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Optimal configuration of manufacturing cells for high flexibility and cost reduction by component substitution

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Abstract

In the current competitive market manufacturing companies are driven by significant price pressure as well as high fluctuation in demand and are faced with the challenge of producing cost-effectively. Especially serial and variant manufacturers struggle to achieve high capacity utilization even though they consistently try to reduce the gap between the requested capacity and available capacity. Already in the procurement phase of manufacturing resources enterprises seek for defining the available capacity to cover the requested capacity precisely. However, due to fixed costs, the level of available capacity must be carefully decided. Methods for production planning and improvement are used but it is still difficult to avoid capacity bottlenecks or waste completely. Consequently, the objective is the efficient use of spare capacity. For this purpose, in this article a new method for an optimal configuration of manufacturing cells is described which allows the increase of flexibility as well as the reduction of costs by *component substitution*. Therefore, both the *component substitution* and optimal configuration of manufacturing cells will be described. The main result is a cost-optimized and highly utilized manufacturing process.

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Keywords: Capacity Planning; Flexibility; Manufacturing Cells; Capacity Utilisation; Cost Reduction

1. Introduction

The prevailing economic development such as globalization, regionalization, urbanization and individualization has led to high end-user requirements in recent years. New innovative products with short delivery times, high variety and good quality at reasonable prices are required [1]. In order to meet the customer requirements, today's companies are facing the challenge to produce economically, by making their production competitive. This mainly includes the factors flexibility and responsiveness as well as a high versatility to changes in production due to turbulent markets [2].

In case of strong internal and external turbulences, one of the main challenges of companies is to achieve the necessary capacity utilization for economic production. Especially in situations of drop in orders, that is followed by a lower utilization of production resources and leads to high losses due to rising fixed costs up to unavoidable insolvencies [3].

This causes manufacturing companies to use the variable costs, such as personnel and material costs, as the main levers for reducing the overall costs [4].

The development of unit labor costs in selected European countries shows, however, according to statistical analysis by EUROSTAT, an extremely volatile behavior. In Germany, for example, an increase of over 15% of labor costs exhibits from 2007 to 2014 [5]. Similar behavior in terms of predictability shows the evolution of material prices on the world market. Looking at the course of aluminum a decline in price from +105% in 1990 to -55% in 2014 is evident [6].

Against this background methods and tools to increase the flexibility and to reduce costs under changing market conditions have to be available for manufacturing companies. To react purposefully to product adaption or production system adjustment the requested methods have to support in case of [7]

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- capacitive fluctuation in demand,
- increasing product and varieties diversity,
- high and fluctuating variable costs,
- high fixed costs of technical resources.

In this context, the key competitive factors include the accomplishment of the ever increasing uncertainty in planning and the control of cost pressure in competitive situations [8].

2. State of the art

Despite of numerous proposals in literature, how to realize the increase of flexibility and reduction of costs, not all companies compete and succeed [9]. The influence of increasing product complexity due to individual customer requirements, globalization, regionalization and the impact of fluctuating unit labor costs or market price developments is too strong [10].

In the automotive industry as well as in the manufacturing sector, companies complain about the difficulty to optimally utilize their production resources such as staff or resources at prevailing internal and external turbulences to achieve high economic success. Any unused capacity means loss of money and thus reduction of the profit [11]. In response, production planners are always striving to adapt technical systems, organizational processes, developed strategies and concepts, so that the greatest possible scope to control the present uncertainties is available [12].

To achieve a highly flexible production, in case of capacitive fluctuations, the capacity distribution in company networks [13-16], the use of buffer stocks [17], and flexible working time models [18] can be regarded as efficient and widely proven concepts. In case of strong product or model mix fluctuations, approaches such as the flexible system structure adjustment [19], the flexible use of technical resources [20], the flexible work organization [21,22] or the flexible use of materials [23-25] have been proven as useful methods for production flexibility.

The application of these approaches allows manufacturing companies to adapt fast to changes of their production system in the context of a given flexibility corridor (see Fig. 1). The flexibility corridor describes the scope of action of the company, which is limited by the efficiency of the present approaches and existing restrictions of production [26]. Here, the flexibility can be defined as the capacity of a production system to adapt to changing factors in an established system quickly and at low costs. Any changes, e.g. increase in customer demand, are coupled to a set of measures that ensures a short-term adaptation of the production system [27].

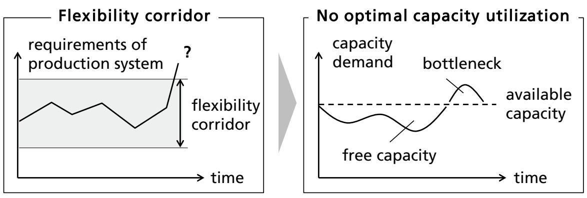

Fig. 1. Unavoidable free capacity and bottlenecks.

However, reality shows that due to the limited flexibility corridor the optimum of one hundred percent capacity utilization cannot be achieved with current approaches. Although it is possible to minimize the difference between requested and available capacity by applying different optimization methods, previous approaches do not manage to eliminate free capacity or bottlenecks entirely. The resulting free capacities represent in any case a waste of productive resources and bottlenecks also lead to loss of profits. Today's approaches to increase flexibility are particularly successful in assembly systems with human resources, however, they reach their limits in production systems with linked manufacturing and assembly processes [28,29].

This situation leads companies to the requirement to operate beyond the limits of the flexibility corridor. Therefore, many companies are already using approaches from the research field of versatile production systems. The versatility allows acting beyond boundaries and preventing long-term changes of the established production system. In contrast to the increase of flexibility, the concept of versatile production systems is associated with higher investment and implementation costs, as well as a greater amount of time. The approaches to increase versatility are primarily used for the displacement of the flexibility corridor, but do not solve the problems within the corridor, thus not the problem of under- or overload of production resources [30].

The last-mentioned disadvantages in terms of versatile production systems lead to the interim conclusion that companies first seek the maximum increase of flexibility within the corridor [31,32].

In addition to the management of production-related uncertainties caused by capacitive fluctuations in demand and increased product variety, companies are looking for ways to reduce the unit labor and material costs as well as high fixed costs of technical resources.

When it is necessary to reduce variable costs, companies utilize approaches, such as the insourcing of manufacturing processes for cost-intensive components [33], the worldwide relocation [34-36], an extended supplier network [37-39], the automation of assembly processes [40-43] up to a design change and partly optimization of costly components [44-46]. In contrast, for the reduction of fixed costs, companies use the approach of outsourcing at high investments of manufacturing processes [47], operator models [48-50], and approaches from the field of technology and innovation management for the selection of alternative products and manufacturing concepts [51-55].

The presented approaches to reduce costs are considered as promising long-term solutions, however, they contradict the need for a short-term responsiveness with respect to the required flexibility [56]. The focus of the approaches is in the strategic development of the company to get the variable and fixed costs under control over an extended period. The production-related uncertainties show though, that methods and tools for fast use in daily business are absolutely required.

In summary, it can be stated that companies today are facing the problem to bridge the gap between optimal flexibility and versatility at a given leeway. By the use of existing approaches companies are able to make a system adaptation within the scope of given limits to internal and external changes. But they do not prevent free capacity and bottlenecks, which lead to a loss of economic success. In particular alternatives to control high or low capacity utilization of production resources as well as measures for short-term, cost-optimal adjustments of the existing production system are still missing.

3. Approach

The holistic approach is based on the basic idea that free capacity can be economically exploited to reduce the variable costs and to respond optimally to bottlenecks with respect to variable costs and fixed costs. In the following, the *component substitution* and the optimal configuration of manufacturing cells are presented.

3.1. Component substitution

The core approach *component substitution* focuses on manufacturing of two component variants with the same function and customer requirements but two different component designs on the same manufacturing cell simultaneously. One of the component designs needs a high process time with low variable costs, the other one a low process time with high variable costs. Thus, two component variants with different designs and variable costs allow the use of manufacturing process time as an additional control variable and increase the flexibility in internal or external turbulences.

The following example illustrates the difference between two component concepts (see Fig. 2). It is important that both component concepts accurately perform the same function and are interchangeable. Here, the main technology is injection molding as an integrated production process in a manufacturing cell.

In concept 1 the component consists of the molded body with integrated thread which can be made by a single injection molding shot. In contrast, the component concept 2 is identical in function but consists of two parts. The injection molded body is an internally produced part, while the thread is realized by a purchased inexpensive metal sleeve.

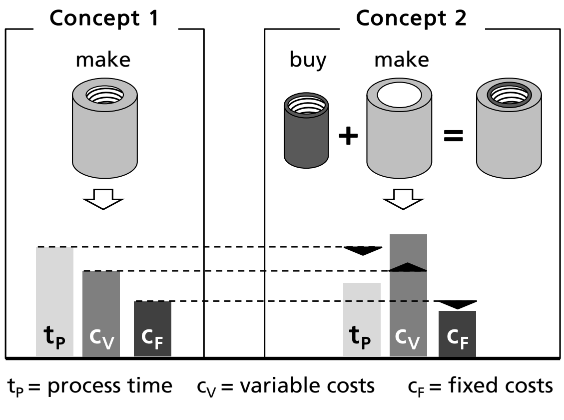

Fig. 2. Increase of flexibility by component substitution.

The crucial difference between both concepts is the respective process time as well as the variable costs. Whereas the process time for the injection molding process is higher in concept 1 than for concept 2, the resulting variable costs are lower for concept 1. It must also be noted that, due to simultaneously manufactured components, a slight increase in fixed costs for concept 1 is recorded for a tool with integrated thread. The following paragraph will explain the benefit of having two different component concepts.

3.2. Optimal configuration of manufacturing cells

With regard to the optimal configuration of manufacturing cells, two issues are important:

- Configuration of the manufacturing cell for components with different component concepts
- Optimal capacity distribution of components with different concepts for a given capacity limit of the production cell

Due to different designs of the components, new technological requests on the necessary manufacturing processes arise. For example, new tools or software modifications for the manufacturing program are required. The total cost for the change in the manufacturing process must be less than the implementation of the developed approach of *component substitution* to ensure profitability.

Another important factor is the optimal capacity distribution of the components on the existing manufacturing resources. In the case of an emerging free capacity, a potential cost reduction by applying the new approach component substitution is shown in Fig. 3.

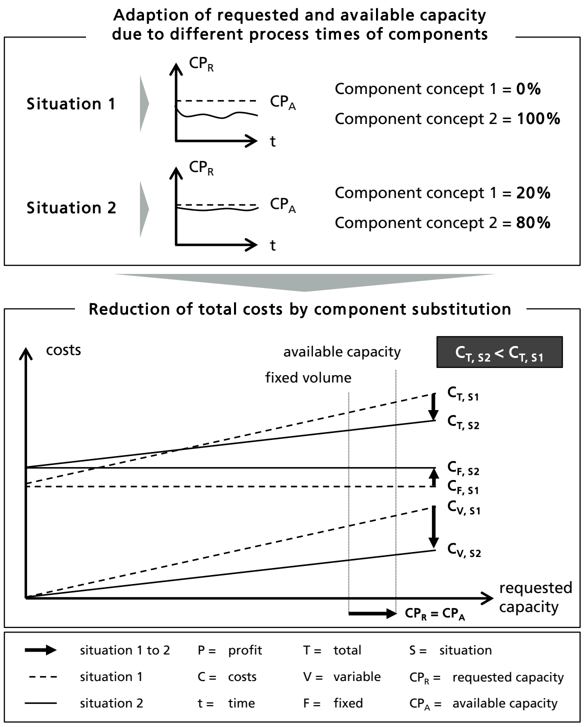

Fig. 3. Reduction of costs by component substitution.

It is assumed for situation 1 that the requested components are made completely with component concept 2 (short process time, high variable costs). However, since the requested capacity is less than the available capacity, a capacity distribution is carried out with the aim of "request equal to availability" (see situation 2 in Fig. 3). The result of the capacity distribution is that 20% of the components can be produced with concept 1, 80% with concept 2. In the lower part of figure 3 a significant reduction in the total cost is recognizable by the approach *component substitution*. By adapting the requested and available capacity due to different process times of the component concepts, the variable costs per unit drop. It should be noted that the demanded quantity at change of capacity remains constant. In return, the fixed costs rise slightly for additional investments in the manufacturing cell to achieve a synchronized production with both component concepts. In sum, it appears that because of the disproportionate reduction in variable costs, the total costs are reduced using the approach *component substitution*.

In the case of a capacitive bottleneck in situation 2 a new capacity distribution could now be carried. Instead of an investment in additional equipment and, therefore, a high risk, more components can be produced with concept 2 again. Indeed the variable costs would increase, but a company can meet the demand, decrease the opportunity costs, increase revenue with higher production volume, keep fixed costs constant and mainly satisfy the customer by a high responsiveness.

4. Methodology

The presented approach is transferred into a consistent method for simple application by the company. It consists of five phases with the respective modules. The phases from analysis to implementation are associated to the initial strategic development of an application tool, whereas the last phase focuses on the repeated use of the tool in daily operation (see Fig. 4).

In the *analysis phase* first possible internal and external turbulences and the overall structure of the production system are examined. In addition, an analysis is performed with regard to the predominant variant volume and flexibility of the production system as well as the relevant costs. Due to the functionally identical component concepts a function-based cost accounting is also carried out.

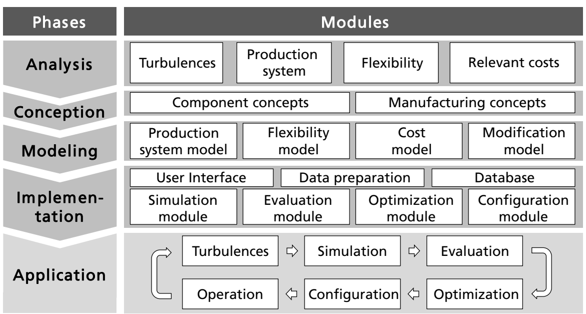

Fig. 4. Phases of the method.

Then, in the *concept phase* alternative component and manufacturing concepts are developed, especially for cost-intensive components and manufacturing processes. The aim is to produce component concepts with negatively correlated manufacturing process times and variable costs to increase flexibility.

The subsequent *modeling phase* is the development of individual abstraction models for the production system, the evaluation of flexibility, the optimization of costs and the modification of the manufacturing cell. These consist of a standardized data model for the transferability of the method to different production systems.

In the *implementation phase*, the models are implemented in software modules. Additionally, a user interface and a module for data preparation as well as a database are required.

Eventually, the *application phase* is divided into six steps which are repeated according to the planning period and prevailing turbulences. At the moment of a change, first the incoming orders for each period are optimally scheduled (e.g. one week). On this basis, a simulation of the production processes is performed to assess the flexibility. Here, flexibility is defined as the degree of determined free capacity and bottlenecks in the manufacturing cells. By *component substitution* the requested and available capacity will be matched to each other to optimize costs. After reconfiguration of the manufacturing cells and optionally other system resources the order release for operating can be made.

At the end of each planning period and if internal or external unpredictable turbulences occur, the application phase will be restarted.

5. Application scenario

The approach has been successfully tested in a real environment for a refrigerator manufacturer with a production volume of two million per year. The technical feasibility of various component concepts with the same functions as well as with necessary adaptations of the manufacturing technologies has been checked with both experts and scientific investigations.

The major considered turbulences on the production system are seasonal fluctuations in demand up to 150%, a product range of more than 40 variants and high volatility of material and labor costs over 100%. This condition was adopted as the basis of a necessary flexibility corridor for the production system.

The production system was analyzed, optimized, then abstracted and modeled. In the modeling phase it was important to get the most possible optimized production system model by practically tested approaches in order to ensure a largely optimized initial situation for the software implementation.

Subsequently, the developed production system model was implemented in the form of a simulation model (see Fig. 5). The entire production was roughly reproduced according to the top-down approach, however, the manufacturing cell in detail using a bottom-up approach [57,58].

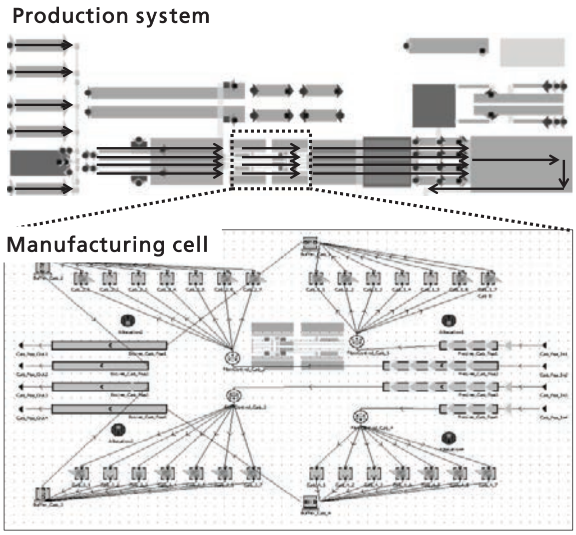

Fig. 5. Modeled production system and manufacturing cell.

The selected components for the approach of *component substitution* are two different foams (depending on the component concept) and a vacuum panel for concept 2 (see Fig. 6). The component concepts represent the same function, “insulation for cooling the internal space of refrigerator”. In the manufacturing cell the refrigerator is fully foamed and insulated between inner and outer body. For concept 1 the foam with higher insulation, for concept 2 the foam with less insulation is used. Therefore, in concept 2 additional vacuum panels are installed in advance in the assembly to get the same insulation values between concept 1 and 2.

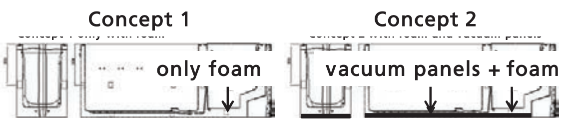

Fig. 6. Functionally identical component concepts.

For the component substitution the respective functional costs were calculated. Components with concept 1 (just with foam) have to be manufactured 20% slower, but can be produced 80% cheaper than components made with concept 2 (with foam and vacuum panels). Besides the costs for material, even the labor costs, costs for installing the vacuum panels in the assembly lines as well as the fixed costs for the adaptation of manufacturing equipment were taken into account. Recent calculations gave the following quantitative results:

- free capacity in the manufacturing cell 4 - 6% despite of optimized production system with today´s approaches (upward trend in seasonal demand fluctuations),
- usage of the free capacity by applying the approach *component substitution* to reduce costs (> 3% per unit).

Regarding the results it must be considered that the potential fundamentally depends on the customer demand, variety and market prices.

6. Conclusion and Outlook

The presented approach and the newly developed method allow an increase in flexibility and a cost reduction as well as meaningful conclusions about effective alternatives in production systems. Here, the focus is put on the economic potential of emerging free capacity and usage of capacitive bottlenecks of manufacturing resources as well as the associated flexibility for manufacturing companies within the limits of existing flexibility corridors.

Unlike today's approaches with the objective to optimize capacity utilization by minimizing the difference between capacity supply and demand, the approach *component substitution* rather intends to answer the question of how this gap can be efficiently used by manufacturing companies.

For a further development of the approach, additional steps are necessary. On the one hand, important analysis to examine the limitations of the approach with respect to the profitability and flexibility under the influence of strong turbulences in different production systems will be carried out. On the other hand, various component designs and manufacturing processes with their associated characteristics have to be investigated. The objective is the independent generic application of the presented methodology in a high variety of manufacturing companies.

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