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Performance analysis of a batch production system with limited flexibility

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Abstract

The concept of limited flexibility, originally applied to production planning, has shown that many benefits of totally flexible systems can be obtained by less flexible systems. This concept is here applied to shop floor control. Limited flexibility is considered as a particular routing flexibility that allows system resources to process some products according to a logic chain, as an intermediate configuration between a totally flexible system (where every resource can process every product) and a non-flexible system (dedicated resources). A simulation study is carried out to measure the system performance such as the lead time and work-in-process for different system configurations, with variable demand, setup times and processing times. © 2001 Elsevier Science B.V. All rights reserved.

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1. Introduction

The increase of customer requirements, for instance, in terms of demand variability and differentiation, together with the stiffening of competition, forces many manufacturing companies to be flexible and innovative. In particular, a large number of products variable in volumes and mix has to be provided, without neglecting cost competition. In fact, flexibility has to be pursued together with scale economies, as stated by "mass customization" [1].

The search for system flexibility, agility and versatility on the one hand, and of high volumes and low costs on the other, have led to modifications in the design and production activities as well as in the supply management. For instance, design modularity and quick response are some of the devices pursued by the manufacturing companies.

From the operations management point of view, batch production systems are among the most interesting in the search for a competitive trade-off between cost and flexibility.

Job shop and cellular organization are the usual manufacturing systems adopted to perform batch production. In particular, in cellular manufacturing systems (CMS) parts that have similar processing needs are grouped into part families, and machines that meet these needs into machine cells. When part families can be manufactured by cells, group technology allows to reduce the setup time, throughput time and work-in-process. In this case, technical and economic benefits, such as improved productivity, part quality and operations control, arise.

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However, despite many performance improvements, some disadvantages (such as lower machine and labor utilization and other performance decrease) can make the production system design and management more complex, especially when the environment is affected by high uncertainty. For instance, demand variability and resource dependability can force management to adopt more flexible manufacturing organizations, such as job shops, which can better deal with uncertainty [2].

Many studies (for instance [3–5]) have addressed the benefits and the costs of cellular manufacturing systems and job shop in different scenarios, for instance, depending on the performance analyzed (e.g., lead time and system utilization) and on the ranges assumed by various parameters (e.g., product volume and mix variability, setup and processing time, machine dedication, batch size, loading rule). The discrepancy between the empirical and model-based studies on this topic has also been stressed [6].

A combination of the typical job shop flexibility with the cellular systems productivity has then to be searched. Two ways, in particular, can be addressed to improve batch production system performance: designing hybrid configurations between cells and job shop or increasing CMS flexibility. Referring to hybrid production systems, many studies on different production system configurations have been proposed to find trade-offs between CMS and job shops (for instance [7,8]), including "virtual" cellular manufacturing [9]. On the other side, the CMS flexibility can be increased, for instance, by the system routing flexibility, i.e. the ability to use alternative product routes inside a cell (intracell flow) or to route products to cells offering the same processes (intercell flow) [10]. Routing flexibility allows to properly respond to a changing environment, so that the possibility of switching products to different cells in the case of environmental changes can reduce the negative impact of variability on the system performance [11].

Routing flexibility benefits can balance the cost of additional instructions, skills, material handling, tools and fixtures, as well as the increased setup times and work in process of routing flexibility implementation. However, solving demand fluctuation problems by transferring work-load from congested resources to other less congested ones involves some disadvantages, as it has been shown by Ang and Willey [7]. First, extra costs of material handling are incurred; second, work flow simplicity is lost and the costs of production planning and scheduling are increased; third, the number of components being processed only by a cell is reduced and job satisfaction associated with task identity and task significance may diminish. Ang and Willey [7] have shown that only a limited use of intercell work-load transfer is expected to improve shop performance with a small increase of scheduling effort.

Ideally, it is preferred that a product family is completely processed by a cell. Since this is hard to be accomplished for all the families, studies based on cluster analysis, in most instances, have focused on minimizing total intercell moves [12]. Given that the resources associated to the route implementations are usually expensive, it is often not economic to implement more than few routes per product. The trade-off between productivity and flexibility needs then to be investigated.

In this paper, the concept of limited flexibility, proposed in the literature in a multi-plant production planning context [13], is applied to the shop floor management. Limited flexibility is considered here as a particular intercellular routing flexibility allowing some resources (cells) to process some product family according to a logic chain. In particular, products and resources are chained by a minimum number of links and forming the longest close loop. This chain can provide many typical benefits of a totally flexible system (where every resource can process every family, as in a job shop) and of a non-flexible system (where every resource is dedicated to just one family).

Differently from the demand assignment problem [14], focused on a static simulation study with the optimization of resource utilization and lost sales performance, in this paper a dynamic simulation study is carried out to measure system performance such as lead time and work-in-process for different system configurations, with variable demand, setup times, processing times. In particular, the comparison between the limited flexibility and the two extremes of totally flexible and non-flexible system configurations are investigated.