CONTEXT-SPECIFIC PROCESS DESIGN: AN INTEGRATED PROCESS LIFECYCLE MODEL AND SITUATIONS FOR CONTEXT FACTOR USE

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Abstract

The development of complex systems such as e.g. Product-Service Systems relies on complex processes. Corresponding design contexts are often complex and evolving over time, with factors such as e.g. organizational structures, location, product type, impacting the development process. Companies rely on process models for a number of purposes. However, process models used within companies are often „flat" and the context the process models are used in is often inadequately acquired and considered during modelling. This becomes evident, e.g. when process models are used as a basis for tailoring project-specific processes. In this paper, we first present a literature-based integrated lifecycle model for product development processes and models thereof. From it we derive situations (application cases), in which identified context factors can be used to improve activities such as reference process modelling, process model use, process analysis, and process evolution. The situations have been partially validated in industrial case studies and serve as the foundation to further develop methodological support to increase context awareness in product development process modelling and management.

Keywords: Design process, Design management, Process modelling, Context-specific process design

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1 INTRODUCTION AND MOTIVATION

The development of innovative solutions to customer's problems puts a lot of pressure on companies, when combined with issues of cost, time and resource constraints. The endeavour of developing increasingly complex offerings commonly spans multiple disciplines, such as in mechatronic or Product-Service System design. This results in equal or larger complexity regarding the processes relied upon to develop these offerings. Furthermore, the contexts ("interrelated conditions in which something exists or occurs" (Merriam-Webster, 2016)) in which modern companies operate are equally complex, as well as changing over time. One such example we investigated is a supplier of locking mechanisms for large home appliances, who has recently also become an original equipment manufacturer in the areas of building equipment and environmental technology. Moreover, the company is planning to relocate some of its development activities closer to their customer markets, e.g. in Asia and North America. Such changes in context result in new requirement profiles regarding the underlying product development processes (PDP), potentially causing larger changes in process descriptions than just minor revisions and updates. While companies rely on models of their processes for purposes such as visualizing, planning, executing and developing PD projects (Browning et al., 2006), disregarding the processes application context and changes therein can cause problems related to these purposes, e.g. when it is unclear to model users which context the model was originally designed for or when processes are used for contexts they were originally not intended for. Currently, little context orientation is found within process design in industry, as well as in research (Gericke et al., 2013).
Processes are generally defined as virtual objects (sets of activities and objects such as methods, artefacts, and roles) with the objective of solving a specific task. Thus the focused processes differ in their properties from regular business processes (Vajna, 2005). Within the scope of this paper, the focus lies on PDPs and their constituent sub-processes as knowledge-intensive processes.
In this paper, we address the design and modelling of PDPs in complex contexts and the resulting variance in process models. In our ongoing research, we investigate how context data in the form of individual, decomposed context factors can be used as an additional source of knowledge in process design and modelling, besides traditional methods for process acquisition and design, such as SIPOC diagrams, flowcharts etc. The overall goal is to develop a methodology and supporting methods to enable process designers to systematically consider a PDPs application context during its design and modelling. In order to achieve this, in this paper we first shortly present a process lifecycle model to serve as a frame of reference. Based on this we investigate, what process management activities along this lifecycle exist which can be supported in order to design more context-specific processes. From that we derive application cases for the use of context factors as additional knowledge to support modelling and managing flexible and adaptable PDPs. These application factors represent starting points for further research.

2 RESEARCH METHODOLOGY

As the general framework in order to achieve the objective stated above, the Design Research Methodology (DRM) as proposed by Blessing and Chakrabarti (2009) is used. Earlier work in our ongoing research includes a literature review regarding the identification, structuring and modelling of context factors of PDPs. This has been done in order to identify generic influencing factors as well as existing approaches, e.g. in the field of process tailoring (Hollauer and Lindemann, 2017). Concerning process modelling, current approaches have already been reviewed in literature (e.g. Browning, 2014; Amigo et al., 2013). The literature research has been accompanied by seven industrial case studies at this point. These case studies have been performed in order to identify issues related to the design of variant-rich processes in complex contexts, to support the derivation of application cases for the use of context factors and their added value in process design and modelling, as well as in order to repeatedly apply, test, and improve our solution support (prescriptive study) (Sections 3.3 and 5).
The focus of this paper therefore lies on the elicitation and presentation of application cases for context information, derived from these studies. In order to structure these application cases, we have derived a process lifecycle model as a frame of reference. With this work, we intend to demonstrate the benefits that can be realised by the analysis of application contexts of PDPs.

3 BACKGROUND AND RELATED WORK

For a better understanding of the following sections, the most relevant terms, existing issues and identified research gaps are explained briefly.

3.1 Product development processes

As stated before, this paper focusses on PDPs and constituent sub processes. Such processes are knowledge-intensive, complex, dynamic and have iterations and jumps. They are lacking of predictability, are affected by the product subject to development, and have an overall high variability (Vajna, 2005; Gericke et al., 2013; Kreimeyer, 2010). Within the scope of this paper, different levels of PDP models with increasing concretization are differentiated (Figure 1), ranging from generic design methodologies from literature to company-specific adapted reference processes, tailored project plans, and the actual process that is performed within these projects. Due to the fact that processes are virtual objects, the management of processes relies heavily on process models (Vajna, 2005). Due to the issues presented above, modelling product development processes is challenging and the resulting models are a simplified representation of these processes (Gericke et al., 2016).

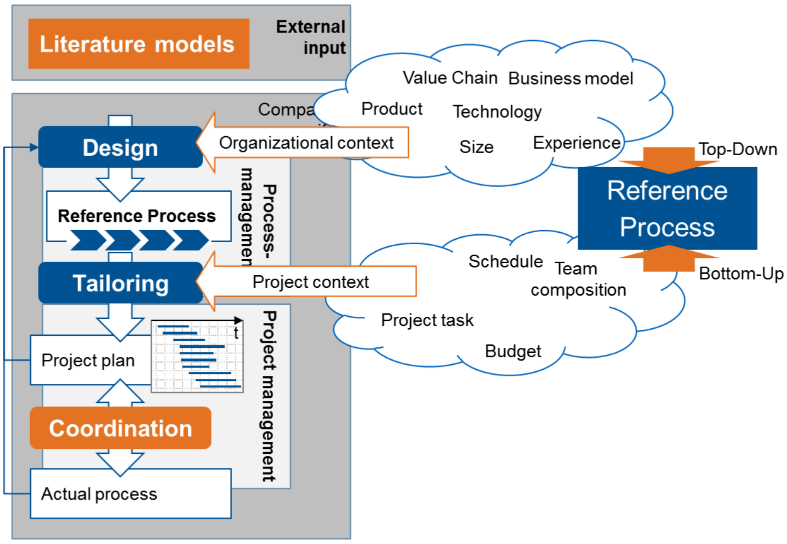

Figure 1. Process levels and context influence

3.2 Context factors and process variability modelling

In order to successfully concretize and adapt PDPs over the levels presented in Figure 1, the context of a company as well as its specific projects needs to be taken into account (Gericke et al., 2013). Contexts can be decomposed into individual context factors with corresponding values (e.g. "development location" may have multiple and differing values such as "Germany", "USA", or "China".) that have influence over the design of PDPs. So far, different schemes for organizing context factors have been proposed (e.g. Langer and Lindemann, 2009). The literature provides a plethora of checklists of context factors, some of which also give generic advice on how they affect the PDP (Kalus and Kuhrmann, 2013; Gericke et al., 2013; Ulrich and Eppinger, 2004). These lists are generally meant to give an overview over context factors to provide a starting point for the analysis of specific product development contexts (Gericke et al., 2013).

Examples for generic context factors and their values are: the type of the design task (adaption, new development), the scope of the design task (entire product, module or single component), the type of product (e.g. simple/complex), the organizational structure, the local distribution of development teams, the knowledge (high/low) of a development team regarding tools, domain, and technology, as well as size and turnover of a team. As such, context factors can be clustered in hard (bound to an artefact or object in reality such as the local distribution) and soft factors, which are harder to elicit and describe.

Further related work regarding approaches for context analysis and modelling can be found in the area of software and business process engineering, often related to the topic of tailoring project-specific processes (e.g. Hollauer and Lindemann, 2017).

A field closely associated with context-specific process design is the topic of variability modelling (e.g. Milani et al., 2016). In order to represent system variability caused by contextual factors and differing values, concepts such as the Common Variability Language or feature models have been proposed, mainly in the area of software engineering as well as business process management (e.g. Ayora et al., 2012; Thörn and Sandkuhl, 2009). Variability modelling originates from the concept of "domain engineering" in software design, which is concerned with the reuse of software knowledge and components by analysing of the intended application domain (Reinhartz-Berger et al., 2013).

3.3 Identified issues and research gaps

In literature, only few contributions have been made over the recent years addressing context-dependent adaptation of design methodologies and processes (Gericke et al., 2013).

We have conducted a number of descriptive studies in industrial environments, investigating the context-orientation, context variability (i.e. diversity of process application context) and the resulting as well as necessary variance of the investigated processes. In a first interview study with ten companies, we found that tailoring is a time-consuming activity that, in most cases (eight companies), is unsupported by a tailoring methodology or framework. Instead, the activity relies only on the experience and tacit knowledge of project leaders.

Another issue we found in practice is the context-agnostic treatment of PDP models, concerning their design and use ("One-fits-all"). PDPs are generally defined as abstract and generic models applied to different organizational (e.g. different engineering departments) and project contexts (e.g. different design tasks), causing problems during tailoring and application, especially with inexperienced project managers. During the observation of a workshop tasked with defining a new PDP, issues regarding the adaption of the process to different project contexts arose (in this case caused by different steps that need to be taken to ramp up production, depending on the lot size to be produced). This knowledge was eventually lost in the resulting abstract PDP model. This issue is corroborated by a case study in which we investigated a process standardization initiative within a department of an automotive company (Case study B, Figure 3). The case study showed that the applied PDP has justified differences within individual sub-departments and hence could not be easily standardized. Instead, the reasons for the differences had to be investigated in order to aid a targeted standardization by understanding the causes for differentiation. The identified variability drivers can be further investigated in order to either resolve them or develop sub-department-specific process variants (e.g. via an abstract process and instantiation rules, or individual process model variants).

Evidence points to the fact that a lot of knowledge regarding complex application contexts of the designed PDPs, as well as the contextually required adaptation, is lost during process modelling or due to standardization and abstraction. However, this knowledge is necessary during later stages of the process lifecycle, e.g. during the selection, application and tailoring of reference models. Hence, there is a need to integrate a more comprehensive context perspective into design and modelling of PDPs. For this, process designers need to gain and document richer and more structured information about the contexts that processes are developed for in order to design realistic, usable and adaptable process models with the right level of abstraction.

In other domains, approaches have been identified in order to support an increased context perspective as well as modelling variability in processes (Section 3.2). However, while the need for these approaches has been established, such approaches need yet to be transferred into the domain of PDP modelling and management. In order to support the selection and adaptation of approaches, we have derived situations in which the use of identified context factors is beneficial.

4 PROCESS LIFECYCLE MODEL

In order to support the identification of application cases for the use of context factors we have first developed a comprehensive product development process lifecycle model to serve as a conceptual framework. The lifecycle model (Figure 2) is based on a literature review, for which sources are listed in Table 1. The models presented in these sources in turn have also largely been based on literature reviews within their domains.

The literature review showed that a large number of process lifecycle models are established in business process management (BPM), neglecting the fact that engineering design work is done in the form of projects. The rest of the investigated models is rooted in software engineering. Furthermore, the process lifecycles offer a perspective on either the "real" process, or the models thereof. The investigated lifecycle models are generally on a rather abstract level. The consolidated process lifecycle model is shown in Figure 2. To further detail the process modelling aspects within the lifecycle model, we have used insights from structural modelling (Kasperek et al., 2015).

Table 1. Sources for the developed process lifecycle model

Source	Name of the process lifecycle model	Domain
(Gericke *et al.*, 2016)	Process model lifecycle	PD
(van der Aalst *et al.*, 2008; Schramm *et al.*, 2014)	Business process management lifecycle	BPM
(Balzert *et al.*, 2011)	Generic process lifecycles with three and four phases	BPM
(Schramm *et al.*, 2014)	Process model lifecycle with structural and activity view	Software development
(Fink, 2003; based on Meyer, 1999)	Process lifecycle model, with specific subcycles, such as "observation cycle", "design cycle" etc.	BPM
(Scacchi and Mi, 1997)	Process engineering lifecycle, textual description	BPM
(Lohrmann, 2015)	Business process lifecycle in two stages: "design & implementation", "enactment"	BPM
(Kuhrmann, 2008)	Lifecycle aspects focussing on maintenance of process models	Software development

In order to keep the model understandable, jumps and possible iterations have been omitted but are of course possible (e.g. from "Model validation" to "Derivation of modelling need"). The model describes the overall lifecycle of PDP models and how they are connected to the real processes in industry, on organizational and project level. The model contains overarching phases, from the initial analysis via modelling preparation in terms of data acquisition and analysis, the actual process modelling, process implementation, process use, analysis of process use, and continued process evolution and improvement. Per phase, individual activities as well as final results have been detailed. With this model, on the one hand we intend to consolidate aspects of real processes and process models, on the other hand we expand upon the existing process modelling perspective by integrating context-related activities for acquisition, analysis and use of context data in relation to process modelling (Section 5).

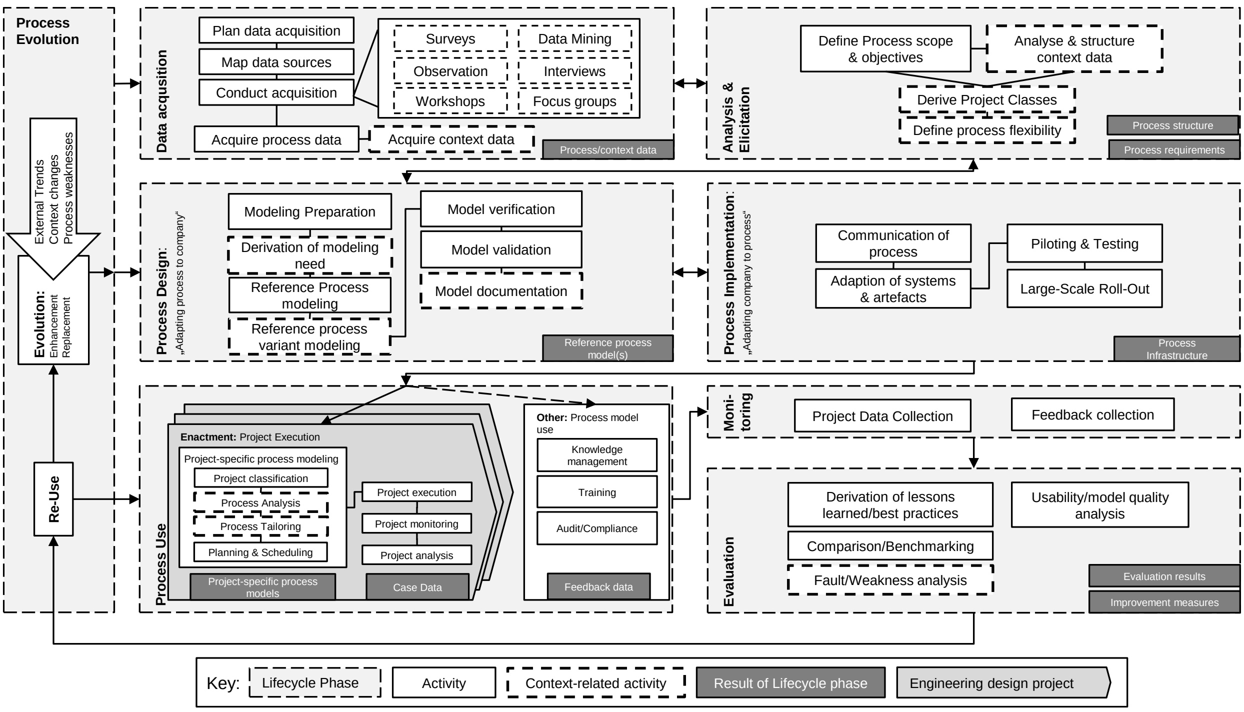

Figure 2. Process lifecycle model: Phases, activities, and results. Context-related activities are highlighted

5 SITUATIONS BENEFITTING FROM THE USE OF CONTEXT FACTORS

Based on the previously shown process lifecycle model, activities have been identified where the consideration of context factors can be beneficial in order to support PDP design, modelling and model application. In this section, the individual application cases are detailed. Figure 3 gives an overview over the identified application cases, structured according to overarching process lifecycle phases and correlated to the case studies where they have been identified and investigated. In these case studies, first descriptive knowledge is gained by analysing the identified application case before concrete approaches are developed to support the application case in an industrial context.

			Lifecycle Phases	Reference process modeling (5.1)				Process model use (5.2)		Process analysis (5.3)			Process evolution (5.4)		
Company description	Case Study Objective	Case Study ID	**Application cases**	Derive context-specific process requirements and design measures	Capture process design rationale	Structure necessary process variants	Support targeted process standardization (base process and adaption blocks)	Derive project-specific design processes	Derive adaptation rules	structure lessons learned and best practices according to context	Analyse transferability and context-dependency of best practices	Context-specific process analysis (weakness analysis)	Monitoring and strategic analysis of context factors to trigger evolution	Re-evaluate existing process models	Process roadmapping
Supplier of automotive engine components (Company A)	Comparison of two PDP contexts within the company using a catalog of context factors. Workshop-based derivation of design measures to improve a newly designed process based on the comparison.	A		■	■		■						■	■	■
Automotive OEM (Company B)	Context analysis of different organizational units in order to identify justified differences between PDP variants. Identify potential and barriers for process standardization between the investigated units.	B				■	■			■	■				
Automotive OEM (Company C)	Modularization of a subprocess of the PDP in regard to its application context. Create a concept for a process configurator to aid in future project planning.	C				■		■	■						
Automotive OEM (Company B)	Analysis of a reocurring sub-process within the PDP for its different context values and define necessary process variants. Weakness analysis of the process and usage of context values to characterize the occurrence of weaknesses.	D		■		■		■	■			■	■		■
Automotive OEM (Company C)	Identification of context factors and values in order to aid in tailoring a subprocess of a PDP.	E				■		■	■						
Automotive OEM (Company D)	Identification of high-level context factors and their impact on the PDP based on workshops and analysis of historical project data.	F				■		■	■						
Plant engineering supplier	Analysis of the PDP and it application context focussing on mapping of the process variant space in order to derive process modules. Derivation of major project classes/process variants and development of a configurator to configure project-specific processes.	G				■		■	■						

Figure 3. Identified application cases for context data use in PDP modelling and corresponding case studies

5.1 Reference process modelling

5.1.1 Process requirements, design measures and process design rationale

From literature, abstract strategies can be derived, based on the identified context factors and values for an organization. These represent starting points for process designers. For example, generic product-related strategies for process adaption can be found in Ulrich and Eppinger (2004). We have consolidated such strategies in a PDP design catalogue, structured by generic context factors. However, such general strategies can only give limited support and need to be evaluated and further detailed on an individual basis. Depending on the contextual diversity within an organization, different process strategies and design measures might be necessary, e.g. for different product lines, locations or when catering to different customers/markets, resulting in process variants (Section 5.1.2). Context transparency can support this step of reference process design by capturing the process design rationale in response to different contexts. Over time, a company-specific knowledge base of process strategies in different contexts can be cultivated. This would give individuals a richer understanding of the applied processes and justified differences that might occur, e.g. when transferring between different contexts. It would further support a periodic reflection of the process, preventing attempted reinvention of the process due to an increased traceability of the underlying causes for process design.

5.1.2 Structuring context and process variant space

As mentioned in 5.1.1, context factors can be used to structure the required "process variant space" of a company, i.e. required base processes and context-specific variants. In this case, context factors can be used like the concept of "features" in product variant management (Section 3.2). Methods from this field can be investigated in order to support the modelling of relationships between context factors (such as feature modelling). Context values may for example be mutually exclusive or depend on each other (e.g. the head development office is always involved in development projects, but only one other international location).

For a selected process (e.g. new product development, redesign, or variant development), context-induced variants of that process can then be defined, which include variant-specific aspects e.g. processes for specific products within the portfolio, catering to a specific customer, or including a specific development site. Based on a systematic context analysis, a reference base process and corresponding building blocks for process adaption can be defined.

However, each new process variant needs to be carefully evaluated in order to justify its existence and the associated effort of modelling and managing it. This issue is not within the scope of this work, but there is existing work addressing issues of managing process variants (Hallerbach, 2010).

5.1.3 Supporting targeted process standardization

Standardization of processes is an activity which is necessary in order to generate widely applicable reference processes in organizations and often required for process audits (e.g. in regard to ISO9000 or CMMI). However, the resulting processes - while technically always correct - often do not reflect the actual processes and activities performed. Thus, knowledge of the relevant contexts can support a targeted process standardization by identifying standardization barriers and potentials (Section 3.3).

5.2 Reference process model use: Adaptation rules and process tailoring

A further step for context-specific process concretization is the tailoring of reference process models to specific project conditions. This application case addresses the issue of knowledge loss during the act of modelling reference processes. As we have observed in a process modelling workshop (Hollauer et al., 2016), participants often show great individual knowledge regarding the necessary adaption of a reference process model during its instantiation into a project-specific process. However, in most cases, such knowledge is eventually not represented in the final, "flat" process model and thus lost to other model stakeholders. In the example, an engineer mentioned that depending on the planned lot size of the product in development, the later stages in the design process, such as prototyping and ramp-up would differ significantly. Such knowledge could be documented in a rule-based format during process modelling.

We are currently investigating this application case in further case studies (Figure 3). The objective is to support the externalization of knowledge from project stakeholders relevant to process tailoring related to context factors such as the product variants to be developed.

5.3 Supporting process analysis and best practice management

As described in Sections 5.1 and 5.1.2, processes often have to address different contexts. Hence closely associated with variant-rich processes is the analysis of variant-specific process weaknesses and the derivation of corresponding process improvements. The integration of new elements such as methods or partial processes can be supported through knowledge of the respective process contexts, as to where the respective changes should be implemented. Thus, root causes of weaknesses in the investigated process can be better characterized and improvement measures can be introduced more targeted.

We are currently investigating the support of process analysis by contextualization by analysing the release process for product configurations within a large manufacturing company (case study D). The process currently does not produce the desired outcome regarding the quality of results, triggering an investigation by the company in question. In this case, different units working on different aspects of the product feed data into the release process, which also has to be executed at different stages of the design process. These are only two selected aspects that contribute to the complex environment of the release process, complicating the investigation into the causes of the quality issues. The objective in this case is to describe the possible context configurations of the release process and use the resulting descriptions in order to structure the possible process variant space and support the weakness analysis

(e.g. conducted as a design process FMEA similar to Chao and Ishii (2007)) by characterizing the identified weaknesses and enabling the targeted implementation of improvements.
A complementary aspect which is relevant regarding the use of process models, is the transferability of best practices and lessons learned between different contexts. Analogous to the weakness analysis, best practices may only work in a certain context and only have limited transferability into other contexts since they may depend on the value of a certain context factor.

5.4 Process evolution

Once context factors and their respective values have been identified, they can be monitored over time for their cyclicality in order to detect changes early on (Section 1) and enable process managers to respond early and plan accordingly. Based on the temporal characteristics of individual context factors such as trends, impacts in the form of new requirements for future, to be planned processes and variants thereof can be derived. For example, when new product variants or new technologies are introduced and the product portfolio grows while other, legacy products are discontinued (e.g. by introducing electro mobility, a number of new test routines and activities will become necessary). new development sites established, etc. In order to manage these temporal dependencies and support strategic process planning, road mapping approaches can be used (which are currently more commonly used to synchronize technology with product planning e.g. Phaal et al. (2004)).

6 EVALUATION & DISCUSSION

The presented process lifecycle model is rooted in literature. It is not the intention of this paper to present an extensive literature review on this topic. It serves as a frame of reference in order to identify and classify application cases for context data to support and improve modelling and use of PDPs.
By identifying relevant application cases and validating them in industrial case studies, we have illustrated the importance of a context perspective for supporting process modelling in product development. This also provides starting points for the selection, transfer and development of specific approaches. We showed that adaptation and tailoring of processes is a continuous activity over multiple steps and hierarchical levels in order to eventually reach fully tailored project processes. The depth of the levels for adaption is determined by the complexity of contexts found within a specific organization as well as the complexity of the process in question.
The concluded case studies so far (A-D) yielded positive results regarding the implementation of the application cases. For example, in case study B, the context analysis has led to additional insights as to where standardization is constrained and why variance in processes existed (e.g. due to different amounts of outsourcing of tasks to suppliers, caused by different product variants developed within the individual sub-departments). It also led to further insights into project risks associated with context factors and generated ideas on how to further integrate the context perspective into project management. This shows great potential for the integration of context-related methods and activities into regular process management tasks. Issues associated with the approach in case study B have been identified during the initial identification of context factors and concerning the further analysis of context factors. Using cause-and-effect chains proved to be difficult because the associated effort was high, and causes and effects could not always be clearly connected. Furthermore, the correct definition of the scope for the context analysis is important in order to reach a manageable level of complexity regarding the analysis. These identified issues are input for further work. In case study C, the investigated process has been successfully modularized and a concept for a process configurator has been developed, although not yet implemented in software. The project managers involved were very confident about its applicability and the context perspective helped them to decompose a process that was first described as "very complex". Feedback indicated that the investigated department intends to use the methodology to extend process modularization to further processes.
Based on the results presented in this paper, we have defined a domain engineering-based methodology with which modular processes ("process building kits") can be designed, using the analysis of a processes application context as a starting point. In order to enable a clearer description of contexts, a modelling approach is necessary with which the necessary aspects, such as interdependencies of context factors can be described using dependency modelling (e.g. using relationship types such as "mutual exclusivity"). Such an approach is currently being developed.

To summarize, by supporting context orientation in process modelling in practice, the following benefits can be expected over the lifecycle of process models:

- Support for process designers in regard to what processes and process variants are needed, and what the corresponding process models need to include. This enables a more goal-oriented and focused modelling process and potentially avoids rework and duplication of modelling efforts.
- Increased transparency and traceability of modelling decisions due to context-awareness (e.g. when communicating processes, auditing, transferring lessons learned etc.).
- More realistic, and thus more useful process models due to a more accurate reflection of the actual processes within the intended contexts, as well as an increased support for tailoring.
- Decrease in project planning effort by supporting process tailoring.
- More targeted and timely adaption of process models for future contexts (thus more time for planning and organizational change management regarding systems, tools, and people).

Besides these benefits, there are limitations associated with the approach: The upfront effort during preparation and process modelling increases. Traditional process modelling and management activities need to be extended to include a context perspective, e.g. by preparing and conducting interviews to identify relevant context factors. This is not a one-time but an iterative activity in order to be effective. Further, the construction of a knowledge-base is necessary to function as a repository to collect, monitor and update relevant influencing factors and their impact on the PDP. However, benefits are expected to impact the organization repeatedly (e.g. project planning is a repeated activity supported by tailoring) so that the cumulative effects of the benefits would outweigh the additional effort.

7 CONCLUSION & OUTLOOK

In this paper, we have proposed several application cases that can support the contextualisation of processes in product development. The application cases have been structured using a process lifecycle model based on literature and identified and validated by empirical evidence identified in observations and case studies.

The proposed framework is not intended to replace traditional means of process identification and modelling (such as Interviews, workshops, and process modelling techniques such as SIPOC-Diagrams or BPMN), but to augment and enhance them by enriching existing models with a context perspective. Through knowledge of the process context, higher flexibility and agility, as well as shortened time for project planning are to be expected. Existing approaches to further support context orientation as well as the consideration of variability aspects in process models have been briefly described.

Multiple case studies are currently conducted using the general framework presented in this paper, enabling a deeper understanding of the presented application cases, such as defining reference process variants and project-specific tailoring.

Further work requires the consolidation of the presented findings into an applicable approach for identifying, describing, and classifying context factors and deriving processual consequences. As a foundation, an approach based on the philosophy of model-based systems engineering is envisioned, defining views for different activities in order to manage the emerging complexity. The approach eventually needs to contain elements such as procedural models to identify and analyse context factors, a repository to store the associated information and method support, e.g. for describing attributes of context factors and their eventual impact on the PDP (e.g. in the form of aforementioned views).

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