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A Multi-Period Cell Formation Model for Reconfigurable Manufacturing Systems

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Abstract

The effective design of a reconfigurable manufacturing system (RMS) exerts the need for a design approach to group the parts into families and determine the corresponding system configurations. A mixed integer programming model was developed to form simultaneously the part families and corresponding cell configurations in RMS in a dynamic production environment. A novel reconfiguration planning heuristic, responsible for determining the reconfiguration plan on both machines and system levels between successive time periods, is introduced. The model was tested by solving a dynamic cell formation problem and it was able to find the optimal solution found in the literature. Also a numerical example is included to illustrate the proposed model and the reconfiguration planning heuristic.

Keywords: Cell formation; Reconfiguration planning; Reconfigurable manufacturing systems

1. Introduction

Reconfigurable manufacturing systems (RMSs) are the next step in manufacturing, a new paradigm designed specifically for rapid modification in production capacity and functionality through system reconfiguration [1]. The machines that comprise a RMS are called reconfigurable machine tools (RMTs). The concept of multispindle scalable-RMT was introduced in [2]. This concept describes RMT as a machine base with multiple identical modules (spindles and axes). These modules can be added or removed from the machine base to adjust the RMT capacity and/or functionality as required. The RMS concept implies the design of the system for the production of a part family. Thus, one of the challenges that face the application of RMS is the use of group technology (GT) to capitalize on commonality and standardization of parts, operation sequence and product structure [3].

Cellular manufacturing (CM) is an application of the GT in manufacturing and due to the variation of product mix and demand over succeeding time periods; the dynamic cell formation problem was introduced. It implies that the planning horizon shall cover a set of time periods having deterministic product demand and mix instead of a single period in CM [4].

A comprehensive mixed integer programming model was developed in [5] to solve the dynamic cell formation problem. The model incorporated the concepts of lot splitting, routing flexibility and subcontracting in the problem. The model was solved optimally for small and medium size problems proving the advantages of considering system reconfigurations, lot splitting and system flexibility. Later on in their work, large size problems were solved using genetic algorithm (GA) [6] and parallel GA [7]. In recent years many studies have been carried out in the context of modeling and solution methodology for the dynamic cell formation problem [8, 9, 10, 11].

Although the dynamic cellular manufacturing system (DCM) shares some of the characteristics of RMS i.e. the dynamic nature of production requirements and system reconfiguration, they are dissimilar. This was attributed to the fact that DCM lacks capacity scalability, function adaptability, modularity and reconfigurable machines as shown in table 1.

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Table 1.Comparaison between RMS and DCM.

Element	RMS	DCM
Production requirements	Dynamic	Dynamic
Reconfiguration level	System and machine levels	System level
Reconfiguration cost	Low	High
Machine capacity	Adjustable	Fixed
Machine functionality	Adjustable	Fixed

Many researchers adapted and modified the methodologies used in CM to address the cell formation problem in the RMS. An approach based on Jacard's similarity coefficient and an analytical hierarchical process model was developed in [12], for grouping the products in families and determines the appropriate part family at each configuration stage. Other approaches based on average linkage clustering algorithm and Jacard's similarity coefficient were used in [13, 14] for the formation of part families. The outcome of the algorithm is a dendogram which presents different sets of product families and the corresponding similarity coefficients. A GA was presented in [15] to group parts into families based on maximizing the sum of two similarity coefficients adopted from [13].

From the previous presented literature, it can be noticed that most of the work done to date handled the cell formation in RMS from the perspective of part family formation and neglected the machine cell formation. Failing to consider the corresponding cell configurations (the number of every machine types in each cell and its capabilities) and the associated reconfiguration effort may lead to sub-optimality of the part family selection. Also many of the reported literature did not provide a systematic methodology to determine the best set of part families. Another major shortcoming is neglecting the dynamic nature of product mix and demand in RMS. The dynamic production requirements imply the division of the entire planning horizon into multiple periods where each has different production mix and demand.

The research presented in this work aims to solve the cell formation problem in the RMS context. This is to be done by developing an approach for grouping the machines into cells (each cell responsible of producing a part family) in the context of RMS, and simultaneously form and select the best set of part families that minimizes a summation of relevant costs. The rest of the sections are organized as follows, section 2 presents the problem description and the assumptions taken along with the mathematical model and reconfiguration planning heuristic. Section 3 describes a procedure to optimally solve the model. In section 4, two numerical examples are optimally solved. Conclusion and summary are finally presented in section 5.

2. Problem description

The multiple time period cell formation problem in the RMS context addresses the problem of grouping parts into families and determining the corresponding machine cells in RMS for several time periods, each period differs from its preceding one in its product mix and its demand. The RMS consists of a number of RMTs, Which are to be grouped into cells where each cell is responsible of producing a part family with minimum total cost.

Following the definition of the RMT, each RMT type in the system has several possible configurations. Each configuration is defined with the number of modules installed on the machine base. So each configuration is capable of performing different set of processing operations with a limited capacity. A part may require several operations in a given sequence. An operation of a part may be processed by a machine if it has a configuration that can process this operation. If there are several configurations on more than one machine that can process an operation of a certain part, these machines are considered as possible routings for the part.

As a response to the gaps found in the literature, a mixed integer programming model is formulated to address multiple time period cell formation problem in RMS taking into consideration the dynamic nature of product mix and demand, capacity scalability, functional adaptability, and routing flexibility. This model is a modification to the model presented by [7] to solve the dynamic cell formation problem. The objective function and the constraints were modified to cope with the RMS context. The objective of this model is to minimize machine procurement cost, operation and setup cost, inter-cell travel cost, subcontracting cost and reconfiguration cost for the entire planning horizon.

2.1. Assumptions

This model is developed under the following assumptions:

- The product mix and demand varies between time periods in a deterministic manner and are predetermined.
- All the demand must be satisfied. Demand that is not met by production is to be subcontracted with a given cost.
- Parts are processed in batches and every part can have different batch size.
- Each operation has one or several possible machine configurations that can process it.
- Lot splitting is allowed but within the same cell, i.e. if a part has alternative routings at a certain operation, the demand of this part at this operation can be split and processed on different machines but the machines has to be in the same cell.
- Machines are reconfigurable. Each machine can be reconfigured to a set of machine configurations associated to each machine type.
- Each machine configuration can perform one or more operations with different processing times.
- Machine capacity is expressed in processing hours per time period.
- Machines that cannot be located in the same cell due to technical and environmental requirements should be separated.
- The time required for machines and system reconfiguration between different time periods is not considered in the model (assumed to be zero).
- Machines are reliable (availability is 100%).
- The number of cells is predetermined.
- The lower and upper boundaries on the number of machines in every cell are predetermined.