and much simpler production plan. As a result, the required in-stock and in-process inventories decrease substantially. These benefits lead naturally to better delivery times, quality improvements, more efficient management, and customer satisfaction (Spiliopoulos & Sofianopoulou, 2007) (see Table 1).

Cellular manufacturing (CM) is a practice that applies GT philosophy to create mutually separable machine cells. This requires identification of groups of machines that can produce parts with similar processing requirements. Each dedicated cell with dissimilar machines process a family of parts. However, the need to dedicate machines to cells leads to increased number of machines and therefore reduced machine utilization and flexibility (Suer, Huang, & Maddisetty, 2010). An alternative design to the classical cellular designs is introduced by Suer et al. (2010) to deal with probabilistic demand. Suer et al. (2010) proposed a layered cellular system with multiple components namely, dedicated, shared and reminder cells. The dedicated cells process only one part family, shared cells usually process two part families, and a remainder cell is designed to work on more than two part families. Therefore, multiple opportunities are also available for a part family to be manufactured when a machine cell capacity is limited.

Current trend for automated factory systems indicates increased usage of DNC, CNC, machining centers, industrial robots, microprocessors, etc., and moves toward more computer integrated manufacturing systems. The present automated factory systems worldwide are essentially based on a hierarchical computer control system of automated manufacturing cells. This means that the basic concept for such a system is based on the use of GT cells, each devoted to the production of a given family of parts. A highly automated and computer controlled GT cell is also recognized as a Flexible Manufacturing Cell. The cells are independent units but may be tied together by an automated material handling system. Furthermore, today's advanced and more flexible multifunctional machines can be helpful in the process of machine cell formation. Multifunctional machines can perform more than one operation. Therefore, a part that is allocated to a machine cell may not have to travel to another cell for other required operations. This eliminates the intercellular moves and produces better machine grouping.

In cellular manufacturing environment multiple process routings for a part can be planned since each operation of a particular part may be performed on alternative machines (Kusiak, 1987). In

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Table 1
6 Machines 8 parts-problem 1.

Parts	V	R	Machines					
			M1	M2	M3	M4	M5	M6
P1	50	1	1	3		2		
		2		1	2		3	4
		3		2	1		3	4
P2	30	1			1		3	2
P3	20	1			1		2	3
P4	30	1	1			2		
		2	2	1		3		
P5	20	1		3	2		4	1
		2			1			2
P6	10	1	1	2	3			
		2	1	2				3
P7	15	1		3			1	2
		2			3		1	2
		3		1				2
P8	40	1		2		1		

some cases, there may be many alternative process plans for making a specific part, specially when the part is complex (Qiao, Yang, & Wang, 1994). Explicit consideration of alternative process plans invoke changes in the composition of all manufacturing cells so that lower capital investment in machines, more independent manufacturing cells and higher machine utilization can be achieved (Hwang & Ree, 1996). Most cell formation methods appeared in the literature assumed that each part has one process plan. Furthermore, important production parameters such as operations sequence, production volumes, and machines capacities are rarely considered together in the machine cell formation problem. Therefore, dedicated measures are needed to capture the similarity of machines based on the characteristics of the important production data and to overcome the limitations of the existing methods. A new procedure is developed for solving the machine-part grouping problem in cellular manufacturing systems using the Similarity Coefficient Method (SCM). A new similarity coefficient equation that incorporates alternative process routings in addition to operations sequence, production volumes, duplicate machines, and machines capacity is developed.

2. Generalized similarity coefficient

The cell formation problem incorporating alternative process routings is called generalized GT problem. Different mathematical procedures including similarity coefficient method were suggested in the literature to solve the cell formation problem under multiple process routings. Kusiak (1987) and Hwang and Ree (1996) solved the generalized GT problem using generalized p-median model. Sofianopoulou (1999) used a two-dimensional simulated annealing heuristic approach to select process routings for parts and construct machine cells sequentially. Wu, Chung, and Chang (2009) also proposed a hybrid simulated annealing algorithm with mutation operator to solve the cell formation problem considering multiple process routings for parts, so that either the intercellular moves are minimized or the grouping efficiency is maximized. Jayaswal and Adil (2004) proposed an algorithm comprised of simulated annealing and local search heuristics to solve the problem of cell formation considering multiple routings to minimize the sum of cost of intercellular moves, machine investment, and machine operating costs. Wu, Chen, and Yeh (2004) solved the cell formation problem with alternative process plans sequentially in three stages: process routing selection, part assignment, and machine assignment, respectively. Chung, Wu, and Chang (2011) proposed a tabu search algorithm based on similarity coefficient to solve the cell formation problem with alternative process routings and machine reliability. Lei and Wu (2005) addressed a hybrid algorithm based on a similarity coefficient based hierarchical clustering method and tabu search to solve the generalized GT problem. Spiliopoulos and Sofianopoulou (2007) presented a bounding scheme which examines all combinations of alternative routings and solve only a few cell-formation problems, thereby limiting the solution space. Most of these machine cell formation methodologies focus mainly on considering parts multiple routes in solving machine cell formation problem. Other important production data are generally ignored, such as operations sequence, production volume, batch size, machine duplicate, and machine capacity.

Procedures using the SCM provide a quantitative basis for machine-part grouping and are more flexible in incorporating various important production data into the machine-part grouping process (Seifoddini, 1988). SCM also lends itself more easily to computer applications (Gupta & Seifoddini, 1990). Furthermore, the optimal solution methodology fails to solve larger instances of problems (Islam & Sarker, 2000). Few similarity coefficient algorithms have been proposed to solve the generalized GT cell formation problem. Most cell formation methods appeared in the literature use conventional 0–1 data similarity coefficients which are unable to capture the sequence of operations. The sequence of operations between two machines greatly influences their similarity. The number of moves that a part makes between two machines in sequence should increase their similarity and should decrease it if they are not in sequence. Most similarity measures in the literature assume that the trips that a part makes between two machines increase the machines similarity even if the trips between the two machines are not in sequence (Alhourani & Seifoddini, 2007).

Jaccard's similarity coefficient is the basic similarity coefficient which assumes that there is only one process plan for each part and ignores the other production parameters such as production volume and operations sequence. Jaccard's similarity coefficient is:

$$S_{il} = \frac{N_{il}}{N_i + N_l - N_{il}} \tag{1}$$

where N_i, N_l are the number of parts processed by machines i and l and N_{il} is the number of common parts processed by both machines i and l.

Kusiak and Cho (1992) developed a part-based approach which uses a similarity coefficient defined between routings of parts. His method does not effectively solve the cases which do not contain mutually separable cells (Won & Kim, 1997). Furthermore, a machine based approach using similarity coefficient defined between machines is favored since the number of parts included in a cellular manufacturing problem is usually much more than that of machines (Chow & Hawaleshka, 1992).

Gupta (1993) extended Jaccard's similarity coefficient to solve the generalized GT problem. He considered alternative process routings, operation sequences, operation times, and production volumes. His developed similarity coefficient is:

$$S_{il} = \frac{\sum_{j=1}^{n}\left[\sum_{r=1}^{r_j}(X_{iljr}T_{iljr} + C_{jr})P_{jr}\right]V_j}{\sum_{j=1}^{n}\left[\sum_{r=1}^{r_j}(X_{iljr}T_{iljr} + C_{jr} + Y_{iljr})P_{jr}\right]V_j} \tag{2}$$

where

X_{iljr} is the $\begin{cases} 1, & \text{if part type } j \text{ visits both machines } i \text{ and } l \\ 0, & \text{otherwise} \end{cases}$

T_{iljr} the proportion of total smaller unit operation time to the total larger unit operation time with machine pair i and l, for part type j in the rth route