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Design of virtual manufacturing cells: a mathematical programming approach

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Abstract

In this paper, a new type of virtual cellular manufacturing (CM) system is considered, and a multi-objective design procedure is developed for designing such cells in real time. Retaining the functional layout, virtual cells are addressed as temporary groupings of machines, jobs and workers to realize the benefits of CM. The virtual cells are created periodically, for instance every week or every month, depending on changes in demand volumes and mix, as new jobs accumulate during a planning period. The procedure includes labor grouping considerations in addition to part-machine grouping. The procedure is based on interactive goal programming methods. Factors such as capacity constraints, cell size restrictions, minimization of load imbalances, minimization of inter-cell movements of parts, provision of flexibility, etc. are considered. In labor grouping, the functionally specialized labor pools are partitioned and regrouped into virtual cells. Factors such as ensuring balanced loads for workers, minimization of inter-cell movements of workers, providing adequate levels of labor flexibility, etc. are considered in a pragmatic manner.

Keywords: Virtual cellular manufacturing; Group technology; Layout; Cell design

1. Introduction

The manufacturing sector has become increasingly competitive as markets have become more globalized. Producers of goods are under intense pressure to improve their operations by enhancing productivity, quality, customer responsiveness, and reducing manufacturing costs. Consequently, there have been major shifts in the design of manufacturing systems using innovative concepts. The adoption of cellular manufacturing (CM) has consistently formed a central element of many of these efforts and has received considerable interest from both practitioners and academicians.

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CM is known to offer several major advantages, including reduction in lead times and work-in-process inventories, full accountability for jobs by teams of workers, etc. [1]. Other critical advantages include reduction of setup times due to similarity of part types produced in manufacturing cells.

However, although CM offers important advantages, there also exist some important reasons why many firms still prefer the 'traditional' functional layout. In contrast to the cellular layout, the functional layout is more robust to changes in product mix. It also offers a certain routing flexibility which may improve shop performance significantly [2,3]. Furthermore, a functional layout preserves functional specialization of workers and tends to foster functional synergies and expertise. At times, it may also provide the economies of scale required for justifying new investments in manufacturing technology. A functional layout is associated with high machine utilization and shop flexibility [4] and superior performance in the queue-related variables [2]. These are important reasons why a functional layout is still dominant in manufacturing industry and why some firms have even shifted from a cellular layout back to functional layout [5,6].

The concept of *dynamic manufacturing cells*, where machines are mobile and will be reallocated as soon as production runs are competed, can be used to adapt a CM system to turbulent environments [7]. This concept may reduce some of the negative implications of CM, while keeping the positive effects. Reorganizing the cellular layout to meet the changed needs, however, may be time-consuming and costly. Further, if these changes occur very frequently, reconfiguration may become impractical or even infeasible [8].

A relatively new alternative has been considered in recent years, namely the concept of virtual cellular manufacturing (VCM) systems. Retaining the functional layout, virtual manufacturing cells have been defined as a temporarily grouping of machines, jobs and workers to realize the benefits normally associated with CM. A virtual cell is a logical grouping of workstations that are not necessarily transposed into physical proximity [9]. The logical grouping of jobs, machines and workers is based on a predefined logic, and it is only resident in the production control system and in the minds of the workers. Machines are not physically relocated into cells, in other words. Virtual manufacturing cells are created periodically, for instance every week or every month, depending on changes in volumes and mix of demand as new jobs accumulate during a planning period.

In recent years, the concept of 'agile manufacturing' has also been explored. This involves facilities that can produce a variety of customized products with minimal reconfiguration and setup. A high degree of volatility in demand, production lots, processing times and setup times, frequent changes in product mix and/or unique product orders, varying production sequences, and presence of strong competition, all characteristics of a turbulent environment, form the rationale for agile manufacturing [10]. In such an environment, it appears that manufacturers tend to adopt a traditional job shop layout combined with the benefits of CM systems.

Conventional CM systems, involving physical changes to the layout, as stated earlier, possess certain disadvantages relating to the loss of routing flexibility, and the inflexibility arising from machine dedication [2,11]. VCM concept was proposed primarily as a means to overcome these limitations [12–15].

Research on VCM systems has gained momentum during last decade. Past studies on virtual cells (e.g., [16]), however, have focused primarily on improvements in queue-related performance measures of the job shop. The emphasis has been on performance evaluation of VCM compared to traditional functional and cellular layouts.

There has been very little research to date on *design* of VCM systems, which forms the theme of this paper. The objective of this paper is to first propose a new concept of VCM approach. Secondly, a multi-objective procedure is developed for designing virtual cells that includes not only job-machine grouping, but also labor grouping. Unlike past research on virtual cells, a dual resource constrained system is considered here, in other words.

This paper is organized as follows. A literature review of VCM system research is presented in Section 2. This is followed, in Section 3, by a description of the new type of VCM system considered in this paper, along with problem definition. A general formulation for virtual cell creation is presented as a goal programming formulation in Section 4. This is partitioned into two more solvable formulations in Section 5. A numerical example is presented in Section 6 as an illustrative example. This is followed by the conclusions in the last section.

2. Virtual cells: a literature review

The virtual manufacturing concept was first developed at National Bureau of Standards to address specific control problems encountered in the design phase of the automated manufacturing of small batches of machined parts [9]. A virtual cell was defined as a *logical grouping* of products and resources within a controller. The job shop based upon virtual manufacturing cells provides greater flexibility than GT shop configurations by time sharing of machines. Machines are at all times under the control of either a particular virtual cell or a pool of idle machines. Basically, the shop control system schedules cell activation and allocates machines and other resources to these cells.

Virtual cells may also help to minimize load balancing problems which are due to sharing of machines by various part families [12]. Further, the authors of [12] argue that the machine groups can be 'virtual', i.e., parts of several families can be loaded on a particular machine shared by several cells. They developed a two-stage flow-based approach for formation of virtual manufacturing cells with an objective of minimizing travel distances. The study addressed the issues of machine grouping, machine sharing, intra-cell layout and inter-cell layout.

The impact of utilizing part family-oriented scheduling rules within a functional layout was explored in [3]. This study showed that a functional layout system using part family-oriented scheduling (referred to in this work as an 'FLP' system), and a first-come-first-serve selection of jobs within each family, fares significantly better