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Interchangeable Product Designs for the Increase of Capacity Flexibility in Production Systems

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Abstract

In the current competitive market, production companies are driven by significant price pressure, as well as high fluctuation in demand. They are faced with the challenge of producing products cost-effectively. Serial and variant manufacturers especially strive for high capacity utilization to prevent overcapacity and to reduce fixed costs in production. Applying current approaches, companies are able to react on market turbulences by adapting the production system within the limits of a defined flexibility corridor. However, these approaches do not eliminate the existence of overcapacity or bottlenecks. An alternative approach for short and medium term adjustments in the given production system has to be developed. In this article, an approach to increase the capacity flexibility in production systems based on the idea of interchangeable product designs is described. The objective is the economical use of overcapacity and efficient reaction to bottlenecks. Based on extensive scientific studies, the influence on the capacity flexibility of production systems by variation of product designs with the same product function, but different manufacturing process times and variable costs, is presented.

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Keywords: Product Function; Product Design; Capacity Flexibility; Production System; Cost Reduction

1. Introduction

Nowadays, many manufacturing companies are constantly confronted with high turbulences in the market. In particular, turbulences are caused by the current economic development, such as globalization, regionalization, individualization and urbanization, which lead to high end-user requirements. New products with short delivery times, high variety and perfect quality at reasonable prices have to be offered [1].

The challenge of manufacturing companies is to produce economically and to be robust against turbulences, in spite of an increasing uncertainty in the dynamic and competitive market. Success and a sustainable future in turbulent markets require high flexibility and fast responsiveness [2].

One success factor of manufacturing companies is having capacity flexibility in response to turbulences, especially to high fluctuation in demand. Today, there are many well-used and practice-oriented approaches to increase the capacity flexibility, such as using flexible machines [3], storages for decoupling [4,5], insourcing and outsourcing [6,7], as well as flexible working time models [8]. The current approaches allow production companies fast adaptions of the production system to changing market conditions, within the limits of an installed flexibility corridor [9].

However, due to the limited flexibility corridor, the optimal capacity utilization cannot be achieved with the current approaches [10]. On the one hand, unused available capacity causes overcapacity and is waste of production resources. Due to high fixed costs, the unused production resources generate costs and thus, a reduction of profits. On the other hand, bottlenecks create immense problems in handling the demand and additionally, imply a loss of profit. The result is a high economic risk and loss of competitiveness that can lead to a threat of corporate existence [11]. Consequently, a new approach has to be developed to extend the corridor and to ensure the optimal capacity utilization.

Therefore, suitable and practice-oriented methods for controlling and reducing the fluctuations in demand have to be provided to manufacturing companies, in order to react purposefully in case of changing market conditions [12,13].

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2. State of the art

The main focus of the following sections is on the capacity flexibility in production systems. For this purpose, the design of a production system and approaches for system modeling are described. Furthermore, the term and characteristics of capacity flexibility are defined and models for the assessment of capacity flexibility are presented. Regarding the presented implementation scenario, the simulation-based optimization method for profit maximization is described.

2.1. Design of a production system

A *production system* can be defined as an organizational, technical and cost-independent allocation of potential factors for production [14]. In terms of the system theory, the levels of a production system can be divided into factory, segment, line and work station [15]. The *factory level* includes the land, buildings and environment, as well as indirect processes (e.g. construction). On *segment level,* the indirect functions (e.g. maintenance, production planning), the production type for each segment (e.g. variant or mass production) and the layouts are defined [16]. On *line level*, production principles (e.g. group or flow production) and the necessary logistic concepts have to be determined [17]. On lowest level, the production resources for each *work station* are planned, based on manufacturing concepts and technologies [18].

According to GUTENBERG, a production system contains the *production resources*, such as manufacturing, material and human resources [19,20,21]. The objective, combining the production resources, is the optimal resource composition for an efficient and flexible production [22]. *Manufacturing resources* can be described as the totality of the equipment and facilities that are used for the operational transformation process [23,24]. The *material resources* are used for the production of products and can be considered as parts of the products or as additives [25]. *Human resources* are employees, performing in an institutional organization for remuneration. Every employee of the organization is defined by a given function (e.g. machine operator) and the associated tasks (e.g. manufacturing) [26,27].

Based on structured, consistent and standard elements, the *system modeling* is used to *design an abstract model* of a production system. Based on the model complex correlations, conditions, processes and effects of a production system can be explained. An abstract model of a production system consists of a set of elements that are related to each other by their characteristics and abilities. The elements can be assigned to subsystems that are characterized by their hierarchical, structural or functional classification in the overall system [28-30].

2.2. Capacity flexibility

Capacity flexibility is defined as the ability to ensure reversible, economic capacity adjustments in a manufacturing system, by using a defined bundle of measures. The bundle of measures focuses on the optimal capacity utilization of manufacturing, human and material resources [31-33].

The request for highly integrated capacity flexibility in production systems is caused by turbulences in the company's environment [34]. The most observed turbulence is caused by the market. Precisely, the *fluctuation in demand* has a strong impact on the capacity utilization and consequently, on the production costs [35]. For identification of fluctuation, scenario-based forecasting methods or time series analyzes are used to predict changes in the market and to determine volumes and capacity requirements in advance [36,37].

2.3. Capacity flexibility corridor

The capacity flexibility is defined by the dimensions *time*, *scope* and *costs* [22]. The first dimension describes the *time for changes,* the second dimension is defined as an established *scope of action* with flexibility potentials and the third dimension illustrates the *costs for system adaptions* and *implementation* of flexibility measures. The highest impact on the capacity flexibility is given by the scope of action that defines the size of the so-called *capacity flexibility corridor*.

The flexibility corridor can be described as a technical and organizational performance bundle of production resources, which can be larger or smaller, depending on the adaptability of each individual resource. According to KALUZA, the size of the performance bundle is given by the combination of the manufacturing, material and human resources, as well as their associated characteristics [38].

The *characteristics of manufacturing resources* with high impact on the manufacturing design and thus, on the capacity flexibility, are determined as: *efficiency and versatility*. The efficiency of manufacturing resources is defined by the available capacity, production volume, technical availability and process time [39-41]. The versatility of manufacturing resources can be measured by the functional performance level and the ability of manufacturing products without any set-ups, despite different product designs [42].

Regarding the *characteristics of material resources*, the following factors have an influence on the product design and thus, on the capacity flexibility: *general parameters, product architecture, product function and material availability*. The general parameters can be summarized as geometric, technical and physical characteristics of material resources [43,44]. The *product architecture* is determined by the characteristics such as complexity, variety, modularity and standardization [45]. A *product function* is defined by the task that has to be accomplished by the design of products, components or parts [46,47]. The *material availability* is mainly determined by the company's suppliers and intra-logistics of the production [48].

The *characteristics of human resources*, with impact on the capacity flexibility, are as follows: *worker qualification and availability*. The *qualification* includes all factors, such as knowledge, skills and attitudes of an employee [49,50]. The *availability* of the human resources is determined by the given working times and the available workers on the market [51].

2.4. Assessment of capacity flexibility

The assessment of the capacity flexibility in production systems is based on historical and future parameters [52], as