AN ADAPTED METHOD FOR DESIGN PROCESS CAPTURING TO MEET THE CHALLENGES OF DIGITAL PRODUCT DEVELOPMENT

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ABSTRACT

In our modern, interconnected and globalized world, design is in motion, to adapt to new situations. But successful Design in Motion must be based on Processes in Motion. For a target-oriented adaptation of the processes to the new, challenging conditions, the as-is procedures must be captured and analysed. For this analysis, established capturing procedures from production or administration cannot be used due to some special features of design processes and workflows, which will be discussed in this contribution. To compensate for the weaknesses of existing methods, we propose an adapted method for holistic design process capturing. With the procedure, we want to enable an economic process analysis, which is crucial for small and medium-size companies in particular. To give an insight into the practical application of the method, we exemplarily analyse the process of a shaft construction and FEM-evaluation by two different employees. Based on this analysis and to verify the relevance of the presented approach, an evaluation with respect to the requirements is done.

Keywords: Process modelling, Organisation of product development, Digital / Digitised engineering value chains

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1 DESIGN IN MOTION REQUIRES PROCESSES IN MOTION

Engineering design is based on established methods and tools, which have been the subject of research for a long time (Pahl et al., 2013), as well as being used extensively in industry. But in our modern, interconnected and globalized world, design is in motion, to adapt to new situations. Current examples are the effects of the COVID-19 pandemic, which obliterates established work models and forces employees to distributed teamwork, e.g. from home. In addition, even before the pandemic, companies recognized potential for cost and time savings by applying new technologies, such as artificial intelligence (AI) or data driven methods, and wanted to integrate them into their design workflows. Unfortunately, "wanting to" is often not enough, as a representative study by the German market research institute Bitkom Research (Grimm and Gentemann, 2020) shows. The study covers the level of digitalisation of more than 500 german companies and shows that especially small and medium-sized companies have problems introducing new methods and see themselves as stragglers. However, the majority of companies consider their digital transformation to be a central necessity for future business success. Apart from the competence of applying new methods and to employ appropriate specialists, one central point is often underestimated. Successful *Design in Motion* must be based on Processes in Motion. For a target-oriented adaptation of the processes to the new conditions, the as-is procedures must be captured and analysed. Based on such an analysis bottlenecks can be identified, which subsequently can be reduced by applying those new technologies. There are established capturing procedures from production or administration. However, in product development these cannot be applied directly due to some special features, which will be discussed in more detail in section 2.1. In addition, the flow of information and data does not receive sufficient attention in the established procedures, since the captured level of detail is inappropriate or the information did not seem necessary to the authors. But for the generation of a process model, intended to provide the basis for the introduction of new data-based methods, the consideration of this data and information is of central necessity. Therefore in this paper a procedure is developed, which enables a complete coverage and sufficient documentation of design processes and the connected data and information.

The following research questions are derived from the points listed above and will be answered throughout our contribution:

- With which prerequisites and which method can digital processes in product development be fully captured?

The further contribution is structured as followed. In section 2.1 we analyze characteristics of the product development process, leading to problems in process capturing. Afterwards established capturing procedures and methods are presented in section 2.2. Section 2.3 evaluates the current tools in respect to the product development process. To compensate actual weaknesses, we present our extended approach in section 3. In section 4 a preliminary evaluation is done. An outlook on further work concludes the article.

2 CONTEXT AND STATE OF THE ART

2.1 Characteristics of product development processes

Product development processes differ from management or production processes (Reolofsen and Lindemann, 2010). Therefore established process management tools are not directly applicable to product development processes (Reolofsen and Lindemann, 2010). Mehlstäubl et al. (2020) present characteristics of design processes in comparison to business processes. First of all, the result of the design process is only roughly known and not defined in detail. Furthermore, the process is subject to a number of iterations and can be seen as highly dynamic and creative. Since all design processes develop some kind of thing, not existing yet, every process is kind of unique (Blessing and Chakrabarti, 2009), although there are some general methodologies like Pahl et al. (2013) or VDI 2206 (2004).

Due to design process characteristics, some challenges have to be respected to record and manage those activities. Creative processes are typically not exactly planned but highly dynamic to chaotic with many iterations and loops while conventional business process are reproducible and predictable (Mehlstäubl et al., 2020). The iterations are necessary, since product requirements change during the development or verification stages (e.g simulation) fail. Another possible result is the change of constraints based on

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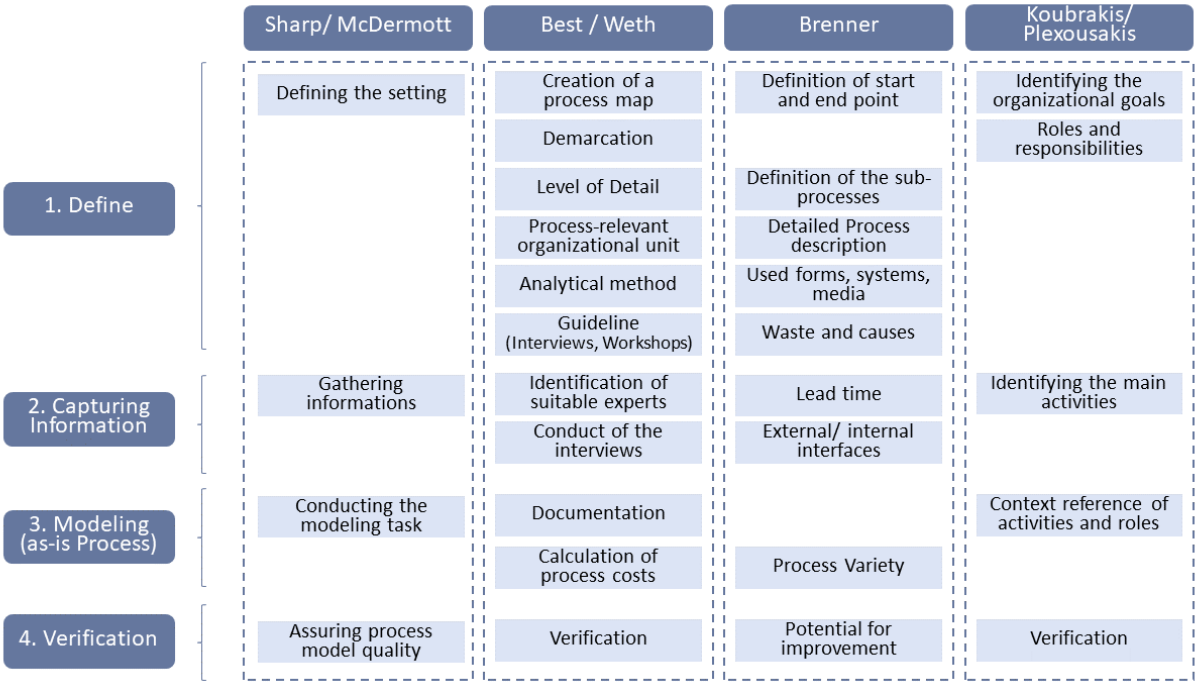

Figure 1. Overview of current process capturing methods.

changes in connected components. The effects of these external influences can be further iteration loops up to process interruptions (Vajna et al., 2018).

Digital resources also have to be respected in the product development process. Unlike the most production resources, e.g. workpieces or machines, their virtual counterparts can be used in parallel by different employees or are in circulation in several versions. Therefore, data management is key in modern companies with digital processes. To obtain transparent data-management, a cloud or server based storage is commonly used. In the optimal case, all employees can access the relevant data in the newest version. In practice, this is not guaranteed. Often local copies are saved or data is send via E-Mail. Changes to the file can then no longer be tracked centrally and reliably.

Beside the challenges already mentioned, there are additional aspects to be considered when processes run digital. In the context of Big Data they are known as the V's (Kitchin and McArdle, 2016).

- **Volume:** Usually, big data has to deal with enormous quantities of data.
- **Velocity:** A significant amount of new data is created in real-time.
- **Variety:** Data in the relevant environment can be structured, semi-structured and unstructured, depending on the used tools or file storages.
- **Value:** Different relevant insights can be extracted from the data and used for further analysis.

2.2 Current process capturing methods

Especially in times of digitalization, companies face the challenge of designing their processes effectively and efficiently in order to be competitive on the future global market. To achieve this goal, internal processes must be discovered, analysed and properly documented. The following procedures introduce, how enterprises can perform process capturing in a structured way. Subsequently, the most popular methods used in process discovery are mentioned. In summary, all models follow the same rough structure, visualized in figure 1. The models are usually built in three or four stages. In the introduction or definition phase, the initial situation and the general conditions of the process landscape are investigated. A procedure for the collection of business processes is proposed by Sharp and McDermott (2009). At the beginning, the setting is defined and a team is formed from the employees involved in the process. In a second step, the information is collected and an understanding of the process is developed. Subsequently, the process is modelled in step three. For this purpose, the process boundaries are identified, the events and activities are named, necessary resources and their locations are determined and finally the control flow and other process-dependent objects are identified. In step four the process is verified. Brenner (2018) presents a similar approach, with particular emphasis on dividing the actual collection

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of information into a qualitative and quantitative analysis. Another model for process capturing is presented by Best and Weth (2009), who divide their approach into three rough phases. Best and Weth choose the expert interview and the workshop as the preferred methods for their process acquisition in order to collect information from the employees. Koubrakis and Plexousakis (1999) presents another approach to business process capturing. The approach contains five steps, which are not only applied in process capturing, but also in the development of an information system.
Subsequently, the information is collected by using different methods. The expert interview is a popular method, as well as the workshop or Process Mining. Finally, the result is transferred in a process model and usually verified by the employees. According to Dumas et al. (2018), the expert interview is a frequently used method in social research to gather information about the actual process. It should be emphasized, that the expert interview provides a very detailed insight into the process and the different perspectives of the employees. The interview-based discovery helps the process analyst to understand the process in detail and reveal inconsistent perceptions of different domain experts. Another method for gathering information is Workshop-Based Discovery as analysed by Dumas et al. (2018) and Brenner (2018). In a workshop, different perspectives on the process can be evaluated at the same time. Together with the moderator, the process model is developed (Dumas et al., 2018). Depending on the complexity of the process, the workshop method can be very time-consuming. Process mining refers to the automated discovery of processes in companies from event logs (van der Aalst, 2016). However, one of the most frequent points of criticism is, that process mining represents only a partial aspect of the actual process and does not fully map the process, contrary to the requirements for process discovery (van der Aalst, 2010). However, Process Mining is used as digital support in addition to the classical methods (Pöhler et al., 2020). Further options during the capturing phase are manual or automated document analysis, observations or questionnaires (Leyh et al., 2017).

2.3 Evaluation of the current methods with respect to product development

Dumas et al. (2018) defines three general problems with process capturing: distributed process knowledge, case-thinking and missing understanding of process notations like BPML. Mehlstäubl et al. (2020) reports a high abstraction of established methods. This is causing disadvantages, if information flows are to be considered, which should be done in these highly dynamic processes. If the process model contains those information flows, it can be used to analyse the tasks and to optimize the whole process with digital engineering methods. Current methods can only capture certain aspects of the process, a whole documentation is not possible. The following aspects cannot be taken into account: which self developed tools are used, which informations are used and where are they saved, are there any data fragments like simulation files, which are simply archived. The method of Best and Weth (2009) enables a deep understanding of the process through the preparatory steps, but does not consider information flows. Brenner (2018) on the other hand focuses primarily on a qualitative and quantitative analysis with probability and time requirement of variants. Documents and informations aren't considered and the process is not aligned to the company context. Lastly process mining fixes the problem of considering information flows but cannot record tasks, which rely on verbal information exchange or analogue documents.
In summary, all process models are characterised by a more or less detailed capturing phase. Many authors emphasise the relevance of the results of this phase (Leyh et al., 2017), but give only a short introduction on how to gather all necessary information. They form the basis for the further procedure, which is why it should be as extensive as possible with the available resources. The process models already provide good aspects for the acquisition of digital processes. But they have been developed to fit the need of analysts, dealing with classic, analogue processes. It is not surprising, that the information flow and the involved systems do not receive special attention. Respectively the effort for a detailed modelling of the information is often no longer economical. With this lack of information in the final model, an evaluation of the process with respect to the applicability and potential enhancements through the use of data-driven methods is hardly possible. Additionally, there is no model known, dealing explicitly with the characteristics of the design process. Therefore, there is a need for adapted procedures, enabling the holistic capturing and further evaluation of digital processes.

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3 EXTENSION OF THE METHODS TO FIT THE DESIGN-PROCESS NEEDS

To compensate for the weaknesses of existing methods, we propose an adapted method for holistic design process capturing. In detail, we have developed a method, to gather classical process aspects combined with elements that have only become relevant in the recent past. Examples for those aspects are used programms and (self developed) tools, file-formats and storage locations. Underlying goal is to obtain a process model, enabling the optimization of processes with data-driven methods. Therefore a model is required, wich has a low abstraction level. Furthermore, with the procedure we want to enable an economic process capturing, which is crucial for small and medium-sized companies in particular.

3.1 Requirements for the new method

To obtain an adequate procedure, some requirements have to be met. The following list is a combination of the results of the literature analysis and identification of weak points found in current methods in section 2.3, the state of the art principles of process modelling (Becker, 2012) and an internal workshop with subsequent industrial feedback. The following requirements are identified:

- the method has to be economic (Becker, 2012). Hence it has to be easy to understand and to use.
- reality must be accurately reflected (Becker, 2012).
- different capturings must be comparable (Becker, 2012).
- automated analysis of the results is possible.
- existing knowledge, necessary data as well as their location is captured (Mehlstäubl et al., 2020).
- characteristics of design processes are considered.

3.2 Relevant Aspects

Established methods focus on aspects like roles, task-chains, schedule, connections and results (Best and Weth, 2009). Mehlstäubl et al. (2020) developed a metamodel for data and information flows, considering digital aspects in the process acquisition. They additionally captured storage location and product-related documents. Since knowledge is key (Wickel et al., 2013), consideration of knowledge is also close at hand. Based on the literature analysis, the following list of aspects should be used, to describe a digital process on an level, which enables the identification of potentials for the use of digital methods. The complete list was subjected to an initial evaluation with industrial feedback. The aspects are summarized in Figure 2 and are explained below.

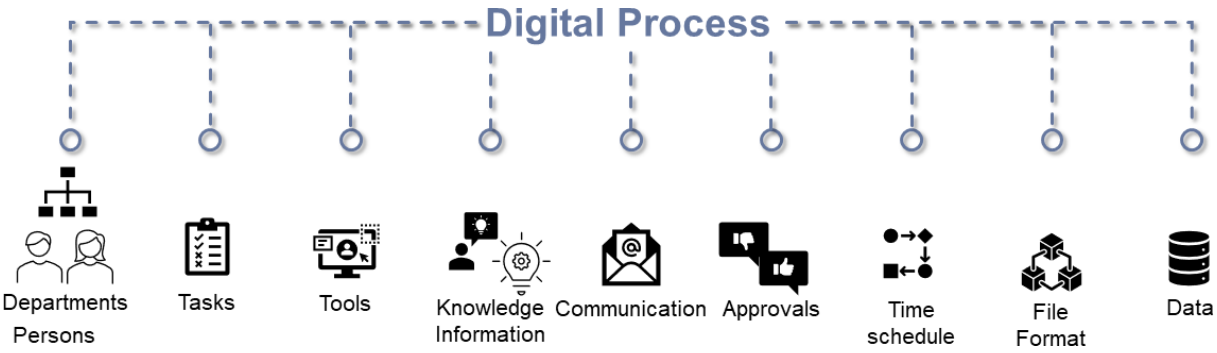

Figure 2. Overview of relevant aspects in the capturing of digital processes.

Departments and persons: Very few processes run completely digital and automated. The involved people from the relevant departments are interviewed as part of the capturing process. In addition, the responsibilities behind interfaces are defined.
Tasks: Core aspect of every process are the tasks, fulfilled to reach the overall process goal. Those tasks should be collected almost on workflow level.
Schedule: Since not all tasks can be executed at the same time, there is some kind of schedule. The Evaluation of this schedule may open additional optimization potential.
Tools: Digital processes have to rely on different tools. In addition to conventional tools such as CAD or simulation solutions, self-developed tools are also included here.
File format: Almost every tool uses its own file format. File conversion usually involves loss of information and should be kept to a minimum.

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Communication: Communication channels between process participants should be recorded. These can range from verbal agreements and printed documents to e-mail or SAP-based communication.
Decisions and Approval: To identify bottlenecks and iterations, a detailed capturing of decision breakpoints and necessary approvals is mandatory.
Knowledge, information and data: In order to distinguish between the different types of data, we use the following distinction. Knowledge is the kind of data, which can be assigned to explicit knowledge, e.g. simulation rules or books. Information is context-related implicit knowledge of the editor or colleagues. In addition, short messages in the sense of "the component withstands the load" are counted as information. Data should be all kinds of process outputs and all files, changed during the process. Examples are CAD-Files or calculation reports. For all three aspects the origin (e.g. department xy) or destination (e.g. archive on server xy) are particularly relevant.

3.3 Procedure

The presented method was developed using a literature-based research approach. For this purpose, an intensive literature analysis on established process capturing methods was performed. Subsequently, previous capturing approaches were examined in respect to their strengths and weaknesses. Based on our findings, a three-piled approach as visualized in figure 3 was developed, to obtain complete process acquisition. The method is based on employee-view, data-view and management view.

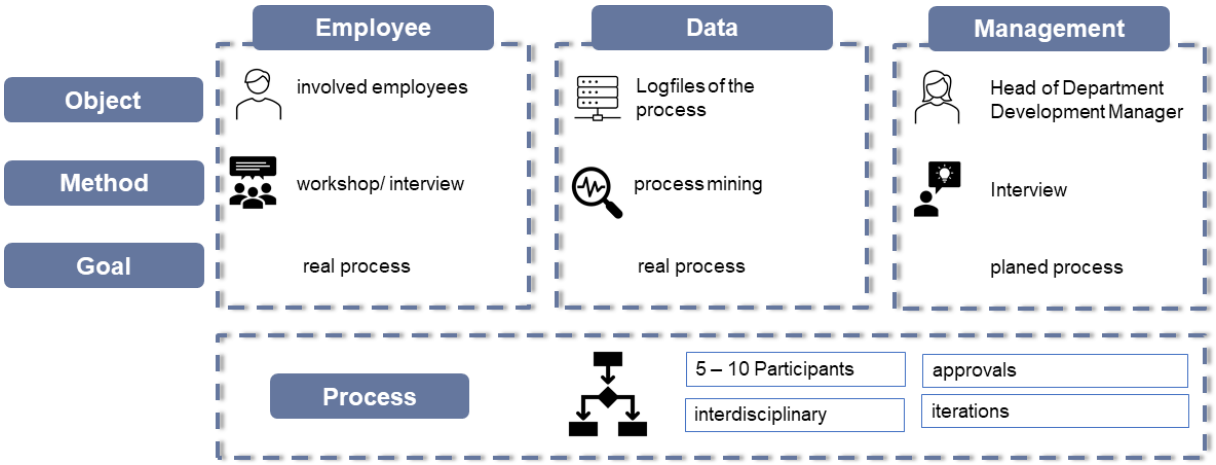

Figure 3. Method for design-process capturing.

The presented procedure is an extension of existing process-analyse methods, to fit the characteristics of design processes. Although we use three different approaches to capture the whole process, there is a uniform procedure for preparation and follow-up. The whole procedure will be discussed in the following section. With the three piled approach, we expect to be able to mitigate the problems mentioned by Dumas et al. (2018). The problem of distributed process knowledge is addressed by the different views itself. In the management view, an overall process picture is generated and relevant roles and employees identified. The data view provides additional support if there is a central data management system in which the digital process knowledge is collected. The second problem mentioned by Dumas et al. (2018) the specialist case thinking is circumvented by deliberately including different cases and variants of the process, as this can lead to further optimization potential.

3.3.1 Preparation

During the preparation, the initial situation is detected and the goal of the process capturing are defined. The goals should be aligned with the corporate goals. With a general process map the relevant process can be classified in the company context. If no process map exists, it can be generated in this step. Furthermore, the process map is used to delimit the relevant process against neighbouring ones. Additionally a first rough as-is capturing is done. This ensures, that the interviewer already has an overview of the process, before the detailed process capturing starts. Furthermore, he is able to prepare the acquisition in the best possible way and to consider all relevant aspects. A capture of the product development

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process, focused on the use of digital methods, should be done on the level of detail-process or workflow, since only at this level relevant aspects like data can be acquired. The identification of relevant organizational units and appropriate experts is done and the available data is analysed in respect to the use of data-mining.

3.3.2 Pillar 1 - employee view

Central aspect of our process acquisition method is the view of the employees involved in the process. This should be the aspect, to focus at the beginning of each project, since those specialists know the process best.

To capture the employee view, we suggest the use of a semi-structured interview. We decided, not to use a workshop format, since the design process is highly specialist-driven. Therefore tasks and interfaces between departments should be clearly defined. Additionally employees cannot be influenced by the opinions of other participants and can clearly name potential optimization potentials and problems. For the purpose of documentation, the whole interview should be audio-recorded. Interview participants should be familiar with the whole process and have a rough overview of previous and subsequent activities in order to place their area of responsibilities in the overall context. They should have some experience in the position to know about process variants, that do not occur regularly.

The interview is done in a systematic but semi-structured way. This option is suitable to support the interviewer in the course of the interview. At the same time, the semi-structured option is formulated abstract enough, to to be used in the different specialist areas involved in the design process. In a short introduction, the interviewer explains the background and goal of the interview. Afterwards, the explanation by the employee starts. First part should be the clarification of the pre-process, to identify necessary prerequisites to start the work. The next interview step, is the capturing of the core process. In this important part, the interviewer must ensure, to capture all relevant aspects, therefore they should be mentioned in his guidelines. After the coverage of the core-process, the employee explain post process tasks. This can include archiving or communication of results and the next responsible persons. An optional personal evaluation of the process ends the interview. In parallel, the interviewer or a second person documents the results graphically. To visualize the captured process, established Methods like Busines Process Modeling Language (BPML) can be used. A method to visualize all aspects, including data and information flows, is currently under development.

3.3.3 Pillar 2 - data view

To reduce errors, which can arise from personal descriptions, the use of process-mining is planed. Thereby the process is captured in data-view. Existing data mining algorithms can be used, to extract process informations from data logs (see section 2.2 for more details). Result of the mining process is a graph including time and user informations.

The data view is captured with established process-mining algorithms. As stated before, those algorithms analyse logfiles to extract single process steps and combining them to a whole process view. This is the aspect where feasibility cannot always be guaranteed. Especially small and medium-sized companies may not meet the requirements, to make process mining even possible. Central prerequisite is a data management tool like a CRM- or ERP-Software, documenting all tasks in logfiles.

3.3.4 Pillar 3 - management view

The last, but not less important, pillar of our method is the management view on the process. The goal is to acquire the planed procedure. Or, in other words, the way the manager thinks, the process works. The used Method is an interview and the same guide as for the employee survey is used. Big advantage in the acquisition of the management view is the option to compare management and employee view to identify optimization potentials. The manager may have a different idea of how certain sub-processes are or how much time is needed for them.

The management view is captured in the same way as the employee view. The interview guideline is abstract enough to fit for the management and the employees. For a detailed description of the method, see chapter 3.3.2. To ensure a purposefully capture process, the interviewed manager should be technically close enough to the process, to avoid that the acquisition is too granular. Therefore the CEO would be the wrong partner in most of the companies. We recommend, asking the team-leader or head of development for a talk.

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3.3.5 Follow-Up

After the process acquisition, the verbal, analogue and digital results of the three captures are evaluated and transferred to a common process model. Contradictions or ambiguities may arise from this merge. In such cases, the study director should consult the participants, to obtain a coherent and correct overall picture. In the last step, a workshop with all interviewed employees and managers is conducted to verify the process flow. In this interview, the supervisor gives a short introduction to the used notation and the overall process in the company context. After that, the captured process is presented and discussed with all parties involved. This gives everyone another opportunity to intervene in case of errors. An optional feedback and optimization input for the study leader ends the workshop.

4 APPLICATION AND PRELIMINARY EVALUATION

To give an insight into the practical application of the method, we analyse the process of a shaft construction and FEM-evaluation by two different employees. The interview with the design engineer is explained as an example.

Preparation: In a first step, the interviewer performs an overview analysis together with the department manager to define the goal of the capturing and definition of process boundaries. In our case, the goal is the evaluation of bottlenecks. The starting point is the begin of computer-aided-design and the approval of the evaluated shaft by the manager is the ending point. Additionally the manager identifies relevant employees. In this short example, this first interview requires 20 minutes and can be done remote or face to face. The interviewer prepares his guidelines and double-checks, if relevant aspects remain unconsidered and must be added. Of course aspects of data protection and confidentiality must be clarified before the first interviews.

Employee View: After the interviewer created the interview guide, he interviews both participants separately. The two interviews, both take about 1 hour and and were conducted online via videoconference. During the interview, the interview leader orientates on the prepared guidelines, which he should have with him in printed form. Additionally, he repeatedly reminds the interviewee to maintain the right level of detail. To ensure the caption of all relevant aspects, the guideline contains the relevant aspects on all pages. The interviewer must repeatedly draw attention to the fact, that the report must follow reality and not represent wishful thinking. Since the CAD engineer performs the first tasks, he is the first interview partner. Following the guidelines, the pre-process is captured first. The interview leader asks about initial events, previous departments and needed information. For all aspects, the interviewee lists, the interviewer asks where he gets them from. Mentioned prerequisites are a list of requirements containing loads, the available space and the type of the needed part. All informations are made available as PDF by mail. The initial event is triggered by the manager via E-Mail. In the core process, the interviewer repeatedly asks about needed data, information and knowledge, to ensure the acquisition of those important aspects. The engineer needs about 30 minutes to analyse the given requirements. Afterwards a first CAD-model is created in 30 minutes. He uses information from a colleague with experience in applying undercuts and knowledge from a list of tables, saved locally on his computer, to estimate the initial dimensions. The final model is saved on a network resource and send to the simulation engineer via E-Mail in STEP-Format. Now the interviewer asks about feedback from the simulation engineer. The interviewee mentions, he is getting feedback by a call with the information, if the evaluation was successful. The evaluation fails in 30 % of cases and he has to revise the model, which takes about one hour. After that, the evaluation is triggered again. In the post process acquisition, the interviewer asks about subsequent activities. Especially important are the storage locations of generated data and subsequent departments.

Data View: Since no central data management is available, process mining cannot be used.

Management View: The interview with the manager is done under the same circumstances as the employee interviews. In this case, the manager reports the process on a more abstract level as the employees, but no significant differences occur.

Follow-Up: After all interviews have been conducted, the interviewer generates a complete process model. This model is discussed in a workshop with the three participants. In the workshop, the process is verified by going through the captured model step by step and solving potential errors.

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To verify the relevance of the presented approach and to identify further optimization potential, a preliminary evaluation with respect to the requirements is done.

The Method is easy to understand and use: For the interview part of the method, this requirement is fully met. Interviews are understandable and easy applicable for everybody. The guidelines contain the basic procedure and serve as a framework and reminder, also for less experienced study directors. During the initial interviews, it became apparent that the assistance of a second interviewer would be helpful to document the process graphically. The process mining is a little bit trickier to establish. Here some prerequisites are crucial and the usage is not guaranteed in all companies. Furthermore, a certain amount of experience with the methodology is necessary, to be able to apply it successfully. Nevertheless the overall process meets the goal. The overlaying goal of an economic process analysis needs further evaluation in industrial application.

Characteristics of design processes are considered: The standards of the procedure are formulated as abstract as possible to enable the acquisition of unique processes with not well defined goals or outputs. The interviewer has to ensure, that the recorded process depicts the basic process and not just a particular special case. A strong involvement of the participants at the end of the process ensures the transparency and clarity of the result. To fully verify this aspect, a detailed industrial evaluation is necessary.

Further Analysis and Optimization is possible: With established process modelling tools like BPMN, not all relavant aspects can be fully captured. Therefore, the development of an adapted representation seems necessary. Optimally, the process is modelled in a computer readable format, allowing an automated analysis.

Collection of all relevant aspects is done: The combination of interviews at different hierarchy levels and process mining can collect all relevant aspects. Basic documentation is possible but not all aspects are supported out of the box (see previous evaluation aspect). Even though process mining is not applicable, the interview can gather the necessary informations.

The result reflect the reality: Provided the interviewed employees report on the real situation and not on wishful thinking, the real process is captured. Data mining always captures reality.

5 CONCLUSION AND FUTURE WORK

It is absolutely essential that processes also adapt to changing conditions, thus enabling a digital revolution in the product development process and making true "*Design in Motion*" possible. The first step of such a change consists in the complete and detailed acquisition of the status quo. From this snapshot of reality, potential use cases for optimization with data-driven methods then can be derived. The simple example presented in section 4 already shows potential. The time to collect information is as big as the construction. This point could therefore be a starting point.

In this contribution, requirements for a process capturing methods are defined, based on characteristics of design processes and established methods. Following the requirements, we introduced our method to enable holistic process acquisition. A first evaluation has shown great potentials for the method as well as some optimization opportunities. First of all, the development of an adapted visualization method seems necessary to document all aspects. The combination of BPML and the value stream method proposed by Lewin et. al. (2019) shows potential and will be pursued in the future. Additionally a detailed evaluation of the whole method is necessary to ensure the capturing of all relevant aspects. Furthermore the method has to be evaluated in respect to the goals length of recoding and level of detail. Those two aspects represent a conflict of objectives but both are a prerequisite for practicality. We are planning to evaluate the entire method together with industrial partners. Unfortunately, due to restrictions caused by the COVID-19 pandemic, the evaluation in an industrial context could not be carried out so far. Lastly we will focus on analysing the captured processes. Relevant analysis aspects are the automated recognition of bottlenecks and problems in die process as well as the identification of data-driven methods to lower the influence of those issues.

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