Quantitative analysis and optimization of the effectiveness of lean methods in small batch production

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Abstract

In order to stay competitive in the globalizing markets with fast changing conditions/requirements small and medium sized enterprises aim to implement methods and tools of the lean production philosophy, which already lead to enormous efficiency improvements in large companies. But these lean methods cannot easily be transferred as they have a different impact on the production system depending on the existing circumstances. The analysis and quantification of these interdependencies is subject of the current research work at the Institute of Production Science (wbk) in Karlsruhe. Using material flow simulation und parametric optimization, efficient combinations of lean methods for small batch productions can be determined under consideration of different target systems. This approach of the simulation-based optimization of small batch productions applying lean methods is explained in the following article.

Keywords: Simulation, Optimization, Lean Methods, Small batch Production

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1 Introduction

These days, the philosophy of lean production derived from Toyota as a chance for achieving optimal costs in a flexible production is established within the automobile industry. By the term of Integrated Production Systems as a system of rules consisting of design principles, methods and tools it is increasingly implemented in other branches and in small and medium-sized companies (Aurich (2006)). The average effects due to the implementation of an IPS in small and medium-sized companies are significant: an increase of sales by 30% with a simultaneously reduction of lead times by 30% and inventory by 20% (Korge (2005)). Moreover, improvements concerning quality rates, delivery time and delivery reliability are achieved (Gulden (2008)).
The transfer of lean methods to individual company characteristics is unconvertible without adaption as they affect the processes in a different way depending on the conditions and requirements (Fleischer (2008)). Hence, these interdependencies have to be clear and transparent for an effective implementation of the methods. But so far it is not known, which quantitative impact these methods have on specific process and target figures of a production system nor the exact specifications of dependencies between single methods (Zäh (2006)). Besides, experiences show that an isolated implementation of single methods often may not achieve the planned success and rather constrains their effectiveness (Spath (2003)).
The characteristics of single piece or small batch productions, which are covered to more than 60% by small and medium-sized companies, differ particularly from large companies in the high product variance with small volumes, thereby low repetitiveness, very complex product structures, a volatile customer demand, high differences of the work extent between the products, order modifications after start of production, external process steps and long replacement time for material (Aurich (2006)). This requires a trade-off between lean but still flexible, buffering processes for the organization of the production system. However, in these companies the necessary time and monetary effort for the planning and specific customization of the lean methods under these aspects often exceeds the available personal and financial resources (Lay (2008)). They need a quantitative forecast of which impact which lean methods with different combinations and characteristics have at the given conditions in order to choose the most efficient methods.
Against this background, the Institute of Production Science (wbk) at the Universität Karlsruhe (TH) deals within the project *LeanKMU* with the quantitative analysis and optimization of the application of lean methods in small batch production. The project is supported by the ministry of science, research and art of Baden-Württemberg and is accompanied by four small and medium-sized companies. In the following, the suitability of the material flow simulation for achieving this objective and the used software are discussed. Then, the approach of the simulation-based analysis and optimization of the application of lean methods using the software program OptiSLang® is presented with some results from a practical example.

2 Simulation Process as an appropriate analysis tool of lean methods in small batch production

For imaging and analyzing the mentioned criteria and standards of a single piece or small batch production as precisely as possible, the event-oriented simulation process is deemed to be a very adequate modeling procedure (Arnold (2007)). With those, complex product structures, in due consideration of dynamic effects and interdependency for example caused by variation and random occurrences can be imaged flexible and in detail.

Furthermore, the event-oriented simulation process is an ideal tool for analyzing and understanding the methods of Lean Production (Evans (2007)). The principal reason can be found in consideration of variations and uncertainties and thereby the acquisition of the stochastic system performance, the analysis and valuation of alternative nominal conditions as well as the validation of a nominal condition before implementation to minimize time for subsequent adoptions (Standridge (2006)). Thus, simulation models suit very well as auxiliary tools for planning the application of Lean Methods within single and small-series production (Fowler (2004)).

Because of the manifold cause-effect relationships of lean methods in a production system, a sensitivity analysis of the simulation model has to be made. Therewith, all effects of relevant parameter changes caused by different characteristics of the lean methods can be captured. In simulation programs this requires a high manual effort as the parameters can only be varied separately. A fast and automated parametrical optimization of the model is enabled by the integration of an optimization tool that allows changing several parameters of a different spectrum at the same time.

Within the project *LeanKMU* the simulation program *Plant Simulation*® by Tecnomatix is used, which is wide spread in industry and research institutions. It is a software program for object-oriented, graphic and integrated modeling, simulation and animation of systems and business processes. The model is build by an enormous option of standard material and information flow elements, which can be parameterized by so-called attributes in any way. The control principle and the generation of information between the material flow elements are realized by individual programmed methods (based on the problem-oriented programming language SimTalk). Plant Simulation® is providing an incremental working method, so that findings of previous studies can be integrated in the existing model at any time without having to modify or redo it (UGS (2008)). The latest version 8.1 does already contain optimization functions with genetic algorithms, but with very restrictive functional options. For that reason, the autonomous optimization tool *OptiSLang*® is integrated, supported by the open system architecture of Plant Simulation®. The following chapter is explaining the combination of the two software programs more detailed.

3 Simulation-based Optimization of Small batch Productions Applying Lean Methods

The objective with the analysis and optimization of production systems by applying lean methods can be illustrated by the control-loop in Figure 1 (Fleischer (2008)). It shows the significant figures and their relations to be considered in a simulation-based optimization.

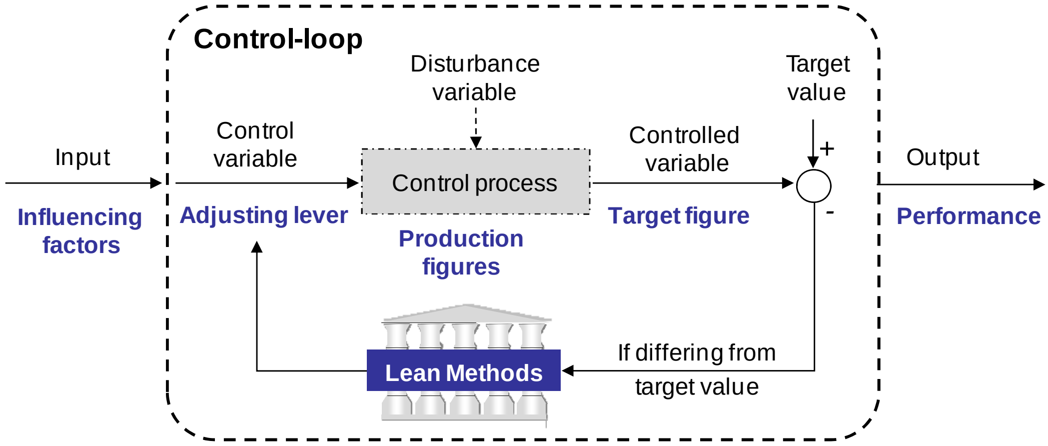

Figure 1: The control-loop of lean methods in a production system.

The small batch production to be analyzed with its influencing factors complies with the control process, which is described in the simulation model by relevant production figures. Different characteristics of a lean method are modeled by the modification of adjusting levers. These levers correspond to the variable input parameters of the optimization studies, which are configured differently within their value range. The consequences of the modifications are measured by production figures as well as by the defined five target figures lead time, productivity, quality, flexibility and delivery reliability. These target figures are the controlled variables in the studies, which will be optimized in the lot of runs according a fixed priority (target function). Based on the determined interdependencies the effect of the levers and thus of the appropriate lean methods are quantified and efficient combinations of methods using a multi-criteria target system can be revealed. As disturbance variables especially stochastic factors like variations of process and set-up times or machine failures are integrated in the simulation studies.
Below, the combination of the two software programs is explained followed by potential results in the form of quantified interdependencies of selected lean methods with the target figures and a comparison according different target systems.

3.1 Combination of OptiSLang® and Plant Simulation®

The interaction of the two software tools with the necessary interfaces is shown in Figure 2. OptiSLang® is autonomously starting Plant Simulation® by a programmed batch file (step 1) and a set of parameters is instantly transmitted through a simple text file (step 2). These parameters represent the input parameters for the simulation study, which is then starting (step 3). After the end of the study all relevant results are documented in a second text file and Plant Simulation® is closed by itself (step 4). Finally, the given simulation results are transferred to OptiSLang® and evaluated related to defined target function (step 5). Based on the gained target function value OptiSLang® is generating a new set of parameters (= design) and the cycle is repeated from step 1. Depending on the applied optimization method OptiSLang® is collecting some more results before generating a new parameter set.

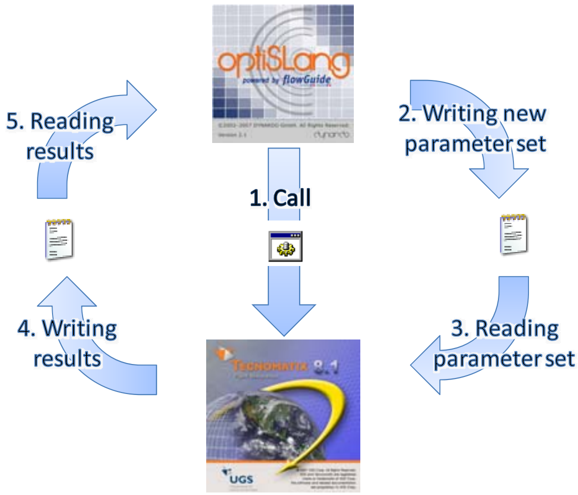

Figure 2: The interaction of the two software tools.

Within the research work at the Institute of Production Science (wbk) a genetic algorithm is used as optimization method in order to enable a target-oriented rapid optimization. The working parameters for the genetic algorithm are identical: the population size and the number of generations are 10, which is leading to 100 simulation runs for each optimization study. Each generation possesses a so-called elitist design and one design to be substituted, and the maximum mutation rate of a chromosome equals 20%. The start population of the algorithm is determined using the methods Design of Experiments and Latin-Hypercube-Sampling. Thus, the broadly spread population panders to the meta-heuristic character of the genetic algorithm and reduces the risk of discovering local optima. The aim is to determine the global optimum for the defined target figures with the possibly minimum number of examined designs (parameter sets).

3.2 Quantification of Interdependencies of Selected Lean Methods

The adjusting levers of the control-loop for the simulative analysis of the effectiveness of lean methods shown in Figure 1 are generally corresponding to process figures like the set-up time using SMED (Single-Minute-Exchange-of-Die) or the scrap rate using methods of TQM (Total Quality Management). These process figures represent the input parameters of the optimization studies, which are varied in relation to the status quo at the reference model. For the fact, that the application of a lean method requires a change of the design of the analyzed production system, especially with control-related methods as pull or kanban systems, the simulation model has to be modified appropriately. In this case, the corresponding input parameter for the optimization is a binary variable in order to apply the method (“on”) or not (“off”). Applying the method further input parameters can be determined as levers, e.g. the number of kanban cards or the number of parts per bin in a kanban system.

After the end of each simulation study the performed interdependencies of the lean methods with process and target figures have to be demonstrated. Therefore, the statistical post processing in OptiSLang® provides a clear and interactively graphic evaluation of the relevant interdependencies. Possible evaluations of the simulation results are presented in the following by means of a practical example.

The simulative analysis refers to a manufacturing cell with 10 different product types and a total of 1.000 numbers per year. The cell, which is run by two employees in 3 shifts, consists of three conventional manufacturing machines (machining, milling and drilling) with a buffer each and a station for deburring and quality testing. This final process step is whether the product is transferred to the outgoing buffer, taken out from the process as scrap or whether it has to be reworked which means the transport to the ingoing buffer of the cell again. The order release at the first process step of the cell is done by a kanban system with the subsequent assembly process; the flow within the cell follows a push system.

Figure 3 shows the illustration of the simulation results in OptiSLang® (Result Monitoring). The left graphic (1) indicates the correlation coefficient with the target figure *lead time* for each input parameter of the optimization.

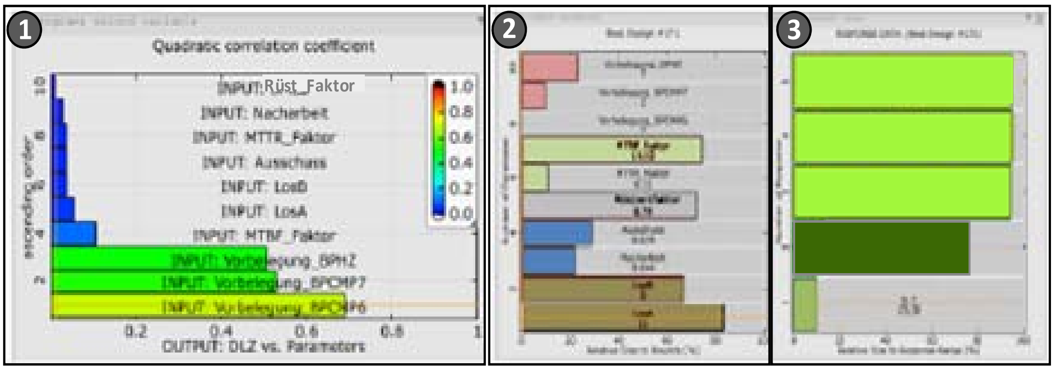

Figure 3: Illustration of the simulation results in OptiSLang®.

The 10 input parameters are corresponding to the 5 lean methods Kanban (size of each buffer), SMED (set-up time), TQM (rework and scrap rate), Total Productive Maintenance TPM (Mean-time-to-repair MTTR and mean-time-before-failure MTBF) and the production leveling (batch size of the two runner product types). It is obvious, that the lead time primarily depends on the size of the three machine buffers which relates to the dimensioning of the Kanban system. The other parameters like set-up time, scrap rate or MTTR have only a low influence. The graphic in the middle (2) shows the values of the input parameters for the simulated best configuration of the parameters (best design) concerning to the given target function. The left and right boarders mark the minimum and maximum value within all simulation runs and the bar the percentage. Thus, the MTBF factor as indication for TPM measures and the set-up time reduction through SMED have high values. The batch size of the two runner products are quite high but not the maximum analyzed value and the buffer size whereas the buffer sizes and the quality oriented parameters show low values. The target function during this study included the weighted productivity of each machine, the lead time and the flexibility. The specific values of these results for the best design are demonstrated in the right graphic (3).

3.3 Evaluation based on Different Target Systems

In order to verify, how lean methods perform correlated to different target systems and which combination of methods is the best one, the simulation model of the analyzed production area is optimized to diverse target functions. For the given example, **three parametrically optimized** scenarios are designed using genetic algorithm. Their results are compared in Figure 4.

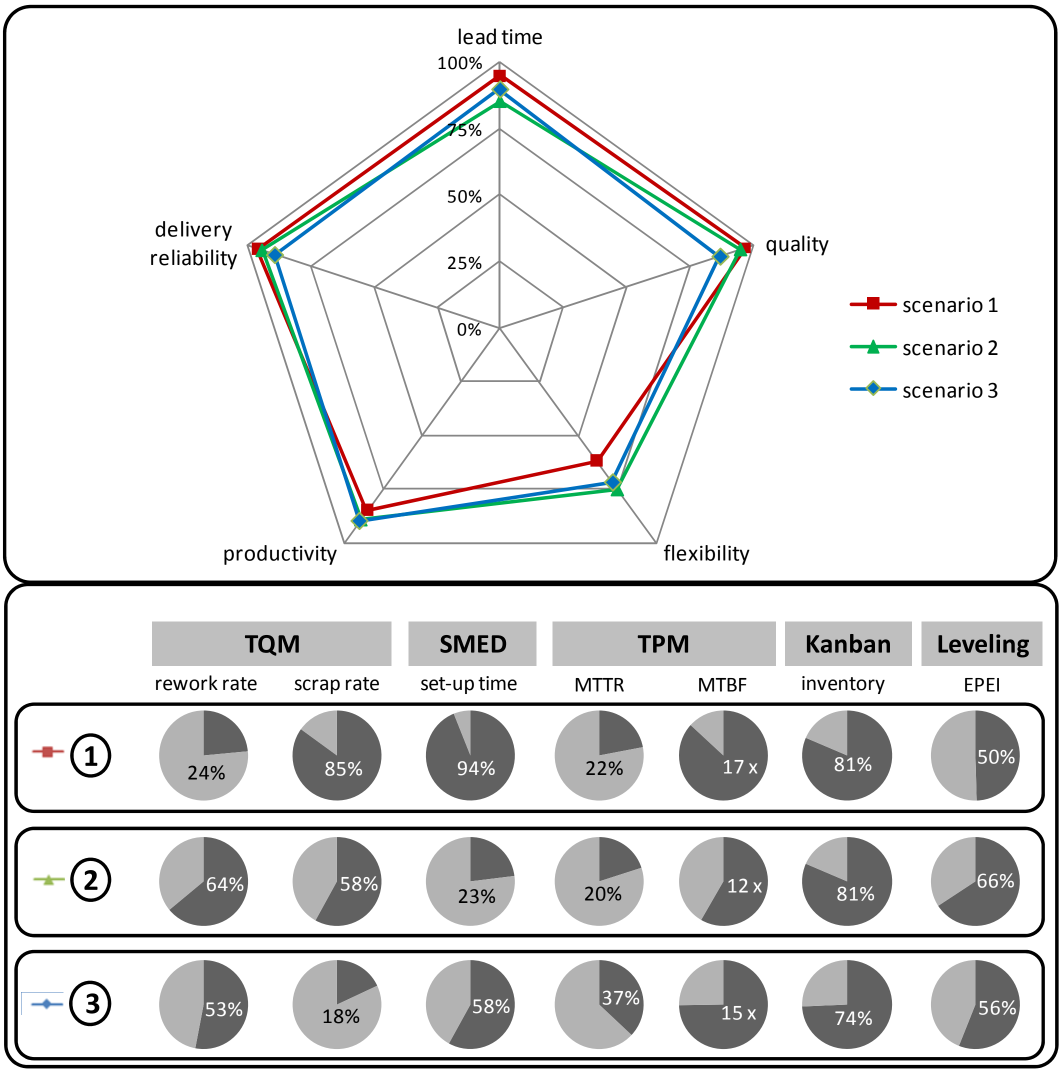

Figure 4: The impact of lean methods based on 3 different target functions.

The achieved performance of the three scenarios related to the five target figures is demonstrated in the net chart in the upper part of the figure (line). The 100% on each axis means the target value of each target figure, whereas the percentage at the lead time axis in contrary to the other figures equals the increase in the amount of the difference from the target value. The lower part of Figure 4 focuses on the input parameters and the pie charts show for each target function (row) the proportional change of the parameter value towards the reference value, which led to the attained performance. Thus, the necessary level of application of the appropriate lean method is revealed. As a conclusion intending to transfer the results to reality, the figure can be interpreted in two ways: on the one hand, it is possible to choose the favored performance from the net chart and correspondingly plan and realize measures to improve the real figures to the simulated values. On the other hand, a feasible configuration of the parameters (out of the three) can be focused and measures to achieve these values will be planned and implemented. In this example in Figure 4, the scenario with the highest lead time may be chosen (red line) and therefore, the company is forced to reduce the figures in the manufacturing cell to the values from scenario 1 in the first row.

4 Summary and outlook

Experiences prove, that methods of the lean production influence the behavior of production systems in different ways depending on the given requirements and conditions. These interdependencies are often known in only a qualitative manner. For this reason, an approach was developed at the Institute of Production Science (wbk) at the Universität Karlsruhe (TH) to enable companies with small batch productions to forecast, which impact selected lean methods at specific conditions have on the production figures and which combination result in the best performance. The approach is based on the simulative optimization with the simulation program Plant Simulation® in combination with the statistic optimization program OptiSLang® to provide a fast dynamic optimization of complex production systems with any variable parameters. This article discussed the first integration of the two software programs, followed by the procedure of the quantitative analysis and optimization of the effectiveness of lean methods in small batch productions with a few results from a real case in practice.
The presented approach currently does not consider the time or financial effort for the realization of the lean methods. In further research studies, time or cost aspects could be included, e.g. by pareto-optimization of competing target functions, in order to increase the correspondence to reality of the designed scenarios. Further improvement potential lies in a more user friendly interaction of OptiSLang® and the solver Plant Simulation®, e.g. a better and automated export of the results.

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