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Solving a dynamic virtual cell formation problem by linear programming embedded particle swarm optimization algorithm

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ABSTRACT

In this paper, a new mathematical model for virtual cell formation problem (VCFP) under condition of multi-period planning horizon is presented where the product mix and demand are different in each period, but they are deterministic moreover production planning decisions are incorporated. The advantages of the proposed model are as follows: considering operation sequence, alternative process plans for part types, machine time-capacity, lot splitting, maximal virtual cell size and balanced workload for virtual cells. The objective of the model is to determine the optimal number of virtual cells while minimizing the manufacturing, material handling, subcontracting, inventory holding and internal production costs in each period. The proposed model for real-world instances cannot be solved optimally within a reasonable amount of computational time. Thus, an efficient linear programming embedded particle swarm optimization algorithm with a simulated annealing-based local search engine (LPEPSO-SA) is proposed for solving it. This model is solved optimally by the LINGO software then the optimal solution is compared with the proposed algorithm.

1. Introduction

A competitive global market is compelling manufacturing firms to increase quality, customer responsibility and reduce production costs. Therefore, there have been major shifts in the design of manufacturing systems from traditional configurations such as job shop and flow shop to new configurations such as cellular manufacturing system (CMS).

Cellular manufacturing (CM) is described as a manufacturing procedure which produces part families within a cell of machines serviced by operators and/or robots that function only within the cell. However, CMSs have some advantages such as reduction in lead times, work-in-process inventories, setup times, etc., there also exist some disadvantages. The performance of CMS, though, depends significantly on the stability of demand with respect to volume and mix. In the cell formation phase of CMS design, it is assumed that the demand pattern is relatively stable over a long product life cycle. It is well known that the performance advantages of CMS deteriorate rapidly with demand instability.

Dynamic cellular manufacturing system (DCMS) is one of the methods which have been proposed for increasing the applicability of CMS in instable demand conditions. In DCMS, to match the demand of each period, configuration of cells can be changed from one period to another. To address this problem, several authors recently proposed models and solution procedures by considering dynamic cell reconfigurations over multiple time periods (e.g. Chen [4]; Mungwattana [13]; Tavakkoli-Moghaddam et al. [31]; Balakrishnan and Cheng [2]; Defersha and Chen [5]; Safaei et al. [22]). Reconfiguration of the cells to meet the unstable demand conditions, however, may be time-consuming and costly. Further, if these changes occur very frequently or machines are immobile, implementation of these systems is impossible [33].

In recent years, several researchers developed the new concept of virtual cellular manufacturing system (VCMS) in order to overcome the disadvantages of traditional CMSs. VCMS belongs to a family of modern production methods, which many industrial sectors have used beneficially. Retaining the functional layout, virtual manufacturing cells have been defined as "a temporary grouping of machines and jobs 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. The logical grouping of jobs and machines is based on a predefined logic, and it is only resident in the production control system. In other words, Machines are not physically relocated into cells. 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 accumulates during a planning period.

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This paper is focused on the design of VCMS where there are existing multiple part types. All part types have different processing routes. To process these part types, multiple machine types and workers are available. Every machine type has more than one individual machine. Every worker has more than an ability to work on multiple machines. Meanwhile, they have ability to train on some new machines. The machines are located in different locations in shop floor. The design decision that is the manufacturing cell formation and the production planning problems for dynamic virtual cellular manufacturing system (DVCMS) to minimize total sum of the manufacturing, material handling, subcontracting, inventory holding and internal production costs over the planning horizon. This paper, unlike previous research on design of VCMS, considers a dual resource constrained (DRC) system is considered.

The cell formation problem is known to be an NP-hard optimization problem [31]. Therefore, effective approaches for the VCMS are necessary to find optimal or near optimal solutions in reasonable amount of time. This paper proposes a linear programming embedded particle swarm optimization algorithm with a simulated annealing based local search engine for the problem under consideration. The advantage of proposed approach is that part of the optimal solution is obtained through the particle swarm optimization algorithm, which is extended by Rezazadeh et al. [20] and the remaining solution is obtained by solving the LP subproblem.

The remainder of this paper is organized as follows: In Section 2, we review relevant literature on the VCMS. Section 3 presents the Problem description and mathematical formulation for the VCMS. In Section 4, we introduce a brief review of particle swarm optimization. Section 5 presents implementation of linear programming embedded particle swarm optimization is described. In Section 7, computational results are reported and in Section 6 the conclusion is given.

2. Literature review

The concept of VCMS was introduced at the National Bureau of Standards (NBS) to address the specific control problems found in the design phase of the automated manufacturing batches of machined parts [25]. Montreuil et al. [12] introduced the idea that the logical system can be separated from the physical system, in other words it is not necessary to have a functional organization if a process layout is in place and that a product organization is not exclusively associated with a product layout.

Vakharia et al. [34] compared the performance of virtual cells and multi-stage flow shops through analytical model. They used some resource elements such as number of processing stages, number of machines per processing stage, batch size and ratio of setup to run time per batch for the implementation of the virtual cells. Ratchev [19] proposed a four phase procedure for the virtual cell formation. In the first phase, processing alternatives are generated; in the second phase, the capability of boundaries of the virtual cell is defined; in the third phase, machine tools are selected, and finally, in the fourth phase, the performance of the system is evaluated. Sarker and Li [23] suggested an approach for virtual cell formation with special emphasis on job routing and scheduling rather than on cell sharing. The basic feature of their approach lies in the identification of a sequence of machines to minimize a job throughout time in a multi-stage production system where there are multiple identified machines per stage and a job can only be assigned to one machine per stage. Thomalla [33] addressed the same problem, but with the objective of minimizing tardiness. In this work, the problem is solved by using a Lagrangian relaxation approach. Irani et al. [6] proposed a two-stage procedure which was a combination of the graph theoretic approach and the mathematical programming approach for forming virtual manufacturing cells. Subash et al. [29] proposed a framework for virtual cell formation. In essence, the authors tested several clustering algorithms for the formation of virtual cells. Saad et al. [21] also presented an integrated framework in a three-step approach for production planning and cell formation. They studied the possibility of using virtual cells as a reconfiguration strategy. Besides the above issues, there are a number of papers published on virtual cell formation. Most of them are controlled or simulation-oriented. Furthermore, those papers that specially address the formation of virtual cells are dedicated to special part families. On the other hand, the aspects of shared cell formulation have not received much attention.

Mak and Wang [11] proposed a new genetic-based scheduling algorithm to minimize the total material and component traveling distance incurred when manufacturing the product with the review to set up virtual manufacturing cells and to formulate feasible production schedules for all manufacturing operations. The proposed algorithm differs from the conventional genetic algorithms in that the populations of the candidate solutions consist of individuals from various age-groups, and each individual is incorporated with an age attribute to enable its birth and survival rates to be governed by predefined ageing patterns. In 2005, Mak et al. [10] improved their methodology by adding another objective of minimizing the sum of tardiness of all products. Baykasoglu [3] proposed a simulated annealing algorithm for developing a distributed layout for a virtual manufacturing cell.

Nomden et al. [14] classified the virtual cell formation procedures into three main classes: design, operation and empirical. A comprehensive taxonomy and review of prior research in the area of VCMS can be found in their study. Nomden et al. [15] studied parallel machine shops that implemented the concept of VCMS for production control. They strived to have a more comprehensive study on the relevance of routing configuration in VCMS.

Some authors proposed that workforce requirements should be taken into account at the cell design stage. Suer [30] presented a two-phase hierarchical methodology for operator assignment and cell loading in worker-intensive manufacturing cells. Here, the major concern is determination of the number of workers in each cell and the assignment of workers to specific operations in such a way that worker productivity is maximal. A functional arrangement of tasks was assumed in each cell without considering training and multi-functionality problems. Askin and Huang [1] focused on the relocation of workers into cells and the training needed for effective cellular manufacturing. They proposed a mixed integer goal-programming model for guiding the worker assignment and training process. The model integrates psychological, organizational, and technical factors. They presented greedy heuristics as means to solve the problem. They assumed that the required skills are cell dependent and that workers may need some additional training, again without considering cross-training issues. Norman et al. [16] presented a mixed integer programming formulation for the assignment of workers to operations in a manufacturing cell. Their formulation permits the ability to change the skill levels of workers by providing them with additional training and training decisions (taken in order to balance the productivity and output quality of a manufacturing cell and the training costs). Slomp et al. [26–28] presented a framework for the design of VMCS, specifically accounting for the limited availability of workers and worker skills. They propose a goal programming formulation that first groups jobs and machines then assigns workers to the groups to form VMCS. The objective is not only to use the capacity as efficiently as possible, but also to have VMCS in places that are as independent as possible.