Manufacturing Optimization - How effective are shop floor improvement methods?

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Abstract

Manufacturing processes can be optimized with many different methods. However, the effectiveness and interaction of methods are often difficult to estimate. To date, shop floor improvement methods in series production are not scientifically analyzed by using a business simulation and the selected methods 5S, Poka Yoke, Kanban and Standard Work Sheet. The academic study aims to close the research gap with a business simulation and the generated data using design of experiments. This depicts a new combination for research. The lead time is selected as KPI. First results and interactions were found.

Keywords
Manufacturing Optimization; Business Simulation; Design of Experiments; Lean & Six Sigma

1. Introduction and Motivation

Shop floor processes can be optimized by a lot of different tools and methods (Schmitt/Pfeiffer, 2015). Included in these tools are for example Poka Yoke, 5S, Lean Management and Kanban. An efficient transfer of these methods to their own manufacturing challenges many companies. Not only the choice of the right method is difficult, but also the effectiveness of the respective method is difficult to estimate (Dombrowski/Crespo, 2008). Companies are often not able to evaluate whether process efficiency and effectivity increased or not, after the implementation of these methods (Suzaki, 1993). Even experts on this subject are only able to assess based on their experience. Current research states, that a vast number of different methods for manufacturing optimization are available (Baumgärtner, 2006). To date, shop floor optimization methods in series production are not scientifically analyzed by using a business simulation and the selected methods. A business simulation presents an academically recognized method (Duke, 1996). Nonetheless, experiments like this have not been conducted yet. The following challenges are based on the choice of the right tools and methods and the setup of the experiment, including the collection of data and the human factor. The academic study aims to close the research gap by systematically analyzing series manufacturing. The following hypothesis is given:

"The effectiveness of selected manufacturing optimization methods can be demonstrated via a developed model in form of a business simulation in a model factory".
A model including a business simulation, which supports the assessment of the usage of the optimization methods on the shop floor, was developed, to confirm the hypothesis. Although, this method is scientifically recognized. Therefore, a systematic analysis of series assembly with a simulation and generated data using design of experiments (DoE) is conducted to scientifically close the research gap. Additionally, the deployment of the optimization tools on the shop floor is measured and evaluated.

2. Selection and Definitions of used Methods and KPI

The selection of the methods used in this simulation is based on the prevalence in literature (sample size of over 80 papers and books), group discussion with seven experts from the field assembly optimization and a quantitative survey with 132 participants in 2016. Over 70 optimization methods were found. Finally, 5S, Poka Yoke, Kanban and Standard Work Sheet are selected as methods for this study (see the criteria in table 1). For example, Kanban is the top method in literature to optimize manufacturing processes with over 50 mentions in papers and books. The lead time is the measured Key Performance Indicator (KPI).

Table 1: Selection of experimental methods

Studies / **Method**	Amongst top 15 in quantitative literature research?	Perceived as well applicable in group discussion?	In survey at least among top 15?
Kanban	X	X	X
Standard Worksheet	X	X	X
5S	X	X	X
Poka Yoke	X	X	X

The elimination of waste is the basic concept of **5S** (Land et al., 2008). This concerns every workplace and is achieved through clear standardization of each activity. This approach is comparatively cheap and improves profitability, efficiency, service and safety at the workplace (Jaca et al., 2014) The 5S are:

1. Seiri (Sort: Items that are not required for a certain activity are eliminated) (Becker, 2001)
2. Seiton (Set in order: Every item has its own place nearby in chronological order) (Redmile, 2011)
3. Seiso (Shine: Required materials should be clean and an overview of the workspace should be given) (Morrisette, 2009)
4. Seiketsu (Standardize: Operating instructions and plans should be implemented and standardized for daily use at each workplace) (Dombrowski/Mielke, 2015)
5. Shitsuke (Sustain: The points 1 to 4 should be implemented sustainably and improved) (Ho, 1999)

Poka Yoke depicts a fault prevention method (Sondermann, 2013). It aims for the enablement of zero-fault-processes (Shingo, 1986). The focus lies on human labor controlled processes, since they are considered to be highly error-prone (Kamiske, 2015). "Poka" is Japanese for an unfortunate mistake and "Yoke" means to prevent (Theden/Colsman, 2013). The basis for an implementation of Poka Yoke is the recognition of possible faults and the introduction of relevant measures. An advantage of this method is that other process steps like quality control are not required, since it gets included in existing ones (Black, 2008). Also, it is applicable without the need of high investments. Furthermore, measures developed together with workers on the shopfloor are often the best (Sondermann, 2013). **Kanban** presents a method for production process controlling to realize a just-in-time-system

for inventory reduction (Ohno, 1988). Therefore, it serves the concept of demand-oriented assembly (Womack/Jones, 1996). As a result, assembly only starts on demand (Erlach, 2010). In short, a self-guiding control loop is created. The manufacturing is triggered by Kanban cards which accompany the respective product until consumption (Schulte, 1991). Consequently, the pull-concept is implemented operatively by Kanban cards which also carry and visualize information for employees and the management (Suri, 2010). It presents both, a simple and transparent control system and the possibility of a time-wasting minimization (Sugimori, 1977).
The **Standard Work Sheet** is an organizational resource, which can support the analysis, optimization, standardization and documentation of work processes (Clement/Lacher, 2016). Middle and lower management use this tool for the education of employees and to recognize necessities for improvement (Yagyu, 2009). The representation of a process – as the main purpose of the Standard Work Sheet – creates ideal results according to the current state of knowledge (Reitz, 2008). Processes can be analyzed and optimized regarding waste and space for improvement based on an increasing transparency through the definition of standards (Refa, 2011).

3. Business Simulation and Methology

Situations that need a lot of planning can be recreated by a business simulation. In doing so a better comprehension and assessment can be achieved (Shah/Ward, 2003). In general, science expects this type of experiment (Bötz, 2015). A variation of individual independent variables is distinguished by the experiment, to observe which effects (dependent variable) result from this (Schaffer, 2014). Design of Experiments is a particularly economic and effective method to conduct experiments (Kühl, 2009). This approach was developed in the 1920s. It is widely spread, because of its standardised procedure and its high universality in engineering studies. Using DoE existing coherences between influencing factors of a process and resulting product-/process characteristics can be identified with a minimum of attampts (Siebertz et al., 2014). Furthermore it can help to determine the ideal settings of the process variables within the customer specification. For this paper the software Minitab® was used to analyze the DoE. The production is grouped in two assembly areas, one final assembly and a quality inspection. Fig. 1 shows the setup of the business simulation.

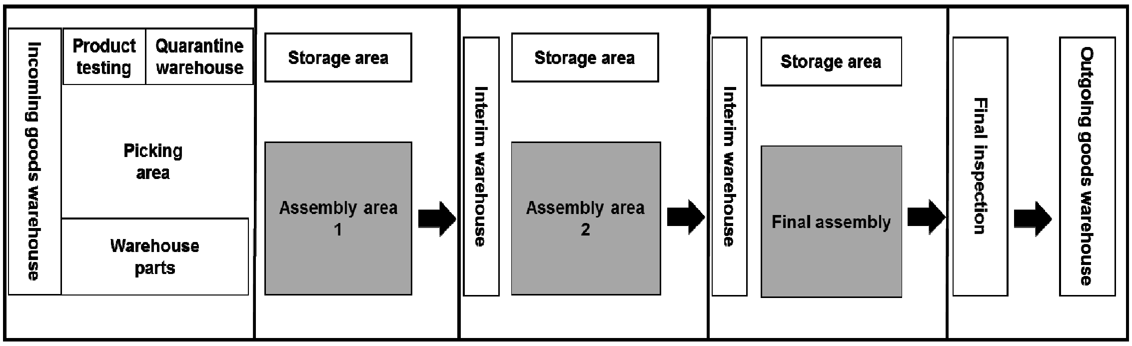

Figure 1: Setup of the business simulation

Eleven participants are needed, to perform the business simulation. Including one person per production stage and one at the final assembly. Fig. 2 shows a model truck which presents the product to be manufactured:


Figure 2: Product

Two logisticians administrate the warehouses. Depending on the used method the administration style varies. Methods are explained later in this chapter. The quality manager completes the final assembly. After the final assembly the finished product is transferred to the outgoing goods warehouse which is also the incoming goods warehouse of the customer. The other five participants left are in charge of the time measurement. The business simulation takes 10 minutes. In this simulation the lead time starts with the removal of the first part at assembly area one and ends at the outgoing goods warehouse.

The simulation is conducted in the form of a game. Each of the sixteen rounds played included different combinations of "chaos" (no method applied) and the methods 5S, Poka Yoke, Kanban and Standard Work Sheet. The participants of each round were students of the production management lecture. To avoid a learning effect each round was conducted by different students. Rounds which included chaos were characterized by a missing standard of how the finished product should look like, or a missing exemplary sequence of the different assembly stations. Materials were provided, but not in the exact quantity. The provided materials determined which activities were carried out at the respective production stages. **5S** was realized by printed pictures of the materials used in the respective department and their optimal assembly sequence. According to the pictures the logisticians deposit the materials. In the course of the **Poka Yoke** method connections are outlined visually by colored material components. In detail, assembly points of the materials are marked by dots in the same color. Thus, the right connection of parts is ensured. Every round Kanban and/or 5S are not used, it can be assumed that the chaos method is applied. The prices of the single parts at every station present the calculation basis for the inventory costs at the end of each round. The **Kanban** method implies the reorder and supply of required materials via so called Kanban cards. Consequently, adequate supply should always be ensured. The Kanban method is applied in all three production stages. The process in every department is described and illustrated by the **Standard Work Sheet** via pictures. This supports the worker in easily recreating the process steps displayed on the pictures.

4. Results

Through a systematic analysis of a serial assembly, the deployment of the optimization tools on the shop floor was measured and evaluated. 48 rounds (3 replications a 16 rounds) were played to achieve a full factorial DoE and to be able to analyze all interaction terms. A significance level of 5% is selected. To evaluate the model quality, the R-squared value is calculated for the model lead times.

4.1 Model "Lead Times"

As part of the experiment, the KPI lead times per truck was determined, of which an average value can be derived per run. A closer look will reveal where and with which optimization tools and methods this it at its lowest point. The Pareto Chart shown here shows the position of the reference line of the 5 % significance level at 2.037.

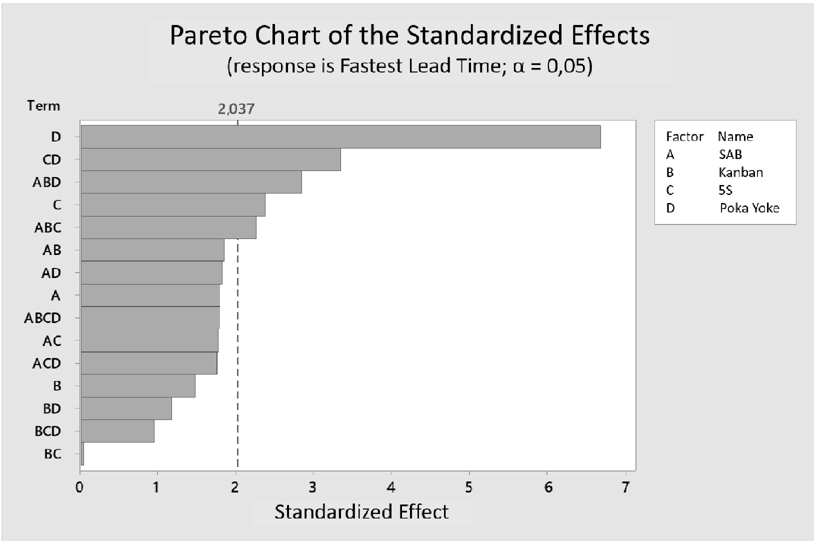

Figure 3: Pareto Chart Model „Lead Time"

Altogether the bars of five model terms exceed the reference line and can therefore be considered statistically significant. The strongest impact on lead time can be observed when Poka Yoke is applied. Consequently, Poka Yoke leads to a significantly shorter lead time when compared to other optimization methods. This impact is due to the production steps being considerably simplified for participants as they are based on color codes. Additional statistically significant effects can be observed when viewing the interaction of 5S/Poka Yoke with SAB/Kanban/Poka Yoke. The reference line is exceeded one more time when the 5S method is used exclusively or in combination with SAB/Kanban/5S. Terms, where bars don't exceed the reference line are not considered statistically significant with no impact on the lead time.

Summary of Model

R-squared	R-squared(kor)	R-squared(prog)
75.51%	64.02%	44.89%

When summarizing the overview of the model, an R^2-squared of 75.51% is identified, which means that the model accounts for 75.51% of the variation in data. However, the amended R^2-squared is crucial for the model quality, which assumes a value of 64.02%.

4.2 Factorial adaptation Model „Lead Times“

The significant terms are to some extent double or threefold interaction effects and consequently all individual factors contained in these terms will remain in the model. For example, an effect became apparent in the initial analysis, which was of statistical significance for the threefold interaction effect of SAB/Kanban/Poka Yoke. To guarantee the existence of this effect - even if non-significant impacts have been eliminated - a continued consideration of both individual factors SAB, Kanban and Poka Yoke as well as the integration of the specific two-factor-interaction is required to create a statistically significant factor combination.
This way the model adaptation requires the interaction of SAB/Kanban, SAB/Poka Yoke and Kanban/Poka Yoke to be taken into account. A factorial adaptation exclusively eliminates the combination of SAB/Kanban/5S/Poka Yoke, Kanban/5S/Poka Yoke and Kanban/5S/Poka Yoke.

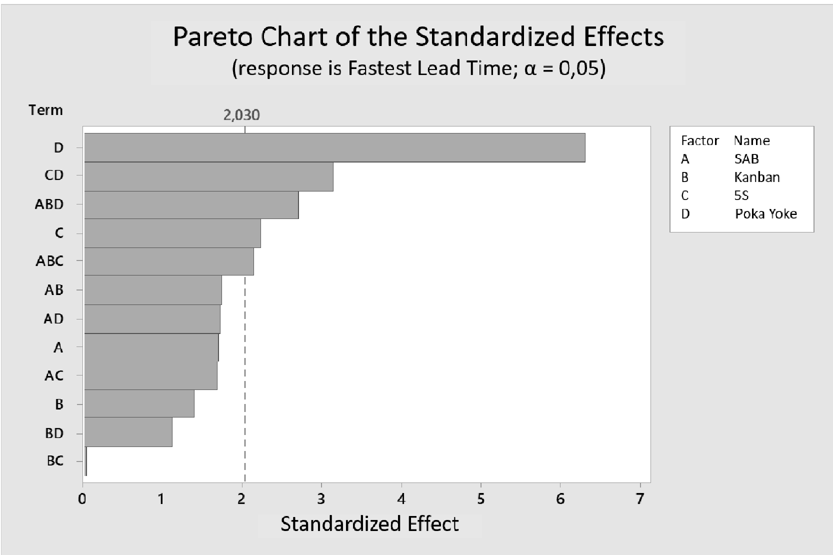

Figure 4: Pareto Chart for factorial Adaptation Model „Lead Time“

Once the non-significant impacts have been eliminated, the reference line of the five-percent significance level shifts to 2.030.An average increase can be identified for the p-values following the model adaptation, nevertheless this will not lead to any new insights with respect to statistical impacts on the lead time. The strongest impact continues to result from applying the Poka Yoke method.

Summary of Model

R-squared	R-squared(kor)	R-squared(prog)
70.01%	59.73%	43.59%

A deterioration of the R²-squared as well as the corrected R²-squared can be observed in the results of the adjusted model. Since the corrected R²-squared provides valuable insights on the model quality, a more accurate focus is essential. This way the corrected coefficient of determination decreases by 4.29 % following the factorial adaptation. Principal effect diagrams serve to clarify which impact the factor levels „used" and „not used" have on the lead time. For this purpose, the optimization methods SAB, Kanban, 5S and Poka Yoke are used for an individual view.

The lead times are shown in days in the principal effect diagram and interaction diagram. To achieve a better understanding days are converted into minutes in the analysis.

Within the columns of individual factors there is a differentiation between the specification „used" und „not used", which corresponds either to the application or abandonement of the respective method. The mean value of the lead time is at 2:40 minutes and is characterized by a horizontal line. A similar effect occurs with the methods SAB and Kanban. Without the application of the respective method, the lead time lies at approximately 00:17 minutes above the mean value. Virtually identical results are achieved when applying both methods in test runs. In both approach concepts the lead time is reduced to 2:23 minutes.

A closer look at the 5S method reveals that the lead time lies at 3:05 minutes without optimization measure, which is above the mean value. With the aid of 5S this goes down to 2:16 minutes. Consequently, the effect shown here is considerably larger than that of SAB or Kanban. Poka Yoke has the most pronounced impact on the lead time, which is characterized by a steep incline of the straight line. When using this method, the lead time drops from 4:48 minutes to 1:32 minutes, which corresponds to a reduction of the lead time of 3:26 minutes between factor levels. When analyzing the principal effects, Poka Yoke is considered the most effective optimization approach which is used to reduce the lead time. It turns out though, that the interaction of 5S and Poka Yoke are likewise significant.

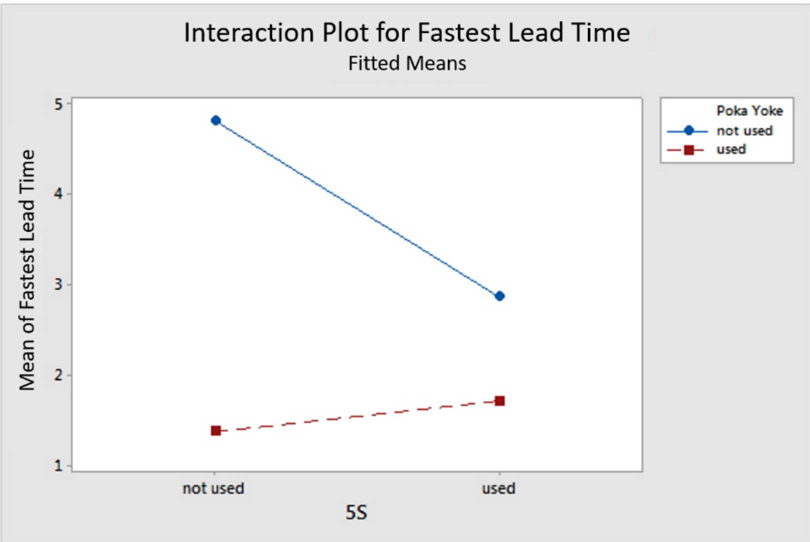

Figure 5: Interaction Diagram Model „Lead Time"

The 5S method is shown on the x-axis and divided into the characteristics „used" and „not used". The blue solid line indicates that the Poka Yoke method is not used, while the red dashed line indicates that Poka Yoke is used. When neither of the optimization methods are applied, an above-average lead time of 4:48 minutes becomes apparent in the test runs. The application of 5S by itself entails a reduction of the response variable. The lead time is then at 2:51 minutes. The rapid drop is reflected in the steep incline of the straight line. With the separate application of the Poka Yoke method the lowest lead time of all possible factor combinations is achieved, which is 1:22 minutes. If both optimization methods are used simultaneously, this will also affect lead time. In conclusion, the model adaptation shows that the application of the Poka Yoke method has the strongest impact on the lead time. At least one optimization method should be used. The combination 5S/Poka Yoke proves to be more effective than the sole application of 5S.

5. Summary and Future need for Research

In this research project the following hypothesis were formulated:

"The effectiveness of selected manufacturing optimization methods can be demonstrated via a developed model in form of a business simulation in a model factory".
To test this hypothesis the chosen methods in the business simulation were analyzed and a simulation model was developed for testing the effects of using those methods. The business simulation model with the chosen methods was tested in 48 rounds with new test persons in every round and with different combinations of the four methods. To compare the effectiveness of the four methods it could be demonstrated that Poka Yoke had the highest influence on the key performance indicator lead times in an assembly. This result cannot be generalized to other types of production processes. Further studies should be realized. Also other types of products can be manufactured. Maybe a product with a higher complexity will have an impact of the results.
In order to get more scientific valid results, the business simulation should be further developed and played more often with new different test persons. Furthermore, other KPIs, like the output, or the adherence to delivery dates should be analyzed. The target size optimization in the software Minitab® can also be used for further analyzes.

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