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ScienceDirect
Int. J. Production Economics 105 (2007) 243–262
international journal of production economics
www.elsevier.com/locate/ijpe

Reliability consideration in the design and analysis of cellular manufacturing systems

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Received 1 January 2005; accepted 1 April 2006
Available online 21 June 2006

Abstract

A multi-objective mixed integer programming model of cellular manufacturing system (CMS) design is presented which minimizes the total system costs and maximizes the machine reliabilities along the selected processing routes. A part may be processed under different process plans, each prescribing a sequence of operations to be performed at various machines in a serial configuration. Thus, each process route is associated with a level of reliability corresponding to the machines in the selected process plan. The CMS design problem consists of assigning the machines to cells, and selecting, for each part type, the process route with the highest overall system reliability while minimizing the total costs of manufacturing operations, machine under-utilization, and inter-cell material handling. The proposed approach provides a flexible routing which ensures high overall performance of the CMS by minimizing the impact of machine failure through the provision of alternative process routes in case of any machine failure. The paper also proposes a performance evaluation criterion in terms of system availability for the parts and process plan assignments. Numerical examples are provided to demonstrate the applicability of the model.

Keywords: Machine reliability; Cellular manufacturing systems; Multi-objective mixed integer programming

1. Introduction

Batch manufacturing accounts for a significant share of the total manufacturing activities. Due to the present competitive market, batch manufacturing needs to produce a large variety of products in small manufacturing lot sizes at a competitive price in response to customer needs. Conventional manufacturing systems (job shops and flow shops) have found it difficult to comply with these requirements, and have resorted to group technology (GT) as a viable alternative to overcome these difficulties (Sofianopoulou, 1999) and to gain economic advantages of mass production systems while retaining the flexibility of job shops. Cellular manufacturing, a practical application of GT in which functionally dissimilar machines are grouped together to produce a family of parts, is widely accepted as an effective configuration for batch type manufacturing systems (Seifoddini and Djassemi, 2001). Many researches have discussed the advantages of CMS such as: reduction of set up times, reduction of material handling costs, reduction of in-process inventory, reduction of cycle times,

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0925-5273/$ - see front matter
doi:10.1016/j.ijpe.2006.04.015

improvement of shop floor control and improvement of production efficiency (Wemmerlov and Hyer, 1989; Wemmerlov and Johnson, 1997; Askin and Estrada, 1999).

While the benefits of CMS are well documented by researchers and practitioners, other studies have pointed out the disadvantages of CMS (Suresh and Meredith, 1994; Flynn and Jacobs, 1986; Morris and Tersine, 1990; Boughton and Arokiam, 2000, Agarwal and Sarkis, 1998). The results of these studies may be summarized as follows:

1. Cell formation reduces flexibility.
2. It reduces the machine utilization by dedicating machines to the cells.
3. Machine breakdowns have a deleterious effect on the due date performance.
4. Excessive inventories due to dedication of machines to machine cells.

Among the factors influencing the performance of CMS are the structure of the machine–part matrix, the stability of the product mix in the manufacturing system, and the reliability of the machines in manufacturing cells (Seifoddini and Djassemi, 2001). Reliability plays an important role in the overall performance of CMS. Traditionally, cell formation and work allocation are performed assuming all the machines to be 100% reliable, which is never the case. Machine failures cause the greatest impact on due date and other performance criteria even if there is the option of rerouting the parts to alternative workstations. Machines are a major component of CMS and often it is not possible to handle machine breakdowns as quickly as the production requirements dictate. In addition, the disturbances caused by these breakdowns lead to scheduling problems, which decrease the productivity of the entire manufacturing operations. This issue points out an important need for the consideration of machine reliability in the design process of CMS, especially in light of the increasing complexity of such systems in recent years.

Any attempt at improving the reliability of a system invariably results in higher costs. Thus, an optimization approach that integrates cost and reliability considerations is the most appropriate strategy to achieve an optimum balance. This paper proposes a model of cell formation and operation allocation that incorporates machine reliability and cost considerations to develop an effective CMS design process. The model, which follows the approach of Atmani et al. (1995), is based on the selection of a process plan for each part which maximizes the overall system reliability, while minimizing the overall costs. In the process of allocating operations to machines, the availabilities of the machines are taken into account to determine their effective capacities. The approach attempts to reduce the inter-cell movement of parts as much as possible, while utilizing the concept of alternative process plan assignments in order to cope with machine breakdowns. Finally, the model evaluates the system availability for each part and process plan as a performance measure.

The remainder of the paper is organized as follows. In Section 2 the relevant literature is reviewed. Section 3 describes the reliability considerations in the design of CMS. Section 4 presents the mathematical model. In Section 5 a numerical example is presented to demonstrate the methodology. Sensitivity of the model solution to selected key parameters is investigated in section 6, and the conclusions are summarized in Section 7.

2. Relevant literature

The literature on the design of cellular manufacturing system is quite extensive. Comprehensive reviews and taxonomies of cellular manufacturing techniques and classifications can be found in Wemmerlov and Hyer (1986), Joines et al. (1996), Selim et al. (1998) and Mansouri et al. (2000).

In the context of the research reported here, the number of research work dealing with the reliability aspects of CMS design is fairly small. Providing routing flexibility through alternative process plans is an effective way to handle machine failure situations. Jeon et al. (1998) and Diallo et al. (2001) proposed CMS design approaches which considered alternative routings to handle machine breakdowns. A number of research works included alternative routings in the design of CMS, not to handle machine breakdowns, but to find the best process plans and the best cell configuration which minimized inter-cell movement of the parts, as well as the costs (e.g., Zhao and Wu, 2000; Askin et al., 1997; Askin and Zhou, 1998). In practice, the consideration of routing flexibility makes it possible to accommodate demand changes, but it falls short of effectively tackling the uncertainty due to machine failures. Machine failures should be taken into account during designing of CMS to improve overall performance of the system (Jeon et al., 1998).