Computers & Industrial Engineering 62 (2012) 953–971

Contents lists available at SciVerse ScienceDirect

Computers & Industrial Engineering

journal homepage: www.elsevier.com/locate/caie

Capability-based virtual cellular manufacturing systems formation in dual-resource constrained settings using Tabu Search

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ARTICLE INFO

Article history:
Received 20 May 2011
Received in revised form 14 December 2011
Accepted 15 December 2011
Available online 27 December 2011

Keywords:
Group technology
Capability-based virtual cellular manufacturing systems
Dual-resource constrained setting
Resource elements
Goal programming
Tabu Search

ABSTRACT

Formation of Virtual Cellular Manufacturing Systems (VCMSs), as one of the main applications of Group Technology (GT), by presentation of unique and shared capability boundaries of machine tools through defining Resource Elements (REs) creates a good solution for Capability-Based VCMSs (CBVCMSs), which increases opportunities to create systems with more efficient utilizations. Considering workers as the second important resources in Dual-Resource Constraint (DRC) settings makes this problem more serious and critical to research because, in reality, jobs cannot be processed if workers, machines, or both are not available. This paper attempts to form CBVCMSs with DRC settings using a multi-objective mathematical model with a Goal Programming (GP) approach. Using the developed model, parts, machines, and workers are grouped and assigned to the generated virtual cells at the same time. The proposed model is solved through a multi-objective Tabu Search (TS) algorithm to find optimum or near-to-optimum solutions. The validity of the developed model is illustrated by two numerical examples taken from the literature and evaluated through comparing the performance of the CBVCMSs and the original classical CMSs in the System Capacity Utilization (SCU) point of view.

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1. Introduction

To accommodate a wide range of production requirements, manufacturing companies are interested in flexible layouts because of maintaining low material handling costs despite fluctuations in the product demand levels and the material handling flows (Benajaafar, 1995; Lahmar et al., 2005). One of the implied assumptions in the modeling and development of Cellular Manufacturing Systems (CMSs) is that the product mix remains stable over the time (Bhandwale et al., 2008; ErhanKesena et al., 2009) and a major deterrent to implement CMSs is changing the layout by entering new demands or variability of them. In the recent decades, it has been tried to develop new layouts with more flexibilities. Many researchers have suggested Virtual Cellular Manufacturing Systems (VCMSs), proposed by National Bureau of Standards (NBS) in the 1980s in USA (McLean et al., 1982). According to McLean et al. (1982), a virtual cell is not identifiable as a fixed physical grouping of workstations, but as data files and processes in a controller. In the both classical and virtual cells, machines are dedicated to a product or a product family, but in VCMSs the machines are not physically relocated close to each other and there is no need to move the machines to respond to changed demand patterns. Therefore, there is no re-arrangement costs (Balakrishnan et al., 2005). In addition to avoiding the re-layout costs, VCMSs are appropriate for small and medium-sized enterprises where physical separation of machines may be constrained by changing practical, technical, and organizational factors (Babu et al., 2000). Cell Formation (CF) is one of the most important stages in the establishment of a CMS (classical, dynamic, and virtual) and includes the formation of manufacturing cells in order to find out which machines dedicated to each cell and part families corresponding to these machines (Moghaddam et al., 2009). Since a virtual cell allows flexible reconfiguration of shop floors in response to changing requirements, a systematic approach is needed for the formation of VCMSs (Fung et al., 2008).

Characteristics of manufacturing systems, including design layouts, process plans, and worker skills can be presented in two ways: first, machine-based in such a way that machines are considered as entities; second, capability-based so that machining capabilities include entities and groups of machine tools contained in a manufacturing facility are defined based on the concept of Resource Elements (REs). For the first time, Gindy et al. (1996) illustrated that in a capability-based approach, all exclusive and shared capabilities of machine tools, available in a manufacturing facility, are identified uniquely as the name of Form Generating

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doi:10.1016/j.cie.2011.12.020

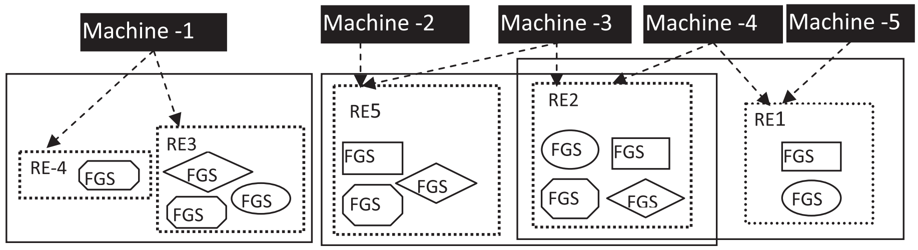

Fig. 1. Representing machines capabilities using REs (Gindy et al., 1996).

Schemas (FGSs). FGSs act as basic capability patterns that can be used for describing the individual/group of machining operation(s). Moreover, Gindy et al. (1996) showed the processing capabilities of a vertical machining center in terms of its FGSs and REs in the form of an example presented in Fig. 1, which demonstrates the relations among FGSs, REs, and machines. The concept of REs helps to representation of unique and shared capability boundaries of machine tools and increases the opportunity to form independent manufacturing cells and efficient utilization of them (Baykasoglu, 2003). In this method, product requirements are generally defined in terms of their processing needs. Once capabilities of available machines are properly defined in terms of REs, parts requiring processing for a RE can equally satisfy it from any machine that has the corresponding RE (Baykasoglu et al., 2001). By using REs in CF applications, it is possible to realize the overlapping capabilities of machines to take advantages of this in configuring cells.

To develop VCMSs, if two constraining resources are considered for the outputs, the system will have a Dual-Resource Constrained (DRC) setting in such a way that a part can be processed only if both resources of concern are available. In another word, in a machine-worker DRC system, capacity constraints on output come from both machines and workers (Hottenstein et al., 1998). Since a cell will be constrained to process because of trained worker shortages as well as the lack of available machines, the problem of assigning workers to machines or cells is critical for classical cells in CMSs or virtual cells in VCMSs. In a DRC system, the operators can be reassigned from one machine to another as needed. According to Treleven (1989), two issues can be considered for DRC systems. Design issues, including worker flexibility or cross-training as the single most important design factor and operational issues involving decisions on dispatching rules as well as due date assignment methods, and decisions on worker allocation rules. Since in DRC systems, the number of machines exceeds the number of workers (Yue et al., 2008), workers need to be multi-skilled to perform more than one function and have to transfer between machines (Bokhorst et al., 2004). Flexible workers can do multi-function or can be cross-trained in different tasks (Cesanı' et al., 2005). In general, the worker flexibility means the responsiveness of a system to variations in the supply and demand of workers. Yue et al. (2008) argued that the worker flexibility can be viewed from a variety of perspectives, including the level of multi-functionality, the pattern of skill overlaps, and the distribution of skills. Based on Cesanı' et al. (2005), the worker flexibility contains decisions regarding the number of workers needed, the number of skills for which workers should be cross-trained, and the assignment of workers to machines. This paper focuses on the design issue, and flexible workers are considered. In cellular systems, including VCMSs and classical CMSs, two types of the worker flexibility are identified; inter-cell and intra-cell, whereas in VCMSs workers have more flexibility regarding the inter-cell flexibility (Cesanı' et al., 2005). From the worker flexibility point of view, workers are different from each other in the case of:

(1) Number of skills
   - Single-level flexibility, which workers assigned to cells are assumed to have the same degree of cross-training or multi-functionality. In these systems, every worker is trained to operate a machine in a similar number of departments (Felan et al., 2001).
   - Multi-level flexibility, which each worker can operate a different number of tasks.

(2) Task proficiencies
   - Homogeneous worker flexibility: if it is assumed that workers assigned to a cell or a shop has the same level of proficiency at performing the assigned task (Felan et al., 2001).
   - Heterogeneous worker flexibility: if it is assumed that workers have a different level of proficiency at performing their assigned tasks (Felan et al., 2001).

Considering the above descriptions, the aim of this research is to develop a multi-objective mathematical model to form CBVCMSs focused on the design issue of DRC settings. Workers as the second important resources, which can affect the performance of the proposed system are considered with a multi-level and heterogeneous flexibility.

2. Literature review

To cover the previous researches related to CBVCMSs and DRC settings, the literature is reviewed in two main subsections.

2.1. Formation of CBVCMSs

Research on VCMSs has attracted considerable attentions in recent years and gained momentum during the last decade. Nomden et al. (2006) surveyed the prior researches in the area of virtual cells and introduced several definitions of VCMSs offered by various researchers. Mostly, researchers agree that VCMSs are generally more efficient than CMSs, especially with respect to the flow performance, production control, quality, average and maximum throughput time, mean and maximum work-in-process, mean and maximum tardiness, and the total marginal cost for a given horizon. In the literature, shorter material traveling distance has been mentioned as the priority of CMSs in comparing with VCMSs for a set of products with deterministic demands, but this problem can be solved using a suitable layout such as distributed layouts as the basic for virtual cells (Hamedi et al., 2011). In addition, according to Baykasoglu (2003), forming a distributed layout prior forming a VCMS helps to improve its performance. Moreover, they presented an example in order to give an idea about the superiority of a capability-based distributed layout over the functional layouts in forming virtual manufacturing cells, but they did not present any method to form a VCMS.

The CF is a complex problem, which considers various production factors, such as alternative process routings, operational sequences,

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