EXCEPTIONAL ELEMENTS FRAMEWORK IN GROUP TECHNOLOGY

David Ang, Auburn University Montgomery, Montgomery, AL. USA, dang@aum.edu

ABSTRACT

The concept of Cellular Manufacturing Systems has become very popular in the 1990's. Recently, the CMS has been considered an integral part of the lean manufacturing systems. The CMS incorporates Group Technology (GT) principles. The basic idea of GT is to utilize the similarity between parts and manufacturing processes. Parts similar in design and manufacture are grouped into part families. Machines are organized into machine cells to process part families. This grouping process is termed as the Cell Formation (CF). Unfortunately, the grouping is not always possible to ensure that all parts of a family can be processed within a machine-cell. The CF process tends to inherit exceptional element problems that can create difficulty in achieving manufacturing benefits and efficiencies. In this research, a concise review of the current state of existing methods that can best be used in eliminating the exceptional elements is conducted. An evaluative framework is presented to discuss the usefulness and limitations of the current existing methods.

Keywords: Cell Formation, Group Technology, Exceptional Elements, Cellular Manufacturing Systems, Lean Manufacturing Systems

INTRODUCTION

The Cellular Manufacturing Systems (CMS) has been considered an integral part of the lean manufacturing systems. It is a manufacturing system that incorporates Group Technology (GT) principles [1]. Group Technology has been proposed to increase productivity in manufacturing. The basic idea of GT is to offer a system approach to the reorganization of the traditional functional batch manufacturing systems such as the job-shop and flow shop to more flexible small-lot production. The CMS is a production system that will allow a set of dissimilar machines to be grouped into a machine cell to process a group of product/part family. A product/part family is a group of parts that can be produced by the same sequence of machining operations because of similarity in design and processing attributes. This will allow the systems to exploit the similarity between parts and manufacturing processes.

The main objective of the CMS is to achieve benefits and efficiencies in manufacturing. The benefits and efficiencies of CMS include work-in-process (WIP) reduction, lead-time or throughput time reduction, productivity improvement, quality improvement, better scheduling, simplicity in tool control, enhanced flexibility and visibility, and better teamwork and communication. The benefits of applying CMS have been extensively discussed in [2].

The Group Technology principles require the ability to classify parts into part families and form machines into machine cells which are dedicated to the manufacture of a specific part family. Unfortunately, the grouping is not always possible to ensure that all parts of a family can be processed within a machine-cell and tend to create the problem of the bottleneck machines and parts issues in the CF effort. The purpose of this research is to present the current state of existing methods in use that deal with the exceptional element problems in GT. The approaches and their effectiveness of these solution methods are discussed and presented in a framework.

BACKGROUND

Most of the grouping methods employ M x P machine-part incidence matrix (see Figure 1) to group machine-cells and part families.

$$
\begin{array}{cc}
 & \text{Part \# }(j) \\
 & \begin{array}{cccccccc} 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 \end{array} \\
\text{Machine \# }(i) \begin{array}{c} 1 \\ 2 \\ 3 \\ 4 \\ 5 \\ 6 \end{array} &
\left[\begin{array}{cccccccc}
1 & & 1 & & & & 1 & 1 \\
1 & 1 & & & 1 & & & 1 \\
1 & 1 & 1 & 1 & & & & \\
1 & & & 1 & 1 & 1 & 1 & \\
 & 1 & & & 1 & & & 1 \\
 & & & 1 & & 1 & &
\end{array} \right]
\end{array}
$$

Figure 1: Machine-Part Incidence Matrix

The incidence matrix is a matrix that describes the machines requirements to process each part type. The matrix consists of binary entries of blanks or '1s', in which an entry of '1' indicates that machine i is used to process part j, i = 1, 2… 6 and j = 1, 2 …8. When an initial machine-part incidence matrix is constructed such as shown in Figure 1, each machine-cell that is dedicated to manufacture of a specific part family is not visible. However, when a leading methodology is employed, machine-cell and its part family can be identified (see Figure 2).

Figure 2 shows the formation of machine cells (MC) and part families (PF) after the grouping process. It shows not all members of a part family can be processed within a single machine cell. The members having operations in more than one machine-cell are called bottleneck parts and the machines processing them are known as bottleneck machines. For instance, Part Type 1 in Figure 2 is a bottleneck part. Part Type 1 has to transfer to Machine Cell-2 (MC-2) and Machine Cell 3 (MC-3) for processing after going through processing in Machine Cell-1 (MC-1) due to its exceptional elements (2,1) and (4,1). The machine #2 in MC-2 is a bottleneck machine.

		PF-1			PF-2			PF-3	
		1	3	7	2	5	8	4	6
MC-1	1	1	1	1			1		
	3	1	1		1			1	
MC-2	2	1			1	1	1		
	5				1	1	1	1	
MC-3	4	1		1		1		1	1
	6							1	1

Figure 2 Bottleneck Machines and Parts

The part types 1, 7, 2, 5, 8, and 4 are termed as the bottleneck parts. The machines 1, 3, 2, 5, and 4 that are required to process the bottleneck parts are called the bottleneck machines. Thus, the existence of a production requirement that necessitates a part having to move between work or machine cells, otherwise slowing or impeding overall efficient production, creates an exceptional element. The bottleneck parts create interactions between machine-cells such as the intercellular movements, which is the obstacle of achieving cellular manufacturing systems efficiencies and the simplicity of production control. Many researchers have studied the handling of bottleneck machines and parts. Numerous research methods were proposed by the researchers to resolve the bottleneck machines and parts problems during or after the cell formation.

LITERATURE REVIEW

The major focus of CMS is the cell formation (CF). Many cell formation grouping methodologies have emerged since 1970. The leading methodologies to grouping machines into machine-cells and parts into part families are the:

- Machine-component Group Analysis [3]
- Coding and Classifications [4] [5]
- Similarity Coefficients Analysis [6] [7][8]
- Knowledge-Based [9][10]
- Fuzzy Theory with Similarity Coefficient [11]
- Mathematical programming [12]
- Heuristics & Algorithms [13] [14]
- Multi-Criteria Objectives [15][16]
- Simulation [17] [18]

The comprehensive reviews for the cell formation design problem and the solution approaches can be found in [19][20]. As compared to cell formation research, the studies of handling of the bottleneck machines and parts problems are much less. Numerous researchers have investigated the exceptional elements problems that appear at the end of the grouping process of cell formation in GT.

Several researchers studied and developed algorithms to eliminate the handling of exceptional elements after the cell formation grouping process. Chow and Hawaleshka [21] proposed a more effective algorithm, which reduced the number of bottleneck parts compared with the average clustering algorithm Seifoddini and Wolfe [8] and linear cell clustering algorithm of Wei and Kern [22]. The other researchers that had developed algorithm to reduce the appearance of the bottleneck parts and machines include Chan and Milner [23], King & Nakornchai [24], Kern & Wei [25], Tsai, Chu, and Barta [26], and Won [27]. The grouping algorithms that were developed by these researchers can only reduce the existence of bottleneck parts, but the bottleneck parts could still be present.

Vannelli and Kumar [28] proposed to eliminate bottleneck parts through bottleneck machines duplication and subcontracting bottleneck parts. They proposed to duplicate bottleneck machines irrespective of the machine cost and cell size constraint and requirement. This model purports to solve the exceptional element problem by duplication bottleneck machine cells that possess the largest number of inter cellular moves and continues duplication until no machine generates more intercellular moves than specified by a threshold value. Seifoddini [29] presented a cost-based duplication procedure, which uses the duplication cost and the associated reduction in intercellular material handling cost as a basis for decision making in the duplication process. The bottleneck machine is duplicated if the duplication cost is less than the associated cost reduction in intercellular material handling. Seifoddini [29] encouraged duplication in the process until duplication no longer can be economically justified. This duplication method cannot eliminate bottleneck parts problems once the duplication process is not economically justified. Ang [30] developed an algorithm for eliminating bottleneck parts that minimizes total duplication costs for the entire system and its duplication process. Ang’s method only assumed bottleneck machines duplication is the only viable method to use to eliminate bottleneck parts. The method is not practical since in the real world, bottleneck machines duplication should not be considered as the only method used to eliminate the bottleneck parts problems. Moreover, the duplication cost, which includes the machine purchasing cost, machine maintenance cost and depreciation, is usually very high.

The subcontracting is an alternative for bottleneck parts and machines elimination which is raised by Kusiak and Chow [31]. Kusiak and Chow [31] proposed subcontracting bottleneck parts if bottleneck part production cost due to intercellular movements is greater than subcontracting cost. Kamien and Li [32] also proposed the important aspect in capacity planning, and it implies that the producer can establish a long-term supplier-producer relationship for parts in long-term planning so that purchasing the exceptional parts is possible. However, if in a specific environment, subcontracting cost is greater than production cost, the offending bottleneck part will not be subcontracted and the bottleneck parts problem remains unsolved.

Another alternative approach purporting to solve the exceptional element problem in group technology is the modification of process plan concept as proposed by

Wemmerlove and Hyer [33]. Wemmerlove and Hyer [33] proposed to solve the bottleneck parts through the modification of process plans. In a case in which parts cannot be grouped into a family, the process plan for bottleneck parts could be modified so that they can be processed in existing machine-cells. Kusiak [34] proposed modification to Generalized p-Median model which, permits it to consider more than one process plan for each part. The initial machine part incidence matrix is expanded to obtain a generalized matrix in which more than one column exists for every part with each column corresponding to a different process plan. This procedure attempts to improve the chances of eliminating the bottleneck parts, but the intercellular movements to transport or the handling time of modifying the process plan so that bottleneck parts can be processed into an existing cell are unavoidable. Again, the issue of eliminating the bottleneck parts problem in CMS remains. Shafer, Kern and Wei [35] also proposed that the organization may design a 'remainder cell' to which the subcontracted parts can assign.

The mathematical programming method has also been developed to handle the existence of bottleneck parts and machines in Group Technology. Shafer, Kern, and Wei [35] used mathematical programming to resolve bottleneck machines and parts problems. The programming resolved the problems through improving cell configuration and optimization by comparing the process of bottleneck machines duplication and subcontracting bottleneck parts. Shafer and Rogers [36] present a goal-programming approach to cell formation in which bottleneck machines and parts can be handled by equipment purchases or allowing the intercellular movements to remain. Gunasingh and Lashkari [37] employ a cost-based integer programming approach to allow for both machine duplication and the possibility of having some intercellular movements remain. The majority of these mathematical programming models developed to handle the existence of bottleneck parts and machines explicitly considered three cost categories: (1) subcontracting costs; (2) machine duplication costs; and (3) intercellular transfer costs. If the practical environments object the use of subcontracting, duplication, and intercellular movements, the bottleneck machines and parts remained unsolved.

Cheng, Goh, and Lee [38] used heuristic branching rule to settle the bottleneck machines and parts problem after the grouping cell process. Unfortunately, the heuristic branching rule can only reduce the number of bottleneck parts, but it cannot eliminate the existence of bottleneck parts completely. Hachicha, Masmoudi, and Haddar [18] used a simulation-based methodology to form cell and handle the bottleneck parts and machines with cost effective measures of either through allowing intercellular transfer or duplication of bottleneck machines. The handling of bottleneck problems is resolved through the duplication and subcontracting through simulation only. If cell size, financial constraint, and proprietary pattern and technology secret do not permit resolving the exceptional elements either through duplication or subcontracting, the bottleneck problems remained unsolved in the cell formation process.

CONCLUSIONS

The purpose of this research is to present the current state of existing, well-documented methods in use that can resolve the bottleneck parts and machines problem in group technology. An evaluative framework of exceptional elements problems is summarized in Table 1 in which the methods of handling the exceptional elements and the method effectiveness are discussed and presented.

Table 1: Summary of Solution Methods to Handling of Exceptional Elements (EE)

Method and Contributors	Method Effectiveness	EE Universally Solved?
Algorithms 1. Chow et al. [21] 2. Seifoddini et al. [8] 3. Wei and Kern [22] 4. Chan et al. [23] 5. King et al [24] 6. Kern & Wei [25] 7. Tsai et al. [26] 8. Won [27]	More effective cell formation algorithms that can result in less exceptional element existence in the final grouping cell formation process.	No
Bottleneck Machine Duplication 1. Vannelli et al. [28] 2. Ang [30]	Duplicate Bottleneck Machines irrespective of their machine costs to configure machine-cells that can be dedicated to process the part-family.	No
Cost Based Bottleneck Machine Duplication 1. Seifoddini [29]	The bottleneck machine is duplicated if the duplication cost is less than the associated cost reduction in intercellular material handling.	No

Table 1: Summary of Solution Methods to Handling of Exceptional Elements (EE) Cont'

Method and Contributors	Method Effectiveness	EE Universally Solved?
Algorithm Bottleneck Machine Duplication 1. Ang [30]	An algorithm for eliminating bottleneck parts that minimizes total duplication costs for the entire cellular manufacturing systems. This algorithm assumed machines duplication is the only viable method to eliminate bottleneck parts.	No
Subcontracting 1. Kusiak and Chow [31] 2. Kamien and Li [32]	Subcontract bottleneck parts if production cost due to intercellular movements is greater than the subcontracting cost. However, if subcontracting cost is greater than production cost, the offending bottleneck part will not be subcontracted and the bottleneck parts problem remains unsolved.	No

Table 1: Summary of Solution Methods to Handling of Exceptional Elements (EE) Cont'

Method and Contributors	Method Effectiveness	EE Universally Solved?
Proc. Plan Modification 1. Wemmerlove et al. [33] 2. Kusiak [34] 3. Shafer et al. [35]	In a case in which parts cannot be grouped into a family, the process plan for bottleneck parts could be modified so that they can be processed in existing machine-cells. Regardless, the intercellular movement is avoidable to transport modified bottleneck parts to the exclusive machine-cell to be processed.	No
Mathematical Programming 1. Shafer et al. [35] 2. Shafer and Rogers [36] 3. Gunasingh et al. [37]	The programming resolved the problems through improving cell configuration and optimization by comparing the process of bottleneck machines duplication and subcontracting bottleneck parts. EE remains if production environments do not allow machine duplication or subcontracting, the problem remains.	No

Table 1: Summary of Solution Methods to Handling of Exceptional Elements (EE) Cont'

Method and Contributors	Method Effectiveness	EE Universally Solved?
Heuristic Rules 1. Cheng et al. [38]	The heuristic branching rule can only reduce the number of bottleneck parts, but it cannot eliminate bottleneck parts completely.	No
Simulation 1. Hachicha et al. [18]	The handling of bottleneck problems is resolved through the duplication and subcontracting through simulation only. The EE problem remains if production environments do not support duplication and subcontracting.	No

This research also confirmed that the exceptional element problem in group technology has the following features:

1. Methods for handling bottleneck machines and parts problems involve both quantitative and qualitative approaches. Efficiency among the methods varies and there are no complete and universally satisfactory methods to date that can eliminate bottleneck parts problems in the cellular manufacturing systems. For instance, the exceptional element problems may be addressed by using an algorithm, a qualitative approach, or a combination of several algorithms and approaches.

2. To date, it seems difficult, if not impossible, to eliminate completely exceptional elements in a production environment in order to avoid intercellular movement. For example, exceptional elements will remain when the duplication machine costs are greater than the intercellular movement handling costs.

3. These methods have benefits and offer to make the production environment a more efficient, more profitable arena. There is no one unique solution formulation capable of handling all exceptional element problems.

It is important to resolve the exceptional element problem in GT so that a complete cell formation solution in group technology can be achieved to offer a more efficient and productive cellular manufacturing systems.

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