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Computers & Industrial Engineering 55 (2008) 15–33
computers & industrial engineering
www.elsevier.com/locate/caie

A parametric fuzzy logic approach to dynamic part routing under full routing flexibility

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Received 22 January 2007; received in revised form 26 October 2007; accepted 26 November 2007
Available online 4 December 2007

Abstract

Manufacturing flexibility is a competitive weapon for surviving today's highly variable and volatile markets. It is critical therefore, to select the appropriate type of flexibility for a given manufacturing system, and to design effective strategies for using this flexibility in a way to improve the system performance. This study focuses on full routing flexibility which includes not only alternative machines for operations but also alternative sequences of operations for producing the same work piece. Upon completion of an operation, an on-line dispatching decision called *part routing* is required to choose one of the alternatives as the next step. This study introduces three new approaches, including a fuzzy logic approach, for dynamic part routing. The fuzzy part routing system adapts itself to the characteristics of a given flexible manufacturing system (FMS) installation by setting the key parameters of the membership functions as well as its Takagi-Sugeno type rule base, in such a way to capture the bottlenecks in the environment. Thus, the model does not require a search or training for the parameter set. The proposed approaches are tested against several crisp and fuzzy routing algorithms taken from the literature, by means of extensive simulation experiments in hypothetical FMS environments under variable system configurations. The results show that the proposed fuzzy approach remains robust across different system configurations and flexibility levels, and performs favourably compared to the other algorithms. The results also reveal important characteristic behaviour regarding routing flexibility.

Keywords: Fuzzy logic; Flexible manufacturing systems; Dynamic part routing; Routing flexibility; Processing flexibility; Flexible process plan

1. Introduction

Today's competitive market conditions are characterized by a high degree of variability and volatility. Variable demand, shorter product life cycles, higher customization, lead-time based pressure and multi-product portfolios describe the nature of the environment in which many manufacturing organizations have to

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doi:10.1016/j.cie.2007.11.013

compete. In this context, flexibility refers to the ability of a manufacturing system to respond cost effectively and rapidly to changing production needs and requirements, and should be seen as a competitive weapon. The challenge is, however, to select the appropriate type and level of flexibility for a given manufacturing system, and to design effective strategies for using this flexibility in a way to improve the system performance.

Current literature on manufacturing flexibility offers several competing definitions and classifications (Benjaafar & Ramakrishnan, 1996; Browne, Dubois, Rathmill, Sethi, & Stecke, 1984; Chan, Bhagwat, & Wadhwa, 2006; Chang, 2007; D'Souza & Williams, 2000; Sethi & Sethi, 1990; Wahab, Wu, & Lee, 2008). According to the hierarchical classification suggested by Benjaafar and Ramakrishnan, flexibility can be product-related or process-related. *Process flexibility* is a characteristic of the process which allows it to adjust to various operating conditions and requirements, while *product flexibility* refers to the variety of manufacturing options associated with a product. The product flexibility is further classified into three types: *operation flexibility* is defined as the possibility of performing an operation on more than one machine; *sequencing flexibility* relates to the possibility of interchanging the sequence of operations; and *processing flexibility* is defined as the possibility of producing the same work piece with alternative sequences of operations. Defined as such, the product flexibility is a potential flexibility; while its utilization during execution is often called *routing flexibility*, i.e. ability of a manufacturing system to use multiple alternate routes to produce a set of parts. The realized level of routing flexibility depends on the technological capabilities and the operational control strategies that recognize and utilize different dimensions of the potential product flexibility. In this paper, we focus on *full routing flexibility* to exploit all dimensions of product flexibility. Fig. 1 depicts a flexible process plan for a part with all types of the product flexibility. The nodes in the figure represent different operations on the process plan, and at each node, candidate machines that can carry out the operation are indicated. Upon completion of an operation, an on-line *part routing* decision is required to choose an appropriate operation-workstation pair among the alternatives offered by the flexible process plan of the product. Routing flexibility has been recognized as a fundamental part of a manufacturing system's overall flexibility, as it enhances the effective capacity usage by creating smoother part flow throughout the system and by better balancing the machine loads. The aim of the study presented in this paper is to develop a robust part routing strategy to effectively deal with all types of product flexibility (i.e. full routing flexibility) during real-time control of a flexible manufacturing system (FMS).

Analytical methods have limited ability in tackling real-time operational decisions, mainly due to problems with computational efficiency and realistic modelling of dynamic features of a FMS (Gamila & Motavalli, 2003; Saygın & Kılıç, 1999). In the existing literature on dynamic part routing, the most frequently used strategy is employing single criterion heuristic rules such as "number in next queue" (NINQ) or "work in next queue" (WINQ) (Caprihan & Wadhwa, 1997; Henneke & Choi, 1990; Mahmoodi, Mosier, & Morgan,

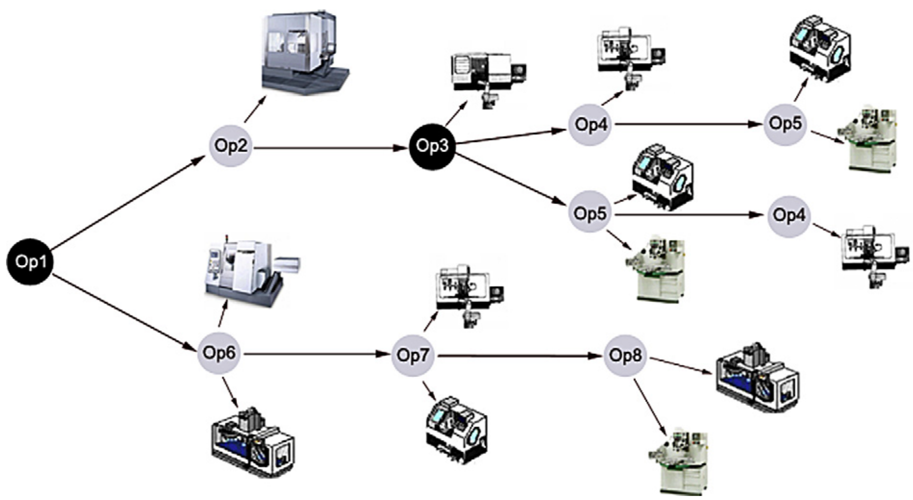

Fig. 1. Flexible process plan for a part which has operation, sequencing and processing flexibilities.