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Grouping efficiency measures and their impact on factory measures for the machine-part cell formation problem: A simulation study

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Abstract

Over the past 25 years, the machine-part cell formation problem has been the subject of numerous studies. Researchers have applied various methodologies to the problem in an effort to determine optimal clusterings of machines and optimal groupings of parts into families. The quality of these machine and part groupings have been evaluated using various objective functions, including grouping efficacy, grouping index, grouping capability index, and doubly weighted grouping efficiency, among others. In this study, we investigate how appropriate these grouping quality measures are in determining cell formations that optimize factory performance. Through the application of a grouping genetic algorithm, we determine machine/part cell formations for several problems from the literature. These cell formations are then simulated to determine their impact on various factory measures, such as flow time, wait time, throughput, and machine utilization, among others. Results indicate that it is not always the case that a ‘‘more efficient’’ machine/part cell formation leads to significant changes or improvements in factory measures over a ‘‘less efficient’’ cell formation. In other words, although researchers are working to optimize cell formations using efficiency measures, cells formed this way do not always demonstrate optimized factory measures.

Keywords: Grouping genetic algorithm; Grouping efficacy; Grouping capability index

1. Introduction

One of the decisions that must be made at a cellular manufacturing facility is how to separate machines into groups and parts into families in order to form efficient cells. The area of research that deals with this problem is known as group technology. Specifically, the machine-part cell formation (MPCF) problem addresses issues concerning the creation of part families based on each part's processing requirements, and the construction of machine groups based on each machine's ability to process particular part families. The efficiency of a cell formation is based on how many parts must leave their assigned cell in order to be processed, and on the machine utilization within each cell. Research has shown that manipulation of a problem's given machine-part (MP) matrix into a block diagonal form is a key component in creating efficient cells.

In order to evaluate and compare the quality of multiple solutions to an MPCF problem, a measure of solution quality must be selected. Numerous such measures have appeared in the literature. Among these are grouping efficiency (Chandrasekharan and Rajagopalan, 1989), grouping efficacy (Kumar and Chandrasekharan, 1990), grouping index (Nair and Narendran, 1996), grouping capability index (Hsu, 1990), and doubly weighted grouping efficiency (Sarker, 2001). Each of these measures uses the block diagonal form of the given MP matrix that results from arranging the rows and columns based on a particular solution for an MPCF problem. In general, researchers agree that high-quality solutions arise when the constructed cells of the solution result in a block diagonal matrix containing minimal voids (zeros in the diagonal

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blocks) and minimal exceptions (ones outside of the diagonal blocks).

From a practical standpoint, floor managers of a cellular manufacturing facility are probably not interested in the efficiency score of the cells based on the measures given above. They are more interested in measures that evaluate how well the plant is performing, such as flow time, wait time, throughput, machine utilization, etc. The focus of this research is to examine how well the cells formed using the "efficiency measures", such as grouping efficacy, grouping index, grouping capability index, or doubly weighted grouping efficiency actually perform when evaluated using "factory measures" such as flow time, wait time, throughput, and machine utilization.

Our simulation results indicate that it is not always the case that improving a particular problem's efficiency score leads to significantly different values for factory measures. In fact, there are even instances when cell formations with higher efficiency scores, when simulated, result in factory measures inferior to the factory measures for cell formations with lower efficiency scores.

This paper is organized as follows. Section 2 provides background on the MPCF problem and a review of the quality measures used to evaluate MPCF solutions. Section 3 describes the solution technique applied in our research. In Section 4, we describe our simulation study and the factory measures it incorporates. In Section 5 we provide an analysis of our results. Conclusions are presented in Section 6.

2. Problem description

2.1. The machine-part cell formation problem

Over the past four decades, numerous researchers have investigated solution methodologies to apply in the area of group technology. Group technology can be defined as "an approach to the organization of work in which the organizational units are relatively independent groups, each responsible for the production of a given family of products" (Burbidge, 1979, p. 36). A key aspect of group technology is determining how to form efficient manufacturing cells. This problem is referred to as the MPCF problem.

The goal of the MPCF problem is to identify part families (i.e., parts with similar processing requirements) and to group each of these families with the set of machines that can process them. Research has indicated that efficient manufacturing cells result when machines are fully (or heavily) utilized and the amount of intercell traffic is minimized. In order to measure machine utilization and intercell traffic, the machine-part incidence matrix is examined. This matrix indicates which machines are required by each part. A member of this matrix, a_{ij}, has a value of 1 if machine i is required by part j, and a value of 0 otherwise. By arranging the columns and rows of this matrix in the order corresponding to the groups identified by a MPCF solution, and then applying one of the objective function measures, one can determine the efficiency of the solution.

2.2. Grouping efficiency measures

Several different measures for evaluating the efficiency of manufacturing cells have been proposed in the literature. Chandrasekharan and Rajagopalan (1989) introduced the first quantitative measure known as grouping efficiency. This measure allows for the normalized weighting of machine utilization and intercell traffic. Work with this measure demonstrated that it had weak discriminating power. That is, it was found that not only was the quality of the block-diagonalization important, so was the ability to distinguish characteristics of different problem matrices. The major problem was the assignment of weights as the MP matrix got larger. To overcome this drawback, Kumar and Chandrasekharan (1990) proposed a measure called grouping efficacy. By incorporating the size of the MP matrix into its formula, grouping efficacy offers improvements over grouping efficiency. Today, grouping efficacy is one of the most widely used measures applied to the MPCF problem (Chandrasekharan and Rajagopalan, 1987; Joines et al., 1996; Srinivasan, 1994; Srinivasan and Narendran, 1991). The formula for grouping efficacy (E) is given in Eq. (1). In this measure, e refers to the total number of ones in the MP matrix. The number of exceptions is given by e_o, and the number of voids is given by e_v:

$$E = \frac{e - e_o}{e + e_v}. \tag{1}$$

With grouping efficacy, the weights assigned to the number of voids and the number of exceptions is a function of the measure and cannot be assigned by the user. This measure is also less sensitive to changes in the number of exceptions.

Nair and Narendran (1996) proposed the grouping index (G) measure to overcome some of the disadvantages of the grouping efficiency and grouping efficacy measures. This measure considers the block-diagonal space to give equal weights to both voids and exceptions and to provide good discriminating power for all problem sizes. In this manner, the weighting factor is linked with the size and sparsity of the MP matrix (Sarker, 2001). This measure incorporates a correction factor into their modified expression for relative grouping efficacy; a measure originally proposed by Kumar and Chandrasekharan (1990). In this measure, given in (2), B is the density (i.e., number of ones) of the solved matrix, q is the weighting factor, and A is a correction factor. As before, the number of exceptions is given by e_o, and the number of voids is given by e_v:

$$G = \frac{B - qe_v + (1 - q)(e_o - A)}{B + qe_v + (1 - q)(e_o - A)}. \tag{2}$$

Other measures have also been presented in the literature, including the index measures such as