A simulation-based framework for the economic evaluation of flexible manufacturing systems

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Abstract

Due to the increasing market demand volatility, globalization of markets and shorter product life cycles, the importance of flexible manufacturing systems gain more and more importance across all industry sectors and sizes of companies. Especially, the increasing planning uncertainties concerning the product mix and volume lead to a growing demand for flexibility. In this context, methods for the economic evaluation of flexible manufacturing systems take a significant role in drawing meaningful conclusions, which allow the creation of an optimized level of flexibility. This paper presents a simulation-based framework for an assessment methodology in order to conduct an economic evaluation of flexible manufacturing systems. Within the developed framework, costs induced by flexibility are allocated activity-based according to their actual cause. The identification of flexibility-induced cost and their causes, provide an overall improved cost transparency. Based on this, target-oriented optimization can be applied more effectively.

Keywords: Flexible manufacturing systems, simulation-based, cost transparency, optimization

1. Introduction

Nowadays, manufacturing companies face the challenge to adapt their manufacturing processes flexible and economically in order to meet the requirements raised by the market and customer demands. To meet these demands in an economically manner, the existing and future multitude of different product variants have to be manufactured according to their optimal manufacturing lot sizes and requested quality standards of the customers. Especially, due to the dynamic change of customer demands and the individualization of all markets, the requested quantities of identical products vary in the majority of the cases the most. Thus, a manufacturing system that is able to simultaneously cope with flexibility requirements in terms of product quantities and product variants, becomes a significant competitive factor for every manufacturing company across all industry sectors and sizes of companies. [1]

Furthermore, manufacturing companies face an increasing cost pressure regarding all processes. This overall cost pressure is largely caused by the globalization of all industry sectors and their inherent dynamic and global connection of suppliers, manufacturers and customers. In spite of this environment, which is mainly characterized by volatile market demands and increasing product variants, the actual manufacturing costs are obliged to maintain a low level. [2]

In this context, flexibility itself gains importance through the ability to create different alternatives within manufacturing systems, which contain an actual economic value. [3] But despite this value-adding ability, flexibility can also lead to different conflicts of manufacturing objectives. Thus, an increased flexibility can lead to decreased throughput times while increasing set-up costs. [4]

These circumstances make it apparent, that variations within manufacturing systems have an impact on manufacturing costs and consequently the cost changes can serve as a measure for
the evaluation of these variations. [5] An essential part of flexible manufacturing systems is therefore the ability to locate the optimal operating point for each variation or situation in order to be able to manufacture economically and efficiently within a certain corridor of flexibility. This kind of flexibility enables companies to quickly adapt to the changes of the market.[6]

The ability of this quick adaption and flexibility becomes also apparent through the diverse set of alternatives, which are derived from being flexible e.g. different forms of flexibility. Hence, it can be followed that a flexible manufacturing system is a key component for manufacturing companies to gain a sustainable competitive advantage. [7]

2. State of scientific knowledge

2.1. Flexibility of manufacturing systems

The term flexibility is often applied in common and daily linguistic usage, which leads to a generalized but also not very distinguished perception of its actual meaning. [8] The existence of more than 70 different definitions within selected English manufacturing literature is an example of its broad understanding among scientist and experts. [9] The main reasons for these differences in perception are the heterogeneous usage of terminology as well as the different under-standing of the specific scope of flexibility including its differentiation from associated terms such as agility, adaption and transformation ability [10]. Hence, the common perception of the term flexibility equals more a complex, multidimensional and intangible concept rather than a generalized definition [11].

This shortcoming leads to a broad interpretation, usage and evaluation within different disciplines e.g. decision making, industrial management, logistics and manufacturing [12]. In general, flexibility describes the ability to appropriately adapt to changes of the environment of the considered system [13].

In context of the description and evaluation of flexible manufacturing systems, flexibility often describes the ability to manufacture different product mixes, e.g. differences in quantities and variants, within existing systems without a comprehensive adaption of the fundamental characteristics of the considered manufacturing system. [14; 15]. The latter perception of flexibility can be extended to the previous mentioned corridor of flexibility, in which a manufacturing system, depending on various input parameters e.g. number of products and variants, can economically and efficiently operate. [16].

Depending on the change or adaption of these input parameters, the flexibility of manufacturing systems can generally be distinguished into a volume flexibility, a product mix flexibility with a variable total production quantity and a product mix flexibility with a constant total production quantity. [14, 17] The first kind of flexibility, the volume flexibility, is characterized by an overlaying increase of the total production quantity. This overall production quantity increase leads to a proportional adjustment of the quantities of all product variants within the existing product mix. The necessity of a volume flexibility may be the case during a general change in demand or the existence of an economic recession respectively a boom.

The second and third kind of flexibility describe the earlier mentioned product mix flexibility. Depending on the kind of product mix flexibility either one with an overlaying variable or constant total production quantity. Both of these kinds of flexibility are characterized by the circumstance, that different upstream products are proportional needed to compound the final product. Thus, the needed quantities of the upstream products are directly depending on the number of requested final products of the corresponding product variant.

The second kind of flexibility, the product mix flexibility with a variable total production quantity, is marked by the adaption of produced quantities of particular product variants or a specific subset of products, which leads to an overall change of product units within the manufacturing system. This may be the case, if e.g. only the demand of particular product variants or specific subsets is changing while other products or variants remain unchanged.

The third kind of flexibility, the product mix flexibility with a constant total production quantity, can be identified through the overall constant number of final production units during a change of the produced units of particular product variants or specific subsets of products. A practical example is given by JONDRAI, in which three different kind of engines variants, e.g. a conventional, a sportive and an eco-friendly engine, are manufactured in the same manufacturing system but change their proportion of the overall constant production units due to an eco-friendlier awareness of certain customer groups. [14]

Figure 1 summarizes the different described kinds of flexibility and illustrates the distinguishing characteristics (allocation, machine utilization and description) of the volume flexibility and product mix flexibility.

![Figure 1: Kinds of flexibility and distinguishing characteristics in the context of the description of manufacturing systems [18]](image)

As mentioned in section one, changes within the volume or product mix have an impact on the manufacturing output and costs and consequently the cost changes can serve as a measure for the evaluation of these changes. An established approach to relate the physical output of manufacturing systems to its actual
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