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A simulation-based framework for improving the ecological and economic transparency in multi-variant production

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Abstract

Multi-variant production has to cope with various challenges caused by external factors such as a customer and competition driven increase in variants, the corresponding growth of internal complexity as well as the rising demand for more resource efficiency. In order to being able to optimize their manufacturing systems continuously and target-oriented, companies need to improve the transparency about ecological and economic inefficiencies. This paper presents a simulation-based framework for improving the ecological and economic transparency in manufacturing systems. Within the presented framework energy consumption and costs are allocated according to their actual cause. This enables a user to identify influencing variables, which cause variety-induced non-value adding energy consumption as well as costs in manufacturing systems. Based on this knowledge, target-oriented lean and green optimization can be applied.

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Keywords: transparency; multi-variant production; simulation-based; lean and green optimization

1. Challenges of multi-variant production

In today's globalized business environment almost every industry sector faces challenges associated with complexity. The complexity can be found in processes and products as well as in the business organizations themselves and causes multiple problems at the operational and strategic levels. Especially manufacturing companies are confronted with these problems and perceive the corresponding complexity e.g. through the frequent adaption of the manufacturing system in order to meet the current and future market demands. These market demands mainly result from megatrends such as the diversified customer demands, shorter product life cycles, shortage of resources and declined manufacturing depths. [1]

In particular the diversified customer demands and the shortening of product life cycles lead to an enormous increase in product variety and enhance the need for managing the induced complexity of multi-variant manufacturing systems. This perception becomes even more important since the proliferation of product variety is a trend in numerous industries and can be considered as one possible strategy to enable companies to maintain and increase market shares through satisfying the variety seeking behavior of customers. The development of product variety and the subsequently change of manufacturing systems towards a more multi-variant production is illustrated in Figure 1. [2]

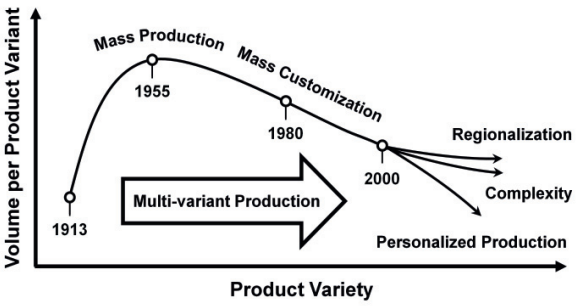

Fig. 1. Development of the proliferation of product variety and manufacturing systems towards a multi-variant production [3].

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The steadily increasing product variety externally induces complexity and is one of the main reasons for the lack of transparency regarding the ecological and economic assessment of manufacturing systems with multi-variant production. In order to identify ecological and economic inefficiencies caused by variety-induced complexity and to optimize such systems it is therefore fundamentally important to establish transparency within the processes. [4]

The existence of transparency is the basis for the identification of efficiency potentials which subsequently provide an insight into energy consumption and costs caused by an enhanced multi-variant production. The exact calculation of such complexity costs still remains a highly difficult task since the available approaches have yet to be entirely successfully implemented in industry practice. [5] However, multiple studies prove the influence of complexity on costs and estimate e.g. that 30 to 40 % of the complexity-caused costs in a manufacturing company can be directly linked to the manufacturing process itself [6] and that the costs for product and process complexity in manufacturing companies can make up to 25 % of the total costs. [7]

The existing approaches for the estimation of the complexity related costs used in these studies are usually based on general complexity indicators and confirm the general perception of a direct connection between variety-induced complexity, loss of efficiency and increase of manufacturing costs. The increase in complexity related costs leads to a decrease of competitiveness and results in a proliferation of product variety in order to increase market shares. This cycle is known as the 'complexity trap' and represents a major challenge for manufacturing companies nowadays (Figure 2).

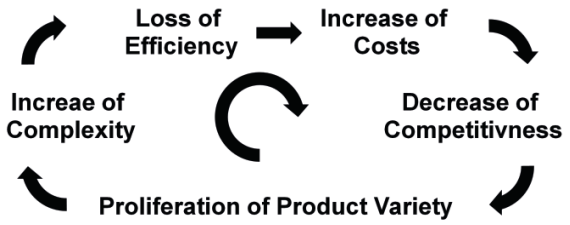

Fig. 2. 'Complexity trap' of multi-variant production in today's manufacturing systems [8].

To overcome this cycle it is necessary to develop conceptual approaches which focus on the establishment of transparency in order to identify and consequently minimize the loss of ecological and economic efficiency. This becomes even more important since the existing approaches do not provide a specific guideline to evaluate the economic and ecological impact of product variety induced complexity on a manufacturing system process level. [2]

2. Conceptual basis of the simulation-based framework

The simulation-based framework presented in this paper describes the entire manufacturing system as a sequence of state-based modules with particular inputs and outputs. This approach enables the modeling on an operational level and allows the continuously consideration of product variety and its economic and ecological effects throughout each process step of the manufacturing system. This form of segmentation of the different process steps of a manufacturing system with multi-variant production was chosen to improve the overall transparency and to simulate different aspects of the considered manufacturing system.

The main components of the simulations-based framework are shown in Figure 3.

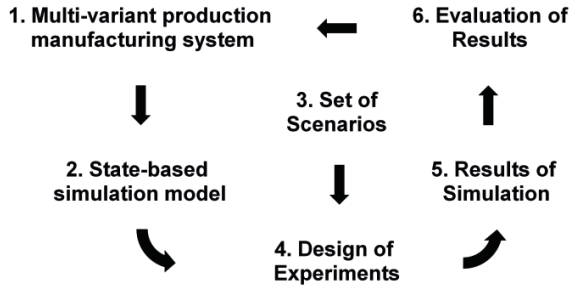

Fig. 3. Main components of the presented simulation-based framework.

The focus of the final evaluation is the identification and assessment of influencing variables regarding the improvement of ecological and economic efficiency. This is achieved through the described modeling technique of the manufacturing systems within the simulation-based framework as well as through the combination of multiple set of scenarios with a systematic design of experiments concerning the influencing lean and green optimization variables.

3. System understanding and cause-based allocation

3.1. Description of the manufacturing system

In regard with the aims of this paper, the improvement of transparency about ecological and economic inefficiencies in multi variant production, the manufacturing system as a whole has to be fragmented into functional elements. These elements (e.g. manufacturing or transportation processes) can be generalized as process modules [9], which are separated in production process modules and logistics process modules (Figure 4). Each process module is characterized by several input (e.g. raw material, parts and energy) and output variables (e.g. products and waste) and aims to transform an input into a specific output. Each process module can furthermore be subdivided into two factors of production ('human' and 'equipment') [10] [11] that perform the transformation process. The factor of production 'human' includes e.g. logistics employees or machine operators whereas means of conveyance and production machinery are part of 'equipment'. In a manufacturing system multiple production and logistics process modules are coupled to a process chain, or, in case of a more complex system, to parallel process chains or network structures with multiple input and output