Optimization of Production Processes in SMEs: Practical Methodology for the Acquisition of Process Information

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Abstract. Production companies are increasingly required to flexibly adapt to competitive situations and, hence, aim to ensure that their production processes have optimal outcome. This combines requirements e.g. on product quality, production time and costs as well as process variability. The cornerstone for optimizing current processes lies in a thorough understanding of these requirements in order to derive optimization potential that can efficiently be realized. Business process modelling provides such a comprehensive view on the processes and accurately reflects the existing workflows – given that all necessary information is considered and acquired accordingly. This includes not only the company's goals and the production processes themselves, but also the implicit knowledge on these processes of the employees. For many companies, a proper systematization and combined realization of these steps is a challenge. We present a practical methodology for acquiring the relevant production process information as basis for a proper process modelling. We develop a generic procedure which is tailored to the characteristics of small and medium-sized companies and describe the goal, the requirements, the methodology as well as a practical application including benefits and limitations. The methodology provides a structured approach for the systematic mapping of heterogeneous production processes and builds the foundation to detect optimization potential.

Keywords: Process modelling · Optimization of production processes · Information acquisition

1 Introduction

Meeting the needs of today's globalized market has become a distinct competitive edge for production companies. This requires a high transparency on the production process to react appropriately and flexibly to varying customers' wishes and to adapt to different batch sizes. In addition to the requirement of achieving the punctual delivery of high-quality products at a reasonable cost, small and medium-sized enterprises (SME) in Europe and Asia face typical challenges like the lack of financial, technological and

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networking resources [6, 15]. Consequently, companies are searching for cost-efficient solutions, specifically addressing their needs and unique situation, to optimize their production processes. This ranges from the retrofitting of existing assets (like machines) over the automated integration of expert knowledge to the implementation of lean approaches [11].

To identify suitable optimization potential, a thorough process analysis is inevitable. The appropriate level of detail and the cost-benefit-ratio of this analysis have to be considered carefully. Depending on the company's goals (e.g. throughput time reduction, AI-based quality control), the potential use of the information builds the basis for the relevant data and knowledge that needs to be acquired. The paper focuses on the formulation of a procedure to efficiently perform this information acquisition and simultaneously create a profound knowledge gain of the employees on the production process chain and the interconnections of the sub-processes.

We present an application-oriented method for the acquisition of information regarding the production process which allows a straightforward realization of digital transformation and optimization processes in SME. This information includes machines, products, relevant data (e.g. order-related) and expert knowledge (e.g. adaptations of the production plan, specific characteristics regarding machine utilization). The approach is tailored to production companies of SME-type as it addresses their special requirements like handling the available process documentation, including the rather high amount of employees' expert knowledge and producing as little additional costs for e.g. software tools as possible. According to the typical steps for process analysis [13], we concentrate on the information acquisition and thereby providing transparency on the production process.

The paper is structured as follows. Section 2 comprises the theoretical background and the state of the art. In Sect. 3, the methodology for the process analysis is described. A practical application in a production company is presented in Sect. 4, whereas Sect. 5 addresses further research questions.

2 Theoretical Background and Related Work

Results on the model-based approach as basis for production process analysis and optimization can already be found in the literature. The model of a production process with respect to realizing a proper quality management is given in [1]. Here, a general process model is developed that allows a statistical analysis of the process, containing e.g. the statistical distribution and the method for determining the capability and performance (in the sense of long-term capability) of the process. However, aspects beyond statistical process evaluation are not considered here.

A conceptual reference model for identifying and organizing production data is given in [2], which aims at analysing and finding relations between the five dimensions production, plant hierarchy, process, context and resources. The approach however concentrates on the organization of digital factory data and does not take the connection with human expert knowledge into account.

In [3], both the product and its production process including their mutual connections are mapped. This allows the modelling of a configurable product as a directed multigraph, a set of (process) model and coupling constraints. Such an instance of the model provides a configured product and the executable process for its production. Similarly, an approach to design a manufacturing system is presented in [12]. Both do however not aim at mapping the existing process chain.

Special focus on production control is set in [7], where a Petri net approach is presented in order to map production process-relevant data, which includes data on the products and on the production facility. Even though we concentrate on the optimization of production processes rather than production control, environmental factors are a relevant aspect for us as well. A systematic literature overview on data acquisition is presented in [4], which reveals that this field is highly granular and realizations differ across machines, processes and on the plant level.

In conclusion, the acquisition of the relevant information for process modelling is crucial for creating proper and meaningful images of the real processes. While process modelling itself is a highly investigated topic, the practical realization of the information acquisition has rarely been addressed in the literature, and to our best knowledge there exist no standardized procedures or methods.

3 Methodology

The methodology presented below aims at acquiring information on production process chains. It was developed by applying action design research [14], combining the scientific study of a problem with the application in a real-life situation. Its goal is to generate prescriptive design knowledge by learning from the realization and evaluation in an organizational setting [10]. This was achieved by developing the methodology together with a production company of SME-type which has the typical characteristics we want to address: the motivation to improve the production process, a partly digitized production process with both high-technological machinery and machinery in need of retrofit, a significant amount of implicit knowledge of the employees. One advantage of the methodology is its generalizability since the company-specific requirements (e.g. level of digitalization) and the varying goals (ranging from simple retrofit to complex real-rime data analysis) are considered in the process. Additionally, as it is described in the upcoming paragraph, it is the goal to take into account and acquire all relevant information and knowledge of the company's employees. Therefore, the respective employees are assigned various roles. The methodology can be applied to SMEs of different size and complexity as it is process- instead of enterprise-oriented. Depending on the availability of different participants, certain roles can be condensed. As company-internals, at least a decision-maker and an implementer must be involved.

We start by defining the relevant roles and designate the respective participants. First, a process analyst (who can be internal, but usually is external) being familiar with the methodology has to be included for implementation as well as guidance of the company's participants. On the company's part, a decision-maker (e.g. CEO or manager) is needed for formulating the target of the production process optimization. Furthermore, a superordinate technology employee (the implementer) has to be involved, who functions as knowledge carrier and interface between the process analyst and the company's employees. Regarding every production sub-process that is considered, both a worker performing this process and having profound knowledge on it (mainly for the information acquisition; especially in small enterprises, this might be the technology employee) as well as the respective team leader (for further inquiries and the final release; this role can be taken by the decision-maker) are included. With the inclusion of the different participants, a holistic view on the processes, the acquisition of all available knowledge as well as a proper release process is guaranteed.

The procedure is illustrated in Fig. 1. After laying the foundations by defining the target and choosing the respective relevant process chain, the acquisition of every sub-process information is iteratively achieved by the conducting three steps visualized in the middle part. These three steps have to be performed for each sub-process individually (and chronologically according to their appearance within the process chain) such that in the end, the outcome builds the basis for process optimization.

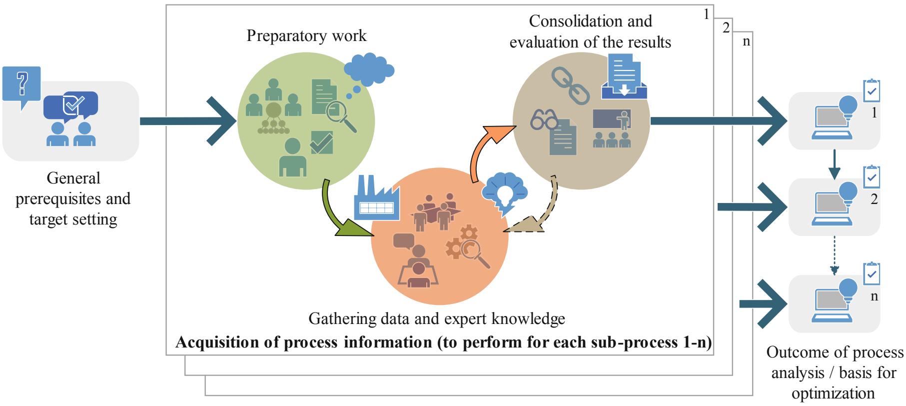

Fig. 1. Visualization of the proposed methodology.

General Prerequisites and Target Setting: Using the top-down-principle, a product family as reference object for the process optimization is defined. Therefore, first an overview over the available product families is created. A prioritized choice is found by evaluating certain criteria, which are split into primary (core) and secondary (supporting) ones: Primary criteria, representing economic and technological factors, depict the strategic view of the management (by key performance indicators, business environment, orientation and competitive differentiation of the company) and the operational view w.r.t. the manufacturing process (by production quantities, importance and impact of production know-how). The availability of relevant product/process information (e.g. test plans, work instructions) is included as secondary criterion since it facilitates the successful implementation of the procedure and, hence, influences the quality of the subsequent process optimization. To gather the relevant information to evaluate these criteria, the process analyst interviews a decision-maker of the company to get an overview of the company's typology (e.g. size, vertical integration). Then, the shop floor is visited to get a deeper understanding of the workflow. Expert interviews with a technology employee who has profound knowledge on the production process complete the first insight. Now the reference product is chosen, and a flow chart of the relevant sub-process of the product family as well as first rough drafts of event-driven process chains (EPC) are created by the process analyst and the technology employee. EPCs were chosen because of their easy understanding for the company and their expedient use ([9]; for a further discussion, see Sect. 5).

Preparatory Work: The next three steps regard the acquisition of detailed information on the relevant sub-processes. First, the planned procedure is announced to the worker who is responsible for the execution of the considered sub-process, with focus on their respective involvement. Furthermore, a preliminary short briefing between the process analyst and the technology employee in which the rough draft of the respective EPC is discussed helps to establish a uniform level of knowledge. New information gathered from this discussion is included in the EPC.

Gathering Data and Expert Knowledge: The worker responsible for the execution of the sub-process is consulted. He or she gives a detailed description of his or her tasks and simultaneously executes them on the respective machine/workstation etc., while the process analyst documents this knowledge. Note that this does not only include the typical work steps, used machines or software but might also address implicit knowledge like machine parametrization or typically arising problems. The focus is explicitly set on the standard procedure and not on rarely occurring exceptions. The technology employee, combining knowledge both on the acquisition procedure and on the company's practical processes, connects the internal staff and external analysts. To raise the worker's motivation to participate and to include a maximum amount of (implicit) knowledge (e.g. regarding information flow, parametrization tasks, interaction with other work steps), he or she is asked about his or her view on necessary or possible need for optimization. Finally, the process analyst describes the further procedure to make the upcoming involvement of the worker transparent.

Consolidation and Evaluation of the Results: The process analyst adds the new information to the roughly designed EPC and transforms it into a detailed one, which is then reviewed and improved by both the technology employee and, afterwards, the worker responsible for executing the sub-process. The final release of the EPC is done by the team leader. If he or she does not approve of the latest version, corrections are performed by the team leader and the technology employee, which corresponds to the arrow in Fig. 1 leading back to the gathering of expert knowledge. The worker responsible for the sub-process is informed about the changes (as a benefit, internal differences in the understanding of the processes are clarified). A subsequent check regarding semantic accuracy and comprehensibility is made by the process analyst.

These three steps are repeated iteratively until every sub-process has been considered and the respective information is acquired.

Outcome: As a result of the methodology, every sub-process of the process chain is mapped as a process model, e.g. EPC (as in our case), Business Process Model and Notation (BPMN), Unified Modelling Language. This includes information on the technical infrastructure, the used machines, hard- and software, relevant data and parametrizations, involved employees, material and information flow, informal information regarding the overarching interaction of the sub-process (e.g. communication in case of high reject rate) as well as sub-process-specific and overall suggestions for improvement. Hence, the information of the process chain is systematized and the connections between the different sub-processes are made transparent.

4 Practical Application

The procedure was developed using action design research methodology in cooperation with a company producing tools (needles for knitting machines) in a high vertical integration (ranging from stamping of the raw material over forming to heat treatments). Since needles are very delicate easily damageable, a comprehensive know-how is inevitable for high production stability. Within a research and development project funded by the German Federal Ministry of Education and Research, the initially rarely digitized production process is optimized using AI-based data analysis to automatically identify variations in the product quality for critical sub-processes.

The process analysis was realized using the procedure introduced above. For the chosen product, a process chain containing 20 sub-processes was identified and investigated. Due to the pandemic situation, on-site visits were only possible in the early stages. The majority of information acquisition and interviews with the company were performed online. The most important perceptions are summarized in Table 1.

Table 1. Perceptions regarding the practical implementation of the methodology.

General prerequisites and target setting
– difficult to conduct digitally as on-site visit of running production (layout, size, routes and temporal relations) is required for overall understanding (especially in the context of complex production processes)
Preparatory work
– during the repetitive cycles of the acquisition process, the gradual qualification of the technology employee led to more efficient realization
Gathering data and expert knowledge
– usage of EPC for modelling, which are easy to understand and map all relevant information, facilitates communication with employees
Consolidation and evaluation of the results
– it is useful to plan additional time for the final release of the EPCs to account for possible (un-)availability of the team leaders

(*continued*)

Table 1. (*continued*)

General prerequisites and target setting
Acquisition of process information
– a digital conduction, which was necessary due to the pandemic situation, had no negative influence on the results (however, photo documentation in this case is highly recommended); this allows more flexibility in scheduling appointments with employees – the rather high amount of repetitive check cycles involving different employees has various positive effects: o implicit employee knowledge is transferred into explicit one o the awareness of employees for their own sub-processes, the neighboring ones and the whole process chain has risen significantly, which led to an increased sense of responsibility for the product and a reduction of uncertainties o cross validation of employee and team leader raises quality of EPCs o increased knowledge of employees in process modelling and information acquisition o optimization potential becomes more transparent and is iteratively refined due to the gained knowledge, transparency and understanding of the processes and their interrelations

5 Further Discussion and Outlook

The initial application of the methodology in the above-mentioned company proved to be a successful starting point for the digitization of the production line and the realization of an automatic process monitoring to reduce the reject rate. The information acquisition, specifically the documentation, led to the involved employees' raised transparency on the processes' complexity as well as interconnections and intrinsically motivated them to actively suggest improvements on the sub-processes. Especially in the project's production process optimization context, this proved to be a profound basis for conducting the actual realization steps.

Even though the process requires a significant commitment of (personal) resources, the step-by-step realization leads to higher transparency and an expedient competence development of the involved employees. The knowledge gain regarding the processes builds the basis for continuous improvement processes and, hence, a wide range of optimization potential. The direct availability of the structured information builds the basis for certification programs (e.g. for a quality management system), leading to a better competitiveness. Applying the methodology is the starting point for the creation of digital twins of assets like machines, products etc. Furthermore, the formulated assets and their underlying architecture allow a risk analysis w.r.t. data security.

For process modelling, EPCs were prioritized because of their easy use and expandability. Additionally, they were understood well by employees who initially were unfamiliar with process modelling. For our further research and application, we intend to use BPMNs from start (note that EPCs can be used to create BPMNs). Hence, the results are also usable in connection with BPMN workflow engines for the visualization of the operational processes and the identification of optimization potential. This is especially of high interest considering platforms (like BaSys [8]) that provide standardized solutions for the optimization of production processes.

The derived information can also serve for maturity models as the thorough analysis of the production processes' actual state allows a straightforward evaluation of the current maturity level and the derivation of the necessary steps to achieve the envisioned target (this is a typical procedure in the context of retrofitting, see e.g. [5]).

The experience and know-how of the involved employees significantly influence the pace and quality of the information acquisition. A high benefit arises for a high vertical integration and a large amount of (differing) sub-processes due to the binding of (expensive) technology employees. It is part of our future research to develop an assessment logic for the economic evaluation w.r.t. the company's initial goals (e.g. basis for digitalization, AI-based production process optimization or certification).

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