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A dynamic approach to measure machine and routing flexibilities of manufacturing systems

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Abstract

The ability for a manufacturing system to easily adapt to various uncertainties in their production system is described as manufacturing flexibility. Over the past two decades manufacturing flexibility has become an important part of many production systems. Existing models, however, only include a few of the many technological attributes that can be found in manufacturing systems. This study considers a number of technological attributes that are common to manufacturing systems and incorporates them in the development of two manufacturing flexibility models that evaluate the performance of production systems. The first model defines a measure for machine flexibility and the second defines a measure for routing flexibility. Technological attributes such as the efficiency of processing an operation, the number of different operations a machine can perform, the fraction of an operation that can be transferred during disturbances, the probability of transferring an operation to alternative routes, are just a few of the attributes included in our flexibility models. We perform a set of tests that illustrate the strength of our models with respect to machine and routing flexibilities and highlight some of the weaknesses present in previous flexibility models.

Keywords: Machine flexibility; Routing flexibility; Manufacturing systems

1. Introduction

Due to recent technological developments, customer satisfaction has grown to include the quick and efficient delivery of new products and merchandize to the shelves of retailers. To remain competitive, many companies have improved their production process by introducing *manufacturing flexibility*. The term manufacturing flexibility has become an exclusive expression that indicates a manufacturing system's ability to adhere to disturbances in the production process and produce customer-oriented products at low costs and greater response sensitivity to dynamically changing manufacturing systems. Manufacturing flexibility has received an increasing amount of popularity in the past two decades as it provides companies with the ability to adhere to disturbances in the production process so that new and existing products can be produced more rapidly. Also, since future customer requirements cannot be predicted, flexibility allows for a quick adaptive response to unpredictable situations in

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manufacturing. In fact, many successful manufacturing companies have the capacity to accommodate for several changes in product design, input, output, and the manufacturing process. Each modification can be categorized as either: an internal or an external change. Internal changes account for manufacturing modifications caused by the deterioration of machines or tools, the failure of machines or tools, or the implementation of different sequencing or dispatching rules to the production process. External changes consist of modifications made to account for customer demand and supply uncertainties. When manufacturing systems are *flexible*, they can respond to dynamic production necessities and requirements easily. The traditional flexibility concept is static; where manufacturing capabilities for handling uncertainties from the environment, the inputs and outputs, and the production process are considered to be fixed (Hyun and Ahn, 1992). There are several articles that detail various static flexibility models (Hyun and Ahn, 1992; Beach et al., 2000; Shuiabi et al., 2005); however, if the manufacturing capabilities for handling uncertainties are subject to change dynamically, the existing mathematical models fail. To account for the inherent flexibility of today's demanding manufacturing systems, the dynamic aspect of flexibility must be incorporated in the mathematical framework of the problem.

Significant efforts to explore the manufacturing concept domain and measure flexibility have been made. Due to the multi-dimensional nature of manufacturing flexibility, various flexibility taxonomies have been developed. Consequently, flexibility has been studied as a physical property, a strategic tool, an attribute of decision making, and an economic indicator. Studies by Buzacott (1982), Gerwin (1987), Taymaz (1989), Gupta and Buzacott (1989), Brill and Mandelbaum (1989), Chandra and Tombak (1992), Bernado and Mohamed (1992), Nagarur (1992), Hyun and Ahn (1992), Das and Nagendra (1993), Stecke and Raman (1995), Chen and Chung (1996), and Shewchuk and Moodie (1998) are just a few amongst the many flexibility models. Many of the existing flexibility studies have only investigated the concept of flexibility in relation to a particular domain and a specific objective, instead of considering an entire manufacturing system (Gerwin, 1987; Sarker et al., 1994). As a result, current flexibility models are simply based on a limited analysis of manufacturing systems (Koste and Malhotra, 1999). Therefore, while there are several taxonomies that attempt to define manufacturing flexibility, they are incomplete or too abstract to explain the fundamental concept of flexibility (Gupta and Buzacott, 1989; Shewchuk and Moodie, 1998). Thus, the meaning and implementation of manufacturing flexibility still remains ambiguous (Chang et al., 2001). Subsequently, an analytical model capable of generating a clear relationship between the degree of a system's flexibility and the level of a system's performance has yet to be defined (Slack, 1987; Kumar, 1987; Gupta and Goyal, 1989).

We develop mathematical models to measure machine and routing flexibilities by integrating a variety of technological attributes and elements within manufacturing systems. Generally, machine flexibility (MF) is the degree of versatility a machine possesses with regards to performing various operations in the production process. Whereas, routing flexibility (RF) is defined as a system's ability to continue with an operation(s) despite disturbances in the production process. In order to capture the dynamic aspect of machine and routing flexibilities, we consider elements such as: the probability of assigning an operation to a machine, the probability of assigning an operation from one machine to another, the probability of transferring an operation from one machine to another, the aggregate efficiency of the material handling system for transferring an operation from one machine to another, and the availability of a machine. These models provide comprehensive flexibility measurements that may be used to evaluate and rank manufacturing systems according to their inherent flexibility. The motivation behind our model stems from the workings of Sarker et al. (1994), in which they present a survey and critical review of flexibility measures in manufacturing systems. The review provides evidence that MF and RF are two of the most fundamental and important types of flexibilities. Also, that existing MF and RF measures are not generic models and should consider more than one or two technological attributes. Although, isolated methods for measuring manufacturing flexibility have been developed, we provide a generic MF model and a generic RF model that incorporates a number of technological attributes in its design. For instance, given a manufacturing system, an investor knows the configuration and the processing capability of each machine, and the material handling system. Also the investor is familiar with the types of products produced. Thus,