Evaluating the logistical performance of production segmentation

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Abstract
Production segmentation is a method to increase logistical performance by combining the advantages of shop fabrication and production lines. In this paper, an approach for evaluating the potential logistical performance of segmentation variants is presented. Therefore a characteristic curve based on simulation studies is proposed.

Keywords: production planning and control, production segmentation, simulation

Introduction

Manufacturing companies in developed high-wage countries, such as the United States or Germany, are facing a continuously challenging market environment. These environments are characterized by volatile, dynamic markets and frequently changing customer demands. Decreasing development and production cycles require a high flexibility and adaptability of production processes (Brecher 2012). The need for flexibility is farther driven by the customers' demand for individualized products and the decreasing predictability of demand. Furthermore, the competition posted by emerging markets and the effects of globalization require an efficient and cost-cutting production. The resulting challenges can be summarized as flexibility, adaptability, the ability to anticipate and robustness. To stay competitive in today's and the future's market, the permanent adaption of production is inevitable (Schuh and Stich 2013).

These challenges require a high logistical performance, which consists of short lead times, a high adherence to delivery dates, high capacity utilization and low stock levels. Especially a high adherence to delivery dates has been found to be a crucial factor for customer satisfaction and for outperforming competitors. Simultaneously, low stock levels and high capacity utilization are pursued to realize cost-savings (Manyika et al. 2012, Schuh and Stich 2013).

To achieve a higher degree of logistical performance, there are primarily two options: adjusting production control and adjusting production structure (Schuh et al. 2012). The aspects of production structure considered in this paper are layout and organizational structure. While a change in production control or scheduling can increase efficiency to a certain degree, the performance of production is effectively limited by its structure. To further increase efficiency, a change in production structure becomes necessary.

In this paper, an approach to evaluate the potential logistical performance of segmentation variants is presented. For this, analytical functions for logistical performance and costs are proposed that are based on simulation studies of different variants of production segmentation. The paper is structured as follows: First, the potential and limits of increasing logistical performance by adjusting production control or scheduling are described. Subsequently, the fundamentals of production segmentation are outlined and the state of current research in this field is considered. The approach for evaluating production segmentation's potential is presented and its three essential components are described in details. This paper concludes with a summary of findings and an outlook upon further research.

Limits of production control adjustments

Production planning and control (PPC) are essential processes of excellence in manufacturing. Utilizing adjustments in production control, a higher logistical performance can be achieved (Stevenson et al. 2005). The performance and potential of an adjustment of production control can be evaluated using *WoPS+*, a simulation-based software tool developed by the *Laboratory for Machine Tools and Production Engineering (WZL) of RWTH Aachen University* (Schuh et al. 2013a). Production feedback data, such as order confirmation data from an enterprise resource planning system, can be analyzed regarding the logistical key performance indicators. To examine the potential performance resulting from an adjustment of production control, a simulation model is automatically generated and different configurations of scheduling can be simulated. Based on this simulation model, the three central elements of PPC, order release, order sequencing and operational capacity management, can be varied and the effects on performance can be assessed (Lödding 2013, Schuh et al. 2012).

By simulating different forms of production control, the constraints of increasing performance through adaption of control become apparent (Schuh et al. 2013b, Schuh et al. 2014). Figure 1 depicts this issue. The vertical axes indicate the level of the individual logistical variables stock, utilization, mean lead time and adherence to delivery dates as well as the total through-put (the number of parts produced in the simulated timeframe). Every indicator is normalized according to its best possible value. The light-grey space is being spanned by the possible control configurations. It indicates the degree of performance that is achievable by adjusting production control accordingly. As apparent in Figure 1, the attainable level for the individual variables, and therefore the overall logistical performance, is limited. Changes in production control and their effects depend on the given structure.

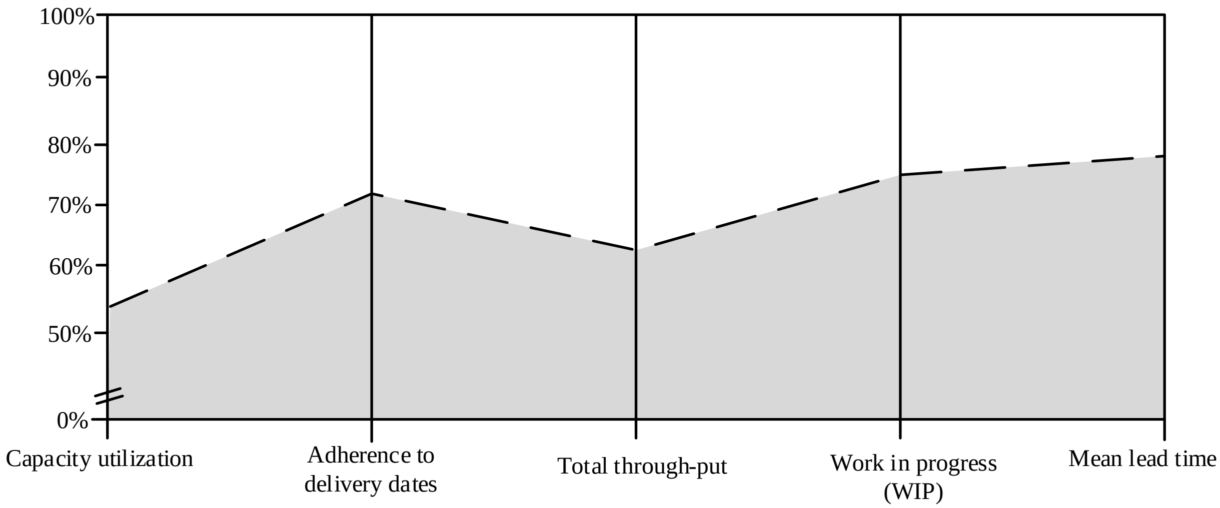

Figure 1 - Potential of production control adjustments

Previous research at the Laboratory for Machine Tools and Production Engineering has shown that production segmentation allows operating the production on a higher level of efficiency and increases the potential logistical performance resulting from adjustments of production control. Production segmentation, as adopted in our research, affects the layout and organizational aspects of production structure. This effect of increased performance is depicted in Figure 2. After segmentation of the original production structure (light-grey space), the new structure displays a much larger potential (dark-grey space) that was previously unattainable.

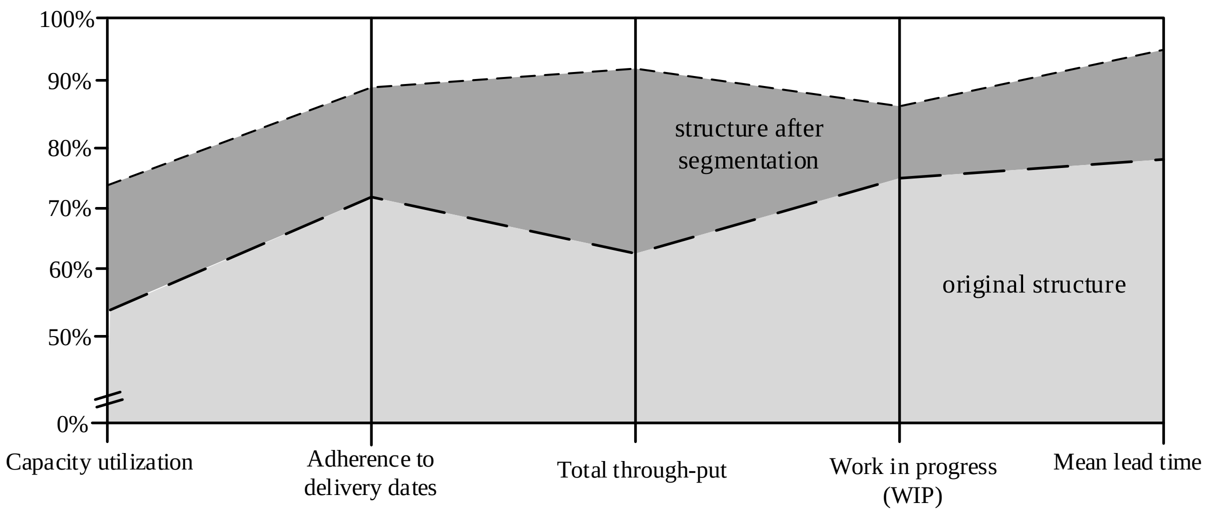

Figure 2 - Effects of production segmentation on logistical performance

Implementing changes in production structure is a complex and multidisciplinary task that usually includes new investments. Because of its nature, structural adjustments have long-term implications. Restructuring production results in interruptions or even total standstill, the implementation of new processes and ramp-up of the new structure, all of which have serious monetary consequences. Thus, structural adjustments and their potential regarding logistical and economic performance have to be evaluated thoroughly beforehand (Grundig 2013).

Fundamentals of production segmentation

The core principle of production segmentation consists of the idea to combine the advantages of traditional shop fabrication and the benefits of line production (Wildemann 1994). Shop fabrication is characterized by a high degree of flexibility. However, the complex flow of material and the high amount of control operations necessary, result in a low productivity that effectively limits its performance. On the contrary, line production strives to implement a directional flow of material and to simplify logistical operations, thereby minimizing the need for production control processes (Chryssolouris 2006).

By combining both production principles in so called segments, a lower complexity in flow of material and control processes can be achieved while maintaining a high degree of flexibility and productivity (Wildemann 2014). The modular design and structure of production segments support the overall reduction of complexity and further enable an increased adaptability of production compared to line production. Furthermore, the changeability of production is increased by the modularity and the segments' autonomous design (Wiendahl et al. 2007, ElMaraghy and Wiendahl 2009). Figure 3 illustrates the principle of production segmentation. The leftmost figure depicts shop fabrication with complex, almost chaotic, undirected processes, while the center one depicts a line production with one directed process. Rightmost, a production segment as combination of shop and line production is shown. As can be seen, there is a manageable number of directed, coherent processes.

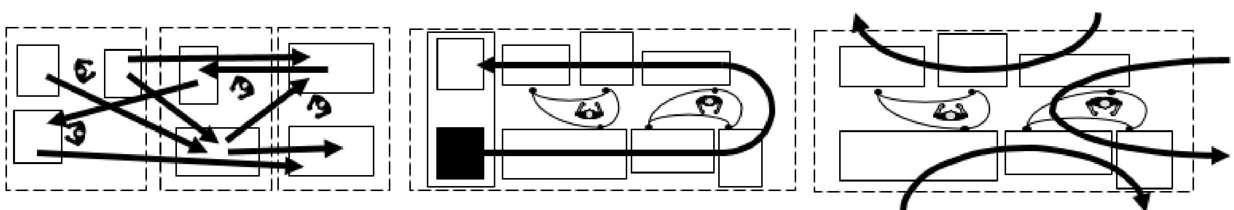

Figure 3 – Illustration of production segmentation

Resource clusters or production segments can be defined using five characteristic features (Wildemann 1994, Wildemann 2014, VDI 2007):

- focus on specific market and economic goals
- concentration on a set of products or product groups
- multiple stages of the value stream within one production segment
- high degree of integration and the integration of indirect functions such as quality control, maintenance and material handling
- responsibility for costs and outcome (e.g. as cost center)

In this paper, the term segment refers to relatively autonomous, modular production units that manufacture a specified set of products in directional fabrication lines within segments. The positive impact of production segmentation on logistical performance has been proven both empirically (Wiendahl et al.1995, Keßler et al. 2010, Wildemann 1994) and on the basis of simulations studies (Lauermann 1994). Empirical studies have found that segmentation generally results in a higher degree of logistical performance and efficiency (Wildemann 1994). While the effects on logistical performance have been determined both qualitatively and quantitatively, the connection between the specifics of segmentation or segments and their precise impact on logistical performance remain unidentified (Lauermann 1994, Wildemann 2014). Research and literature on production segmentation focus mainly on planning and implementation of production segments in special case studies. There is currently no method to evaluate the potential logistical performance based on a proposed segmentation structure.

Approach for evaluating the potential of production segmentation

To evaluate the potential logistical and economic performance of segmentation variants, we propose characteristic curves based on an indicator that describes a segmented production's structure. This characteristic curve allows identifying the current state of performance and possible performance of production. This approach aims for providing the factory planner with a tool to preliminarily assess and compare possible structures. It is intended as a tool for the structural or conceptual stage of the factory planning process (VDI 2011). Before the actual implementation of structural changes, however, a more detailed evaluation and thorough consideration of possible implications is necessary. The three essential components of the approach are outlined in the following.

Line-degree

To describe a segmentation structure, we propose a dimensionless indicator – labelled *line-degree* – that is calculated considering the characteristic features of the structure. This indicator represents the level of segmentation and allows for an easy evaluation of the production's structure. Thereby, different structures and concepts can be compared using a single measure.

The characteristic features considered by the *line-degree* are as follows:

- the total number of machines in production
- the number of shop fabrications within production and the mean number of machines in shops
- the number of fabrication lines within production and the mean number of machines in lines

The *line-degree* is scaled between zero and one, whereas zero represents a production consisting solely of shop fabrications. A degree of one, on the other hand, represents a production that is organized exclusively in fabrication lines. The calculation of the *line-degree* is a crucial element of the approach to evaluate the potential performance, as the further process is based on this indicator. The more precisely the production structure is represented, the higher is the validity of the conclusions yielded from this approach.

Simulation studies

Using a DES (discrete event simulation), a large number of different segmentation concepts is evaluated. For each concept, the *line-degree* is calculated and the logistical variables lead time, adherence to delivery dates, utilization and work in progress are determined. Furthermore, the costs of production are determined. These costs can be divided in manufacturing costs, personnel costs, transportation costs between segments and so-called organizational costs. Organizational costs consist of the fixed costs to establish and operate the individual production segments. The variables determined by the simulation studies are depicted in Table 1. Additionally, the four individual logistical variables are aggregated as a measure for total logistical performance (a method for such aggregation is presented in Schuh et al. 2014).

Table 1 - Variables determined by the simulation studies

	Logistics	**Costs**
Variables	• lead time (throughput time) • adherence to delivery dates • machine utilization • work in progress/stock	• manufacturing costs • personnel costs • organizational costs • transportation costs

The transition of material between production segments results in additional control processes, labor and complexity such as material handling, inter-segmental transport and the transition of responsibility (Wildemann 1994). These aspects are factored in by additional costs and times when transitions between two segments occur. Furthermore, a productivity model based on the segments' size and configuration is implemented.

Characteristic curves

Based on the results gained in the simulation studies, the characteristic curves can be derived. For each logistical variable and the total costs, analytical functions depending on the *line-degree* can be set up. Additionally, the individual logistical variables can be aggregated as total logistical performance. Depending on the use case, individual logistical indicators can be weighted to account for different targets. These analytical functions are statistically derived from the data collected in the simulation studies.

A qualitative example of such characteristic curves is depicted in Figure 4. Here, characteristic curves for total costs and total logistical performance are shown. As can be seen, by calculating the *line-degree* the current state of production regarding performance can be evaluated using a simple measure. Possible future structures/segmentation concepts can easily be evaluated regarding their potential by calculating the *line-degree* and determining the corresponding performance and costs.

In Figure 4, point A indicates the current state of production based on the structure's line-degree. A possible structure is marked by point B. As can be seen, a change in structure would result in a higher logistical performance and at the same time lower costs. Hence, a change in structure is recommended. As previously mentioned, this approach does not and cannot replace a detailed investigation. However, it allows for a simple and straightforward comparison and preliminary evaluation of different structures, thus allowing to filter for possible candidates in a first step and thoroughly evaluate them thereafter.

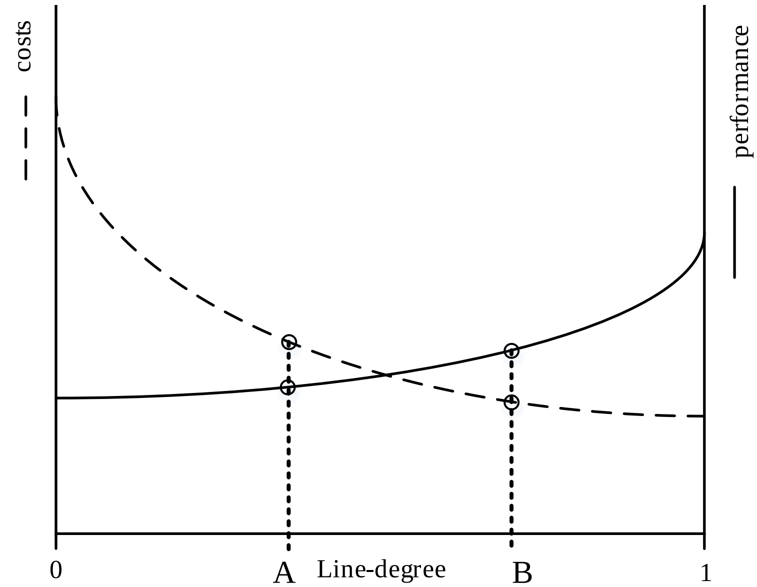

Figure 4 – Qualitative depiction of characteristic curves for segmentation

Validation

In a recent case study at the *Laboratory for Machine Tools and Production Engineering* the aforementioned approach has been applied. Object of this investigation is part of an automotive supplier's production. This production consists of ten machines that manufacture one product in a fabrication line. The relatively small object of investigation was deliberately chosen to reduce complexity and obtain traceability. It is intended mainly as proof of concept rather than a comprehensive investigation. For this production, a quantitative example for characteristic curves has been developed.

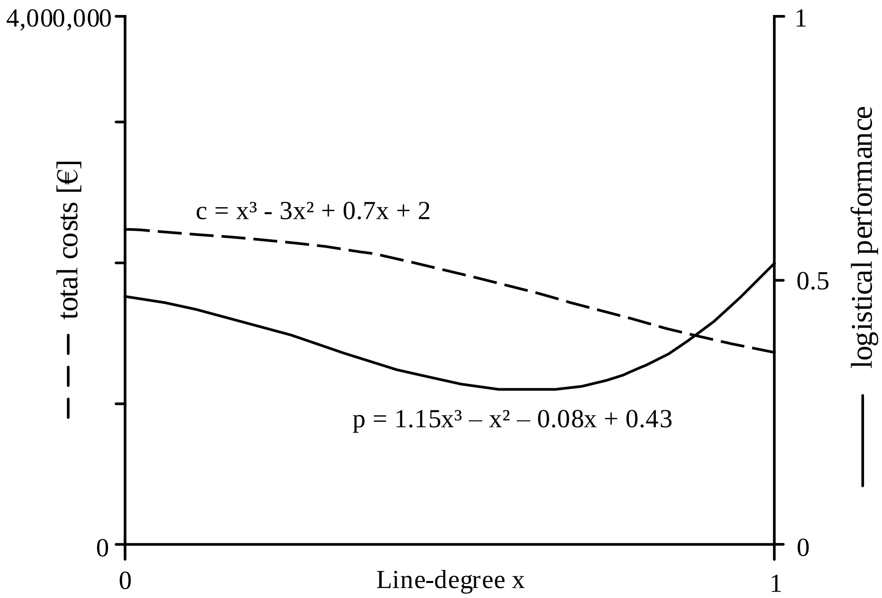

Figure 5 - Quantitative example of characteristic curves for an automotive supplier's production

This quantitative example is depicted in Figure 5, showing a curve for total logistical performance and costs. For both curves, an analytical function has been derived that is depicted as well. It is important to note that the functions depicted in Figure 5 are in fact curves fitted to the noisy data gained in the simulation study. Based on approx. 16,000 data points that were generated in the simulation study, polynomial curves are fitted to the data. Using this quantitative example for characteristic curves, the current state of production can be assessed and possible segmentation concepts can be evaluated. The mathematical nature of the curves allows for an analytical investigation. For example, the change in performance between two states can be analytically evaluated by integrating the performance function between those two states.

Conclusion and future research

In this paper, an approach for evaluating the potential performance – both logistical and economic – of production segmentation has been presented. The limits of increasing logistical performance by adjusting production control were outlined and the resulting need for an adjustment of production structure was described. In this particular case, we focused on the concept of production segmentation, whose fundamentals were subsequently outlined. Based on an indicator for a segmented structure and utilizing simulation studies, characteristic curves for the logistical variables and the costs were derived. These characteristic curves allow for the easy evaluation and comparison of current and potential production structures.

Future research has to be conducted to validate the approach presented in this paper. The concept of evaluating production structures using characteristic curves has to be applied in an industrial case study and its practical applicability tested. Furthermore, the total costs for structural changes have to be taken into account as well as the length of the amortization period.

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