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Evaluation of enterprise-level benefits of manufacturing flexibility

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Abstract

An enterprise-level flexible manufacturing approach for a multi-product manufacturer like an automotive company requires a cost-effective mix of many key enablers, including flexible assembly plants, part commonality between products, and supply base flexibility. This paper develops a strategic planning model that determines the overall business value of flexible manufacturing systems. The model is designed to be capable of dealing with problems of realistic size and scope. Interpretation of results of the model gives important strategic insights on factors influencing manufacturing flexibility and capacity requirements in the presence of these factors. The model is applied to study a flexibility evaluation problem faced by a major automotive company. The experimental results show that flexibility enablers such as flexible product to manufacturing facility assignments and part commonality can lead to improved profitability. Increases in profitability of up to 17% (> $300 M/year) are seen in the modeled system. Increased commonality and/or flexibility also result in a reduction of the optimal capacity for the assembly system while simultaneously slightly improving sales. These results are robust with respect to introduction of the regulatory compliance issue of fuel economy standards, although the incremental profits from improved flexibility and commonality are reduced by approximately 25% when fuel economy standards are included.

Keywords: Manufacturing flexibility; Capacity planning; Parts commonality; Automotive industry

1. Introduction

Strategic decisions regarding the production volume for each vehicle, assignments of vehicles to plants and establishing appropriate manufacturing facilities are long-term decisions for automotive and other durable goods manufacturers. These decisions provide bounds on the manufacturer's abilities to meet customer demand and to achieve the targeted performance [1].

However, these decisions are made using uncertain demand information. Moreover, demand uncertainty is expected to increase in the future because of more intense pricing competition, shorter product life-cycles, less predictable behavior of consumers, and greater numbers of vehicles being offered to consumers. Manufacturing flexibility is a strategy for handling demand uncertainty [2]. An objective of this investigation is to develop a model for flexibility evaluation and capacity planning in flexible manufacturing systems facing demand uncertainty applicable to real business decisions.

An enterprise-level flexible manufacturing system has many facets that impact its ultimate effectiveness. Items

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that have an impact on the financial value of an overall manufacturing flexibility approach are referred to here as flexibility enablers. Some enablers of manufacturing flexibility, e.g. flexible body shops and plant overtime, are a part of the function of the assembly plant itself. Other enablers, such as part commonality and supplier manufacturing flexibility, are not directly associated with the assembly plant. Both in-plant and outside-plant enablers can have a large influence on the value of flexibility. Most importantly, the value of a given flexible manufacturing system may be a complicated function of the levels of the enablers. For example, going from 25% to 50% part commonality might have a different incremental financial benefit depending on whether assembly plant flexibility is low or high. *Therefore, it is important to examine the space of possible enabler configurations with care to determine the most valuable flexible manufacturing systems*. Such examination requires a model having capabilities to handle demand uncertainty, to represent various flexibility enablers, to determine capacity requirements, and to account for other external and internal factors influencing strategic decision making.

Chen et al. [3] point out that research on quantitative models of flexible manufacturing systems at the enterprise level under demand uncertainty is scarce. Jordan and Graves [4] elaborate a framework for strategic analysis of flexibility in the automotive industry. They emphasize that partially flexible systems, if intelligently designed, are capable of yielding similar benefits to completely flexible systems. The authors demonstrate that the value of flexibility depends upon correlation in product demand and the system's capacity. Guidelines for assigning vehicles to plants to achieve different levels of product mix flexibility are provided. However, their framework considers only assembly plant mix flexibility, and does not include other factors of high practical importance, such as supply base capacity. Other authors who investigate the value and properties of flexibility by comparing different assignments of product to manufacturing facilities include Boyer and Keong [5] and Bengtsson and Olhager [6]. The authors have analyzed characteristics of flexible systems at different levels of capacity. However, these capacity levels are taken as given in their analyses, and the capacity levels' selection subject to flexibility is not considered.

Fine and Freund [7] develop a stochastic programming model for optimizing product-flexible capacity under a finite number of possible demand realizations. Gupta et al. [8] develop a similar model for finding optimal investment policies in the presence of fixed initial capacities. Chen et al. [3] optimize the capacity of a flexible manufacturing system using stochastic programming, where the evolution of stochastic demand is represented using demand scenarios. Although their model is designed to handle multiple-product and multiple-facility (technology) situations, their reported numerical results are restricted a maximum of three products and one technology. An optimization model by Van Mieghem [9] analyzes the selection between dedicated and flexible resources in a two-product case. The author considers continuous demand and concludes that selecting flexible resources may be advantageous, even if demand for products is positively correlated.

Strategic planning in the context of flexible manufacturing systems has been addressed using economic justification methods (for instance, [10,11]). These methods provide fair coverage of factors influencing value of flexibility from the economic perspective. However, they provide limited information about characteristics of the system from the manufacturing perspective. The methods employ a scenario-based flexibility evaluation approach that includes representation of demand uncertainty. Olhager and West [12] develop a methodology for linking manufacturing flexibility to market requirements. This methodology allows for identifying issues relevant to implementing flexibility, while other models are needed for quantification purposes. The authors identify capacity as one of the most important flexibility source factors in the case study conducted.

The small size of tractable problems and the restricted number of factors considered limits the application of existing flexibility evaluation models for analysis of real systems. Additionally, the often-used assumption that there are only a small number of demand realization scenarios is not always justifiable.

This paper adopts a scenario-based approach to represent levels of flexibility enablers, such as flexibility of assembly plants and part commonality between products. The levels of the enablers are assumed fixed within each scenario. In contrast to other papers, a comprehensive multi-period capacity optimization model applicable to modeling problems of realistic size is developed. The model determines optimal capacity for a given flexible manufacturing system. It also yields optimal values for two in-plant flexibility enablers: carrying extra capacity (beyond mean demand) and overtime usage. The model accounts for a number of factors relevant to strategic decision making such as marketing costs and legislative regulations. External demand is represented using continuous probability distributions, using Monte-Carlo simulation, and capacity optimization is performed using a genetic algorithm.

Studies with the model have been conducted using an experimental case that represents a strategic capacity investment problem faced by the Ford Motor Company. From an applied perspective, these studies determine the overall dollar value of flexibility and illustrate the impact of the flexibility enablers upon manufacturing system profitability. From an academic perspective, these studies provide insights on: (1) the dependence of capacity decisions upon flexibility enablers, (2) relationships between types of flexibility, and (3) dependence of the value of flexibility upon external factors such as legislative regulations.

The rest of the paper is organized as follows. Section 2 defines the modeling problem. It identifies the problem scope and discusses relevant aspects of manufacturing flexibility. The capacity planning and flexibility evaluation model is