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Simulation-based Analysis of a Value Stream as a Contribution to Sustainable Production and Logistics Systems of SMEs

Simulationsgestützte Analyse eines Wertstroms als Beitrag zu nachhaltigen Produktions- und Logistiksystemen von KMUs

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Abstract: In crises, small and medium-sized enterprises (SMEs) are under more significant pressure than large companies. However, SMEs are more adaptable to changes caused by external influences. To leverage this strength, the focus is on increasing transparency, identifying bottlenecks in the material flow, and evaluating a defined target state of the material flow based on company-specific key performance indicators (KPIs) for sustainable production. Varieties of different methods are suitable for determining these KPIs. In this paper, a simulation-based analysis is performed to determine such indicators. For this purpose, an application example from practice illustrates these methods' applicability to increase the SMEs' adaptability to external influencing factors. First, a value stream analysis of the current state of the material flow is performed. Based on the results, suggestions for changes are given and implemented in a new optimized value stream. A simulation study compares the new value stream with the current one.

1 Introduction

For production, manufacturing in large quantities is very economical. However, the shortening of product life cycles, the demand for more-innovative product concepts, growing product diversity, intensified competition, and changes in behavior in the socio-political environment require a faster response to these change processes and make large-scale production almost impossible (Appenzeller 2021). Especially for SMEs, these demands for high flexibility and quick reactions to new circumstances represent a significant challenge. Current crises such as the Corona pandemic or the war in Ukraine make this particularly clear (Miklian and Hoelscher 2022). This results in challenges like uncertain supply chains and rising raw material prices. The pressure generated by external circumstances is intensified by corporate issues such as low transparency (Becker et al. 2017; Eggers 2020).

Eggers (2020) describes how SMEs can deal with crises optimally. The most significant difference between large enterprises and SMEs in times of crisis is that SMEs can react more flexibly to opportunities or threats (Eggers 2020). To improve the SMEs' flexibility, this paper focuses on increasing transparency, identifying weaknesses and bottlenecks, and evaluating the target state of the material flow using the combination of value stream analysis and simulation.

For this purpose, the research findings around the combination of simulation and value stream analysis are presented in Section 2. Subsequently, the use case is illustrated, and a product group is selected for the demonstration in Section 3. Section 4 describes the conceptual approach, and the combination of the two methods before the value stream analysis (VSA) is performed (Section 5). Based on the analysis findings, a value stream design (VSD) is developed in Section 6. In Section 7, a simulation study is conducted that compares both scenarios. Finally, Section 8 summarizes the results obtained and provides an outlook.

2 Related Work

Sohny (2022), Kaiser (2021), and Urnauer and Metternich (2019) show that the combination of the value stream method and simulation is suitable to support both methods. For example, the value stream analysis complements the simulation study's data procurement and system analysis (Kaiser 2021; Urnauer and Metternich 2019). Especially in the manufacturing industry, numerous literature reviews point this out (Romero and Arce 2017; Hartini et al. 2017; Suhadak et al. 2015). Exemplarily, Suhadak et al. (2015) examined various layout variants through simulation and value stream analysis of an SME operating in the food industry. However, 90 % of the articles deal with the company's manufacturing area, and a large part shows the application based on a case study in which lead time reduction is often considered the most important performance indicator (Romero and Arce 2017).

Nevertheless, SMEs still rarely use these methods despite their great potential (Dingli et al. 2021). Wiese (2016) highlighted that around 85 % of the SMEs did not previously utilize simulation experiments because of short-term costs and barriers by initial resources. This is also the case in the cold-forming sector. In addition, for SMEs in this sector, retooling of the production area due to old machinery, takes an exceptionally long time, and larger investments are often impossible. To demonstrate this potential for small and medium-sized enterprises in the cold-forming sector, an application example is necessary because all identified use cases differ from the objective mentioned and do not take into account the specifications of cold-forming SMEs.

3 Objects of Consideration

An application partner is identified for this purpose. The partner is a traditional German company that is active in the field of cold forming and high-precision turning. The company's customers demand high flexibility and responsiveness to short-term order changes. At the same time, transparency and information flow deficits make planning and controlling for the company difficult. However, the company's organizational form as an order-related production with the push principle leads to overproduction and high inventories. This results in a lead time of over 130 days with a total production time of less than one day. Daily changes in customer orders lead to strong fluctuations in demand, which are further increased by the lot-push principle and a lack of production leveling. Therefore, the company's flexibility must be increased.

Before an analysis of the value stream can be realized in combination with simulation, a suitable product must be identified. Therefore, it is necessary to select a relevant group of products. Following the selection of the product group, a product that is particularly relevant for this group must be determined, which is suitable to carry out a representative value stream analysis.

The cold forging production program was selected for this study together with the company. The object of consideration is a part of the chassis and steering group, which represents a suspension and connection component and contributes to driving safety. Although the corresponding product family has a comparatively low share of sales, a reasonable potential for improvement is expected due to the more-complex production and the higher number of defects.

After choosing the group, it is essential to identify a group representative. For this purpose, the ABC analysis with sales value is suitable. First, the segments must be defined: The A articles comprise 70 % of the sales, B articles 25 %, and C articles 5 % (Ford Dickie 1951). Notably, Articles 1, 2, 3, and 4 are responsible for most of the sales. Figure 1 shows the result of the accomplished ABC analysis.

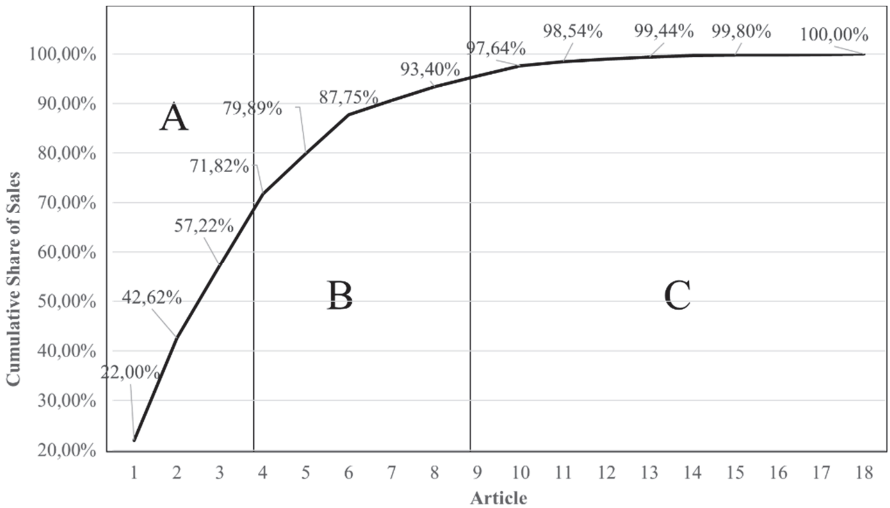

Figure 1: ABC-Analysis of the group of products

However, the company points out that Articles 1 and 2 are irrelevant, because these parts are run-out products. For illustration purposes, sales trends were evaluated. These show that the sales of Articles 5 and 6 have converged to the A products in the last four years and that the trend for Articles 3 and 4 is declining. In contrast, sales for Articles 5 and 6 have risen continuously in the recent years and further sales growth is expected. Hence, Articles 5 and 6 are suitable as representatives for the part family, and the current state is analyzed accordingly.

4 Methodology

The initial situation in this case study shows a non-transparent value stream, leading to an unsuitable data-based value stream analysis. First, transparency must be created to identify unnecessary waste in the flow of materials and information. Kaiser (2021) presents in his study three benchmarks on the classic value stream method by Erlach (2020), Rother et al. (2018), and Klevers (2009). In this paper, the method of Rother et al. (2018) is used for identifying waste and bottlenecks and developing a new value stream.

The value stream has to be compared with the current situation. Simulation is a suitable tool for this purpose. In particular, discrete event simulation is an efficient method as it illustrates the interdependencies of individual logistics processes and enables comparability of scenarios (Clausen et al. 2013). The process model from VDI Guideline 3633 Part 1 is used, since it has considerable relevance in production and logistics in the German-speaking area (Rabe et al. 2008; VDI 2014).

Based on the results of the investigations using the methods identified, recommendations for action are made. These recommendations specify the necessary measures and strategies to eliminate the identified weaknesses and bottlenecks and to implement a more flexible value stream. To make it more comprehensible, the schematic procedure is shown in Figure 2.

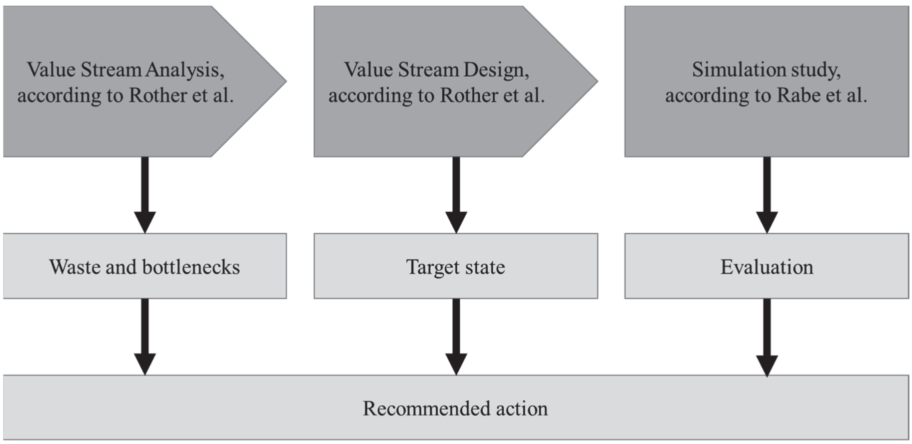

Figure 2: Schematic procedure of the study

5 Value Stream Analysis

As explained in Section 3, the value stream analysis relates to Articles 5 and 6 of the company due to increasing sales. The value stream mapping was carried out according to the specifications of Rother et al. (2018), where uniform symbols and a language were used to create a shared understanding (Bertagnolli 2018). With this language, the value stream and the information flow from the external customer via the production processes to the suppliers were mapped. To determine the current state of the value stream, electronic data processing (EDP) evaluations, expert surveys, and own recorded and estimated values were collected and processed.

Gottmann (2016) was used as a guideline for determining the most important key figures. Thus, the target key figures, flow rate, and responsiveness were determined using the customer requirements. These include the key figures for Overall Equipment Effectiveness (OEE), Every Part of Every Interval (EPEI), the range of how long stock can cover the daily demand, the replenishment time, and the batch size.

All production steps were integrated into the value stream, and the corresponding key performance indicators were added. These cover everything from the entry of the starting material in the form of the supply of the material through the production processes to the shipping department.

Next, all waste has been identified and marked. High inventories, a lack of feedback and key figures, inefficient transports, long setup times, and the push system represent the primary waste in the production process. The high inventories are responsible for a long lead time of 137 days. In addition, high inventories hide the actual reasons for failure-prone processes, the production of defective goods, and other waste. Furthermore, some materials are stored in a block storage, which causes unnecessary restacking.

The lack of feedback and key figures makes the production process intransparent and challenging to measure. The machine operators are, at the same time, logistics employees in the role of material suppliers and transport the materials with forklifts to the next production step. In some cases, the machine operator also collects the materials himself, as there is no buffer near the machine. High setup times slow down the responsiveness to the consumption of subsequent processes.

Furthermore, the push system ignores the actual requirements of the downstream process and induces overproduction, because scheduled materials are not needed at this time. Moreover, machines and employees are unnecessarily employed. Another disadvantage of overproduction is the hiding of failures and unnecessary capital commitment. The already produced and defective parts remain hidden in inventory until their malfunctions are discovered in the downstream process. Short-term changes in the production sequence, fluctuating and short-term changes in demand quantities, fluctuating lead times, and the "replenishment routine" are wastes in the information flow.

While fluctuating and short-term changes in demand quantities cause short-term changes in production orders and fluctuating lead times, the major cause is the push system and the lack of leveling. The "replenishment routine" is closely linked to the bonus system and reports incorrect information back to the system to be able to pay the employees the appropriate bonus. In addition to the waste, the calculated OEE and cycle times provide first indications of the bottleneck machines.

6 Value Stream Design

Based on this VSA, a VSD has been developed according to Rother et al. (2018). Exemplary, two of their seven key questions are answered below.

Key question 1: *What is the cycle time on the pacing process for this product family?*

The pacing process for the articles was identified. Only bottleneck machines were considered, as these set the pace. Since the cycle times of these machines are similar, the machine with the lowest output is selected. Thus, the cycle time on the pacemaker process for this product family is defined.

Key question 2: *Where can you use continuous flow production?*

Due to the spatial separation and arrangement of workshop production, continuous flow production is unsuitable. In addition, some machines cannot process individual work pieces one after the other. Consequently, controlling the production in batch mode through pull systems is adequate.

Based on the guidelines and key questions, a value stream design has been developed together with the employees. The generated value stream design focuses on a pull process with Kanban-controlled supermarkets as buffers. However, this focus is difficult for SMEs, since short setup times are almost impossible due to the old machinery. Furthermore, supermarket buffering can only be reasonably implemented with transparency due to the complexity of the variety of variants. Finally, solutions are necessary to make the material flow transparent without completely changing the production logic that has grown over decades. Simultaneously, setup times for existing machines should be shorted without purchasing a new machine. Nevertheless, the changes developed can have a positive influence on the processes. For example, a one-time process transparency was created for all participants. In addition, optimization potentials were identified and subsequently implemented. An example in this context is the increased performance of the pacemaker process, which was realized through a workshop in cooperation with employees. Further investigation by a simulation study is required before implementing the target process.

7 Simulation

Following the investigations carried out concerning the value stream, the planned changes and measures from the value stream design have to be compared with the current state from the value stream analysis with the help of simulation methodology.

A simulation model has been designed using the simulation software AnyLogic 8.8 according to the described procedure of Rabe et al. (2008). The goal was described and the task defined. The task specification was created with the help of the concept model and the prepared data. Based on this, an executable simulation model has been developed. Finally, the two simulation experiments were executed.

A detailed goal definition, including the task specification, was established. Key figures were defined to be used to evaluate the scenarios. These include throughput, inventory, cycle time, occupied buffer locations, machine utilization, and distances traveled by the forklifts for a period of one production month. All data required for the simulation have been obtained and prepared. Three data types are necessary to model a production system (VDI 2014): technical, organizational, and system data. Technical data contain information concerning the structure of the production building, for example, the layout, equipment, or capacities of storage facilities. Organizational data include the process structures like employees' shift schedules or the allocation of the resources used for the tasks. Finally, the system data, including the production orders, were prepared for simulation.

A conceptual model has been created afterward. Here, the system limits are the warehouse for the raw materials and the product shipment. In addition, the material flow for full and empty containers and waste is shown. A load carrier change occurs at some production steps, e.g., from internal containers to customer containers. Only specific forklifts are available for each production step with its own buffer.

Following the creation of the conceptual model for the entire production process, the entire process was divided into individual processes. These separate processes have been represented as event-driven process chains, which subsequently simplified the implementation of the logistical processes in the simulation model.

Thus, the correctness of the executable model is observed and techniques of validation & verification accompany the simulation study (VDI 2014). Validation in dialog took place with experts from the company. For this purpose, the formal model, the model behavior, the prepared data, and the introduction of new parameters (e.g., the maximum number of buffer locations) were explained. The respective experts' comments and suggestions for correction were adopted in formalizing the system components.

For the simulation, a representative month was defined regarding the order volume. A week includes six working days in 24-hour shifts. Stochastic effects influence the model, and each simulation run has individual starting conditions (due to shift influences, machine failures, RDL initial inventory, ...). This makes it necessary to identify the transient phase to evaluate the simulation experiment independently of this period. Figure 3 depicts the progression of throughput over three months. According to Conway (1963), the transient phase ends after 12 days. According to Welch (1983), a pattern for the method appears from day 18. Due to the extended observation period of 3 months, a misinterpretation of the method's transient phase can be excluded, according to Conway (Gutenschwager et al. 2017). However, the settling period is 12 days. All collected statistics are, thus, reset after 12 days, and the measurements for the simulation experiment start there.

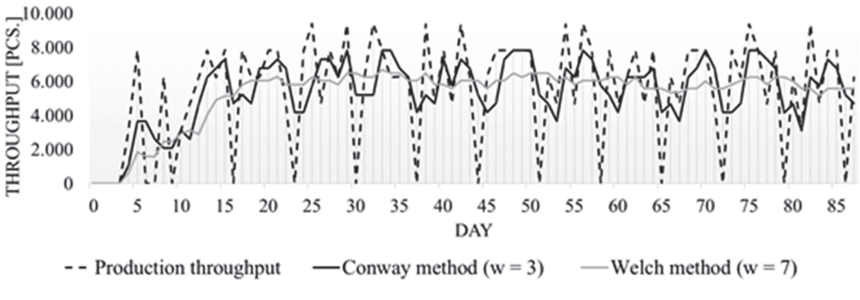

Figure 3: Transient phase according to Conway (1963) and Welch (1983)

As part of the first simulation scenario, comparing the current state with the target state, 30 simulation runs were performed for each state. Figure 4 shows the throughput of all produced items received in the distribution center. The throughput in the actual state is distributed between 130,000 and 185,000 pieces, whereas the target state shows a distribution of 155,000 to 190,000 pieces. A comparison of the median shows a slight improvement in the throughput of 15,000, whereas comparing the boxes shows an improvement in the throughput of about 5,000 pieces. Overall, there is a slight improvement in throughput in the target state.

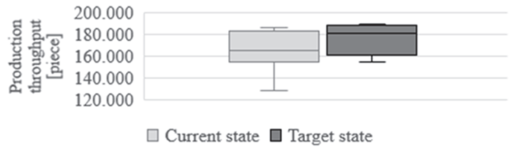

Figure 4: Comparison of the production throughput

Besides throughput, inventory is another important key figure to be evaluated (Figure 5). This indicator shows a decline in inventory for the target state. However, some of the identified outliers have the same high inventory as in the current state of the value stream. Overall, this indicates a marginal change in inventory.

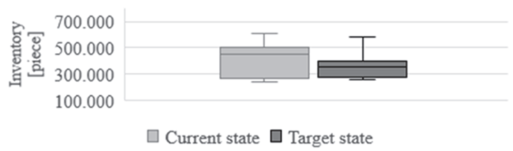

Figure 5: Comparison of inventories

Finally, the lead time needs to be considered. Figure 6 shows the allocation of lead times. The target state enables significantly shorter lead times, but this configuration also leads to the risk of substantially longer lead times. Thus, the overall variation has increased. Although this indicates a slight improvement in lead times, significantly longer lead times than in the current state are also possible, which does not meet the target of shorter lead times.

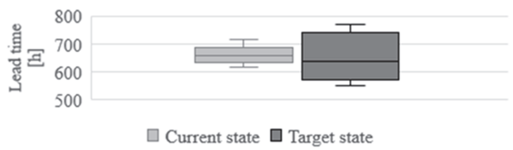

Figure 6: Comparison of lead times

In addition to the throughput, inventory, and lead time evaluation, machine utilization rates and the distances driven by the forklifts were also examined. The machine utilization rates have only slightly changed between the two scenarios. For example, the utilization of an exemplary machine is 50.5 % in the current state and 52.4 % in the target state. All the forklifts considered together have driven around 625 km in both scenarios.

Crucial measures and strategies for the partner company could be identified from the investigations listed in Table 1. Exemplary, the identified Measure 9 can be highlighted, which was carried out directly after the investigations and enables a much stronger data collection and transparency.

Table 1: Table of corresponding measures

	Catalog of measures
Measure 1	Increase the output rate of the pacing process machine
Measure 2	Increase reliability of pacing process machine
Measure 3	Reduce setup times of four machines
Measure 4	Introduce a finished goods supermarket with an annual adjustment to peaks in demand
Measure 5	Introduce self-controlling systems (pull principle)
Measure 6	Dimension & introduce supermarkets (Günthner et al. 2013)
Measure 7	Define & implement scrap feedback
Measure 8	Introduce production leveling with a Heijunka box
Measure 9	Introduce two production data acquisition (PDA) terminals
Measure 10	Introduce the value-stream-oriented KPI-system

8 Summary and Outlook

The circumstances illustrate that the combination of value stream analysis and simulation has increased transparency by enabling KPIs to evaluate the defined target states and is a useful application for KPIs in the cold-forming sector. Furthermore, bottlenecks can be determined. Especially, the SME's old machinery in the cold forming field makes a combination of processes particularly important. Thus, the investigation showed that these machines did not provide any information. The following simulation study was only possible with a value stream analysis, as the data basis proved insufficient. Most data around the machine, like replenishment times, could only be determined by sampling or estimations. Overall, it can be seen that even without the purchase of new machines, an improvement can be achieved in cold forming using a combination of both methods.

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