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Genetic algorithms for integrating cell formation with machine layout and scheduling

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Abstract

Cellular manufacturing (CM) has been recognized as an innovative practice for companies to gain efficiency as well as flexibility under today's small-to-medium lot and customization-oriented manufacturing environment. Among the necessary decisions for a successful CM implementation, cell formation (CF), group layout (GL) and group scheduling (GS) are the three most popular ones. These decisions are interrelated and may impact each other but they are often treated separately or as a sequential decision in prior research. In this paper, we propose a new approach to concurrently make the CF, GL and GS decisions. A conceptual framework and mathematical model, which integrates these decisions, are proposed. A hierarchical genetic algorithm (HGA) is developed to solve the integrated cell design problem. Two heuristic operators are proposed to enhance its computational performance. The results from our study indicate that: (1) the concurrent approach often found better solutions than the sequential one, and (2) with the proposed heuristic operators, the HGA procedure performed better than without them.
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1. Introduction

CM is an innovative manufacturing strategy that has appealed to modern manufacturing systems such as flexible manufacturing systems (FMS) and just-in-time (JIT) production. By grouping, producing and managing parts and machines with closer characteristics together, CM can transform batch- into line-type production while maintaining a high degree of flexibility as in job-shop production. Potential benefits of CM include simplified material flows, faster throughput, reduced setup times, reduced inventory, better control over the shop floor and lower scrap rates (Wemmerlöv & Hyer, 1986).

The design of an effective CM system involves three major decisions: CF or traditionally called group technology, GL and management of cell operations such as GS. CF involves the process of grouping parts with similar design features or processing requirements into part families and the corresponding machines into

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machine cells. GL deals with the problems of laying out cells and the machines within each cell. Cell management concerns the problems of operating and managing the cell operations, including dealing with exceptional elements (EEs), GS, and other resource allocations issues. Where, an EE is a part in which some of its operations need to be processed by machines not located in the same cell; GL concerns the problems of scheduling part families and the parts within a cell.

Over the past decades, many researchers have predominantly focused on solving the CF problems, as it is the first stage in CM. Many analytical methods have been developed as a result of this massive movement. Some researchers have also examined the group layout and cell management problems. Most studies, however, have only addressed these decisions sequentially or independently, despite that these decisions are interrelated and may impact each other. More detailed review and analysis of their interdependent relations can be found in Section 2.

The main purpose of this study is to explore the possibility of determining CF, GL and GS decisions concurrently. A genetic algorithm (GA) based procedure will be developed for this attempt. The remainder of the paper is organized as follows. Section 2 reviews literature concerning at least two of the decisions involved in CM. A hypothetical example will be used to illustrate the deficiencies of current practice. In Section 3, a mathematical model, which integrates CF, GL and GS decisions, will be formulated to help understand the nature of the problem. A GA-based heuristic that concurrently solves these three decisions is described in Section 4. We present results and discuss computational experience in Section 5, followed by conclusions in Section 6.

2. Problems with existing approaches

Past researches in studying CM systems design and implementation have been predominantly focused on the CF decision. Many analytical methods, including simple matrix (array-based) manipulation, mathematical models, graphic theoretical approach, heuristic methods, expert systems, fuzzy logic, neural networks, genetic algorithms, simulated annealing, Tabu search, etc., have been developed. A comprehensive review on the past CF researches can be found, for example, in Chu (1989, 1995), Singh (1993) and Wemmerlöv and Hyer (1986). Some of these early models only considered basic information such as machine/part matrix; thus, they have limited application in practice. Some newly developed models and heuristics such as simulated annealing, and genetic algorithms, etc. are more realistic and appealing to real-world applications (Atmani, Lashkari, & Caron, 1995; Heragu & Gupta, 1994; Kim & Suh, 1998; Vakharia & Wemmerlov, 1990; Verma & Ding, 1995) because they have taken more factors such as demands, processing time, space availability, material handling costs and processing sequence, into considerations.

There have been some researches devoted to the GL decision (Alfa, Chen, & Heragu, 1992; Carrie, 1973; Chandrasekharan & Rajagopalan, 1993; Gupta, Gupta, Kumar, & Sundaram, 1996; Heragu & Kakututi, 1997; Hsu & Su, 1998; Leskowsky, Logan, & Vannelli, 1987; Rajagopalan & Batra, 1975). Most of them proposed to solve the GL problem as a sequel to the CF problem. However, as pointed out by Logendran (1991) that operation sequence and machine layout will have major impact on the CF. Thus far, only a few studies (Alfa et al., 1992; Gupta et al., 1996; Hsu & Su, 1998) have attempted to resolve these decisions concurrently.

Due to the fact that EEs cannot be completely removed from CM system design, some studies have devoted to investigate on dealing with EEs. Common solutions include modifying the part design, moving the exceptional operations to be processed at other cells, subcontracting the operations (or parts), or duplicating the necessary facility, etc. Vakharia and Kaku (1993) developed a model, which includes these factors, to test their potential impact on cell design from a long-term perspective. Shafer, Kern, and Wei (1992) proposed a mathematical model to deal with EEs by considering costs involving in inter-cell and intra-cell movement, machine duplication and subcontracting. These models, however, suffered from the deficiency of presuming that part families have been established. Tsai, Chu, and Barta (1997) proposed a model that can form manufacturing cells and deal with EEs concurrently. A heuristic GA was developed to solve the model (Chu & Tsai, 2001).

There have also some researches studied the GS problems (Allison, 1990; Logendran & Nudtasomboon, 1991; McRoberts & Vaithiannathan, 1981; Taylor & Ham, 1981; Vakharia & Chang, 1990). Again, all these studies attempted to solve the GS problem by assuming that part families have been pre-established. To explore the potential deficiency of this practice, let us examine a simple example. Table 1 lists the machine/part

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